Essays in Environmental Economic History

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Preface

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Contents

3 Impact of Natural Disasters on School Attendance: A Comparative Study from Colonial Jamaica 75

List of Figures

List of Tables

Introduction

The Caribbean, a region historically shaped by the forces of nature and colonial economic agendas, provides an exemplary setting for examining the interaction between environmental events and economic development trajectories. This dissertation focuses on the British Caribbean, with an emphasis on Jamaica, a territory that has experienced significant socio-economic shifts under the influence of natural disasters, technological evolution, and colonial economic policies. The environmental and economic history of the British Caribbean provides an illustrative case study of broader themes pertaining to resilience, adaptation, and the long-term consequences of environmental and economic decisions.

The initial chapter commences an investigation into the historical influence of tropical storms on the banking sector in the British Colonial Caribbean. The Caribbean economy has historically been susceptible to the effects of natural disasters that have caused considerable disruption in a variety of sectors, including the financial sector. This chapter is devoted to an examination of the Colonial Bank's operations during the period from 1922 to 1927, a time of great upheaval in the British West Indies. It considers the impact of tropical cyclones on the banking sector in this region. The analysis employs high-frequency banking data from various branches to explore the effects of these storms on banking activities. The findings reveal a noticeable disruption in banking operations, evidenced by a spike in borrowing via overdrafts following storm strikes and an increase in deposits and savings at the affected branches. These findings highlight the challenges faced by financial institutions and their clients in managing the repercussions of natural calamities and underscore the strategic financial responses to mitigate funding shocks.

The second chapter examines the dual impact of hurricanes on technological adoption within colonial Jamaican sugar estates, exploring both their destructive potential and their role as a catalyst for innovation. Jamaica, previously the main producer of sugar for the British Empire, encountered significant challenges in the 19th century. These included fluctuating sugar prices, the abolition of slavery, and a period of technological stagnation. This chapter examines the potential role of hurricanes as drivers of technological advancement within these estates. By employing a comprehensive geo-referenced database of sugar estates in conjunction with a hurricane damage estimation model, the study elucidates the intricate dynamics between natural disasters and economic resilience. The findings indicate that hurricanes may have served as a creative-destructive force, prompting technologically laggard estates to upgrade their machinery in order to remain competitive. This chapter presents a detailed examination of the complex interplay between external environmental shocks and internal economic structures and strategies.

The third chapter analyses the impact of natural disasters, particularly hurricanes, on school attendance in Jamaica between the years 1892 and 1942. The disruption of education, a critical tool for social control and economic advancement during the colonial era, was a significant consequence of hurricanes. This chapter presents a novel approach to the analysis of monthly school attendance data, which is combined with a measure of storm-induced destruction. This approach is used to shed light on the profound influence of natural disasters on educational outcomes. The analysis demonstrates that hurricanes resulted in considerable reductions in school attendance and performance, highlighting the long-term impact of natural disasters on educational achievement and economic advancement. The chapter explores the broader implications of these disruptions on human capital development in an agrarian colonial society, contributing to the understanding of the socioeconomic consequences of natural disasters on education and future economic growth.

The concluding chapter examines the influence of flood induced variation in market access on local economic activity in colonial Jamaica. Notwithstanding substantial investments in railway and road infrastructure with the objective of reducing internal trade costs and supporting economic development, Jamaica's topography and climate presented considerable challenges. This chapter uses historical maps to create least-cost paths between the parishes as well as flood event data, to examine the interplay between infrastructural development and environmental factors.

This dissertation synthesises these interconnected historical narratives to construct a comprehensive picture of the economic history of the British Caribbean. It highlights the significant role that environmental factors have played in shaping economic and social trajectories over time. Each chapter, while focused on a specific aspect of this history, collectively contributes to a deeper understanding of the enduring legacy of natural disasters, technological changes, and colonial policies in the British Caribbean. The research presented in this dissertation makes a significant contribution to the field of environmental economic history and offers insights that are relevant for contemporary policy-making. Moreover, this dissertation makes a methodological contribution through the utilisation of new archival data. The integration of geo-referenced databases, hurricane damage estimation models, historical maps and high-frequency banking data provides a robust framework for analysing the intricate interactions between environmental events and economic outcomes.

In conclusion, this dissertation provides a comprehensive examination of the economic history of the British Caribbean, with a particular focus on the interplay between natural disasters, technological change, and colonial policies. By examining these themes through the lens of Jamaican sugar estates, transport infrastructure, the financial sector, and education, this work provides valuable insights into the resilience and adaptability of economies in the face of environmental challenges. The findings emphasise the importance of historical context in understanding contemporary economic issues and highlight the necessity for policies that consider the long-term impacts of environmental events on economic development.

Chapter 1

Impact of Tropical Storms on the Banking Sector in the British Colonial Caribbean

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1.1 Introduction

Historically, the Caribbean economy has been significantly impacted by natural disasters, most notably tropical storms, which have caused widespread damage in various sectors. Among the sectors most affected, the decrease in crop exports (Mohan and Strobl, 2013; Mohan, 2017; Mohan and Strobl, 2017), the destruction of structural assets (Smith, 2012a; Mulcahy, 2008), and the degradation of infrastructure (Lugo, 2000; Rasmussen, 2004) stand out, which have had far-reaching implications on the financial system. In the case of Colonial Jamaican sugar estates, Huesler and Strobl (2024a) show that hurricane strikes reduced the amount of sugar produced and destroyed machinery on the estates. In turn, estate owners needed money to either repair or buy new and more advanced machinery (Huesler and Strobl, 2024a). During the period in question, Jamaica seemingly lacked a formalized strategy for post-disaster management. The prevailing British colonial approach to disaster response emphasized maintaining colonial dominance and fiscal conservatism, leading to a reliance on philanthropy for financial assistance rather than direct intervention by the imperial government (Webber, 2018). Similarly, the local authorities did not offer any specific support in the aftermath of natural disasters. Instead, limited aid was available through existing local programs for poverty relief, assisting those who fell into destitution following a hurricane (Bryan, 2000). Consequently, the responsibility for post-disaster recovery largely fell to private efforts, as the government's assistance was minimal.

In the context of the Caribbean, the financial system was in a nascent stage until the advent of the 19^{th} century. This era marked the establishment of the Colonial Bank in 1836, which ushered in a new phase of financial development (Brown, 1990). The establishment of the Colonial Bank was driven by the need to provide the financial necessities of the agricultural industry and to facilitate trade within the Caribbean (Hudson, 2014; Monteith, 2003). The bank offered services that accepted savings and deposits, but its role in providing long-term investment capital was limited due to prohibitions on lending against property (Hudson, 2014; Monteith, 2003; Lobdell, 1972a).

The reason why the Colonial Bank could not lend money against property was that its charter specified that it was a commercial bank, focusing only on short-term financing of agriculture and trade, not long-term financing (Lobdell, 1972a; Monteith, 2003).

During this period, Caribbean colonies were largely agriculturally driven economies, although with varying degrees of dependence (Bulmer-Thomas, 2012). The Colonial Bank successfully fulfilled the role of financial intermediary for its clients in trade and agricultural businesses in the British Caribbean and became the dominant force in the British West Indian financial sector. The Colonial Bank's market position was further bolstered following the sugar price collapse in 1920. This financial shock led to a number of U.S. banks shuttering their Caribbean branches, while maintaining a primary focus on Cuba, leaving the Colonial Bank with a larger share of the market (Quigley, 1989a).

This paper analyses the influence of four historic tropical cyclones on the banking operations of the British West Indies, with a particular focus on the Colonial Bank during the period from 1922 to 1927, acknowledging the institution's significant role in the region's economy. In September 1922, the first of these storms unleashed winds of 90 to 140 km/h, predominantly afflicting the islands of Antigua, Dominica, and St. Kitts. The devastation was not isolated, as a subsequent tempest in 1924, boasting winds that exceeded 133 km/h, extended its impact to include St. Lucia alongside the previously affected islands. The severity of the damages from these events was starkly articulated by the Governor of Antigua, who reported: *"[...] Antigua, 3 killed; estimated damage, £7,500. [...] The estimated damage to private property in St. Kitts is about £60,500 and £8,000 to Public Works."* The Jamaica Gleaner (1924a). Two years thereafter, the islands endured additional meteorological adversities with two more storms in 1926, notably the *Nassau Hurricane* and the *Great Miami Hurricane*, which, despite their reduced wind speeds of 66 to 83 km/h, inflicted significant destruction in the Bahamas and Florida, as well as revisiting the earlier mentioned Caribbean islands.

In assessing the impact of these tropical storms on the clientele of the Colonial Bank, I used high-frequency banking data from 26 geolocated branches. The data, reflecting balances of savings and current accounts, deposits, and the extent of overdrawn accounts, is evaluated semi-monthly at the branch level. This paper intertwines these financial records with storm tracks affecting the Colonial Bank's branches. To this end, I combined the storm tracks with a wind field model to estimate their wind speed at the Colonial Bank branches. By transforming these wind speeds, I derived a proxy for the potential destruction at the exact location of the given branches. The granularity of this high-frequency data is used to shed light on the temporal and spatial variations of the storms' impact on the financial activity of customers in Colonial Bank's network. The findings of this paper reveal a noticeable disruption in banking operations, evidenced by a spike in borrowing via overdrafts of current accounts following storm strikes. Furthermore, the analysis discloses a complex pattern of response to the storms, with the data indicating an increase in deposits and savings at the affected branches, suggesting a strategic approach to mitigate funding shocks.

This paper contributes to the existing literature in several important ways. First, it serves as a unique historical case study, providing an extensive analysis of the early 20^{th} century British West Indies, when the financial system was nascent. As such, it provides information on an era often overlooked compared to contemporary historical case studies or those focussing on singular national entities[1]. This expands our understanding of how clients of financial institutions responded during the late modern era. In particular, the study examines not one but four independent storms, each with varying degrees of impact on different branches. This approach contrasts with case studies centered on a single event (see e.g. Schüwer, Lambert, and Noth, 2019; Mercantini, 2002). Second, the paper uses a unique high-frequency data set of banking variables, which distinguishes it from previous research relying on methods such as questionnaires (Sawada and Shimizutani, 2008), yearly tax returns (Deryugina, Kawano,

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[1] See e.g. Bayangos, Cachuela, and Del Prado (2021), Wu, Qian, and Liu (2022), and Brei, Mohan, and Strobl (2019) exploring the aftermath of natural disasters in the 21^{st} century, while Okazaki, Okubo, and Strobl (2023) examines the impact of the Great Kanto Earthquake during a similar period but restricts its focus to a single event at one geographical location.

and Levitt, 2014), or lower-frequency banking data sets (see e.g. Cortés and Strahan, 2017; Brei, Mohan, and Strobl, 2019; Bayangos, Cachuela, and Del Prado, 2021; Koetter, Noth, and Rehbein, 2020). This aids in tracing the temporal evolution of the storm's impact and sheds further light on client responses to such shocks. Third, the analysis explores the consequences of hurricane strikes in a context where long-term borrowing was markedly constrained by the nascent financial infrastructure. This unique angle sheds light on aspects of hurricane effects that are often overlooked in favor of loan-focused analyses in the prevailing literature.[2] By examining the broader financial repercussions on bank clients, this paper provides a more comprehensive understanding of the economic impact of natural disasters in historical contexts.[3] Finally, this paper explores the impact of tropical storms on several banking variables, allowing a differentiated conclusion on how clients reacted to tropical storms.

The remainder of this paper is organized as follows. Section 2 provides a historical background, followed by the data sources. Section 4 presents the methodology, followed by the econometric analysis in Section 5. Finally, Section 6 briefly concludes.

1.2 Historical Background

1.2.1 History of the Colonial Bank

Before the formal establishment of banking institutions, the plantation system in the Caribbean was financed primarily by capital from merchants who lent money to local planters (Brown, 1990; Bowen, 1939). However, with the abolition of slavery in 1838,

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[2] Typical foci include Hurricane Katrina (Gallagher and Hartley, 2017; Deryugina, Kawano, and Levitt, 2014), earthquakes in China from 2009-2017 (Wu, Qian, and Liu, 2022), the 1995 Kobe earthquake (Sawada and Shimizutani, 2008), various Caribbean hurricanes (Brei, Mohan, and Strobl, 2019), and the 2004 Indian Ocean Tsunami (Nguyen and Wilson, 2020).

[3] When analysing the impact of tropical storms, it is important to consider other natural disasters that may have an impact, such as earthquakes and tsunamis. However, earthquakes and tsunamis are considerably rarer and tend to cause more localized damage. In their study, O'loughlin and Lander (2003) compiled an extensive list of all earthquakes and tsunamis that occurred in the Caribbean between 1498 and 1998. From 1922 to 1927, there were no earthquakes in the Caribbean basin, except for one tsunami that only impacted Galveston, a location where Colonial Bank did not have a branch. Therefore, Colonial Bank's customers were not affected by any other natural disasters.

the increased cost of sugar production necessitated greater capital investment for efficiency improvements (Cumper, 1954; Beachey, 1957). The Colonial Bank's inception in 1836 marked a pivotal shift in the Caribbean's financial landscape. Following the *Bank Charter Act of 1833*, the bank's charter signified the era's burgeoning financial developments (Brown, 1990). As a primary financier of agriculture and trade, the Colonial Bank played a central role in the Caribbean's economic growth (Hudson, 2014; Monteith, 2003). However, since the Colonial Bank was prohibited from lending against real estate or other properties from 1858 onwards, it was effectively unable to provide long-term investment capital (Monteith, 2003; Lobdell, 1972a). Therefore, the Colonial Bank primarily focused on providing clients with the facilities to save and invest their money, as well as granting short-term advances. The bank's operations were initially limited to the British Caribbean colonies, but gradually expanded its reach to other regions in the world (Monteith, 2003). At the same time, the first savings banks were established, allowing the general population of the Caribbean to save money (Hudson, 2014). The first savings banks were established in Jamaica and Guyana, followed by many other islands later in the 19^{th} century (Hudson, 2014). However, these banks were only for smaller clients. Until the end of the 19^{th} century, when the Royal Bank of Canada entered the Caribbean banking sector, the Colonial Bank was the dominant force in the Caribbean and held a monopoly in almost all Caribbean colonies (Monteith, 2003; Lobdell, 1972a).[4] However, primary Canadian banks sought to increase their power in the domestic market through mergers, rather than expanding their influence in the Caribbean (Quigley, 1989a).

In the late 19^{th} century, the beetroot sugar crisis had a detrimental effect on the performance of the Colonial Bank, as evidenced by a decrease in net profits greater than

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[4] Prior to World War I, U.S. banks were prohibited from conducting business outside of the United States (Monteith, 2003; Quigley, 1989a). Following the First World War, the *National City Bank* entered the Caribbean market. Given its close ties with U.S. firms, it emerged as a formidable competitor, particularly in Haiti (Hudson, 2013). However, Canadian banks did not feel threatened as the National City Bank's inexperience with branch banking was seen as a big disadvantage (Quigley, 1989a).

50% between 1877 and 1906 and a ten-fold increase in bad debts (Wai, 2010).[5] The severe decline in sugar prices in the 1920s not only had a significant impact on the performance of the Colonial Bank in the West Indies, but also on banks operating in the United States (Quigley, 1989a). These institutions faced significant financial losses, and as a result, several US banks closed their branches in the Caribbean region (Quigley, 1989a). During the 1920s, the Colonial Bank's market share, which was determined by the currency issued, was approximately equal to the combined market share of all Canadian banks operating in the Caribbean (Ryan, 2019). In 1925, the Colonial Bank became a global bank and changed its name to Barclays Bank (Dominion, Colonial and Overseas). The new bank was formed through the amalgamation of Colonial Bank, Barclays, the Anglo-Egyptian Bank and the National Bank of South Africa (Monteith, 2003; Crossley and Blandford, 1975).

1.2.2 British Colonial Caribbean Economies

At the beginning of the 20^{th} century most Caribbean islands still relied on agricultural industries and commodities (Bulmer-Thomas, 2012). One of the most important crops was sugar, which still represented approximately 70% of Caribbean exports between 1922 and 1927, underscoring the region's significant dependence on the sugar industry (Bulmer-Thomas, 2012). However, these economies also relied on other crops and commodities. As the British Navy transitioned from coal to oil, demand for oil increased, oil production in Trinidad increased, so that the share of petroleum and petroleum products exported from Trinidad increased from not even 5% in 1915 to almost 50% in 1930 (Mulchansingh, 1971). Furthermore, Britain and Commission (1945) reported the extraction of bauxite (the primary ore of aluminium), diamonds, and gold

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[5] It is important to mention that the Colonial Bank was always closely tied to sugar. Monteith (1997) estimates that between 1926 and 1939 the clients of the Colonial Bank were responsible for 80% of the sugar in the West Indies.

in British Guiana, although mineral resources were scarce on other islands. Bulmer-Thomas (2012) argued that the colonies' overreliance on the export of one or two products presented significant challenges.[6] On a broader scale, the West Indies lacked a manufacturing industry, resulting in a high dependence on imports for manufactured goods such as clothing from the United States and Great Britain (Britain and Commission, 1945).

Table A.1 shows the share of the main export products relative to the value of total exports per colony. The data are obtained from Bulmer-Thomas (2012). Although all economies in Table A.1 obtain their exports from the primary sector, there exists a vast heterogeneity with respect to the composition. First, there are *sugar economies*, like Antigua, Barbados, Guyana (Demerara), St.Kitts and St.Lucia, where sugar exports make over half of total exports. Interestingly, the share increases considerably in Barbados and St.Kitts. Second, there is Jamaica, where the share of bananas is almost 50% in 1922 and surpasses it in 1927 (54%). However, Jamaica also produces a considerable amount of sugar (24 to 18%). Third, there is Grenada, which focusses mainly on Cacao (65 to 68%) and Dominica, which focusses on lime (Juice), which makes more than 90% of its exports. Fourth, there are *mixed economies* like, St.Vincent and Trinidad and Tobago, which do not focus on one export product. St.Vincent produces considerable amounts of molasses, arrowroot, and cotton. Similarly, Trinidad and Tobago exports sugar, cacao, asphalt, and oils, whereas the share of sugar exports decreases and the share of asphalt and especially oils increases rapidly between 1922 and 1927.

1.2.3 Tropical Storms

Generally, one can roughly divide tropical cyclones into four groups. First, there are tropical depressions with wind speeds not exceeding 61km/h, followed by tropical storms with wind speeds exceeding 61km/h. In the Atlantic Ocean, storms exceeding 119 km/h are hurricanes (category 1), while major hurricanes (category three) have

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[6] For example, Bulmer-Thomas (2012) underscores that between 1900 and 1960, sugar constituted more than 80% of Antigua and St. Kitts exports, petroleum products made up 67.7% of Trinidad and Tobago's exports, and sugar and molasses together represented 90% of Barbados' exports.

wind speeds exceeding 178km/h. Historically, tropical storms have had profound impacts on the economies of the British Colonial Caribbean (see e.g. Schwartz, 2015; Smith, 2012a; Morgan et al., 2022; Mohan and Strobl, 2013). In general, hurricanes affect houses, infrastructure, and agriculture. Mohan and Strobl (2017) show that hurricanes negatively affect agricultural crops in the Caribbean. For the 1860 Hurricane Season, Dodds, Burnette, and Mock (2009) show that the hurricanes destroyed personal property, transportation infrastructure as well as crops like sugar and cotton. During that time, Jamaica did not have a formal post-disaster strategy. The British colonial response of the time focused on maintaining dominance and fiscal conservatism. The approach relied on philanthropy rather than direct imperial government intervention (Webber, 2018). Similarly, following natural disasters, local authorities did not offer targeted support. Instead, minimal aid was accessible through established poverty relief programmes, aimed at assisting those who were left destitute in the wake of a hurricane (Bryan, 2000). Therefore, the duty of post-disaster rehabilitation mainly rested on private initiatives, as the government's participation was negligible.

Between 1922 and 1927 several tropical storms struck the islands in the Caribbean Basin. The first storm occurred in September 1922 which started as a category one hurricane near Dominica and became a category three hurricane close to Antigua. In the following days, the storm drifted eastward, struck Bermuda and went further north east until the English Channel. Two years later, the next category two hurricane passed between Antigua and Dominica and then to St. Kitts. Subsequently, the storm drifted eastward back to the Atlantic. The hurricane caused great damage throughout the Caribbean as more than 300 people died and thousands of houses were damaged (The Jamaica Gleaner, 1924a).

The two most famous storms were both in 1926: *the 1926 Nassau Hurricane* and *the Great Miami Hurricane of 1926*, both of which impacted several islands in the Caribbean. *The 1926 Nassau Hurricane* initially manifested itself as a tropical storm with wind speeds of 90 to 110km/h near Barbados, St. Lucia, and Dominica, before increasing to more than 165 km/h in Puerto Rico. Its peak wind speeds were recorded in Nassau (200km/h), which also inspired its name, before it made landfall in Florida. The hurricane rendered several Nassau roads impassable and caused damage to houses, churches, and hotels (The Jamaica Gleaner, 1926a).

A few months later, *the Great Miami Hurricane of 1926* struck Miami, earning the reputation as one of the most catastrophic events in U.S. history after the San Francisco fire (The Jamaica Gleaner, 1926b). By September 14, the hurricane had already reached wind speeds of 167km/h near Antigua, elevating it to a category two hurricane. Four days later, it made landfall in Miami with winds that exceeded 220 km/h (category four hurricane), where wind-related flooding caused extensive destruction (The Jamaica Gleaner, 1926b). Generally, the Great Miami Hurricane of 1926 is recognised as one of the most costly storms in U.S. history (Pielke Jr et al., 2008). Weinkle et al. (2018) estimates that it induced direct damage of approximately US$ 105 million[7].

1.3 Data

1.3.1 Banking Data

I created a historical banking panel from the Colonial Bank branches in the British Caribbean by digitizing semi-monthly data from August 1922 to December 1927, obtained from the *Assets & Liabilities of West Indies branches* report (Colonial Bank, 1927). The panel includes data from 26 branches of the Colonial Bank, with 10 branches located in Jamaica (one closed in 1923 and another in 1924), 4 in Demerara (one closed in 1923), 3 in Trinidad (one closed in 1924), 2 in Barbados (one closed in 1925), as well as one each in Antigua, Grenada, Dominica, St. Kitts, St. Lucia, St. Vincent and Tobago (one closed in 1924). From the branches mentioned above, I excluded *Black River*, *Mahaica*, *May Pen*, *Princes Town*, *Speightstown*, *Suddie* and *Tobago* because there were less than 2/3 of the total number of observations available between 1922

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[7] This is approximately US$ 1.7 billion today.

and 1927[8]. I georeferenced the branches to assess whether it has been affected by a tropical storm. The spatial distribution of the Colonial Bank branches can be seen in Figure 1.1.

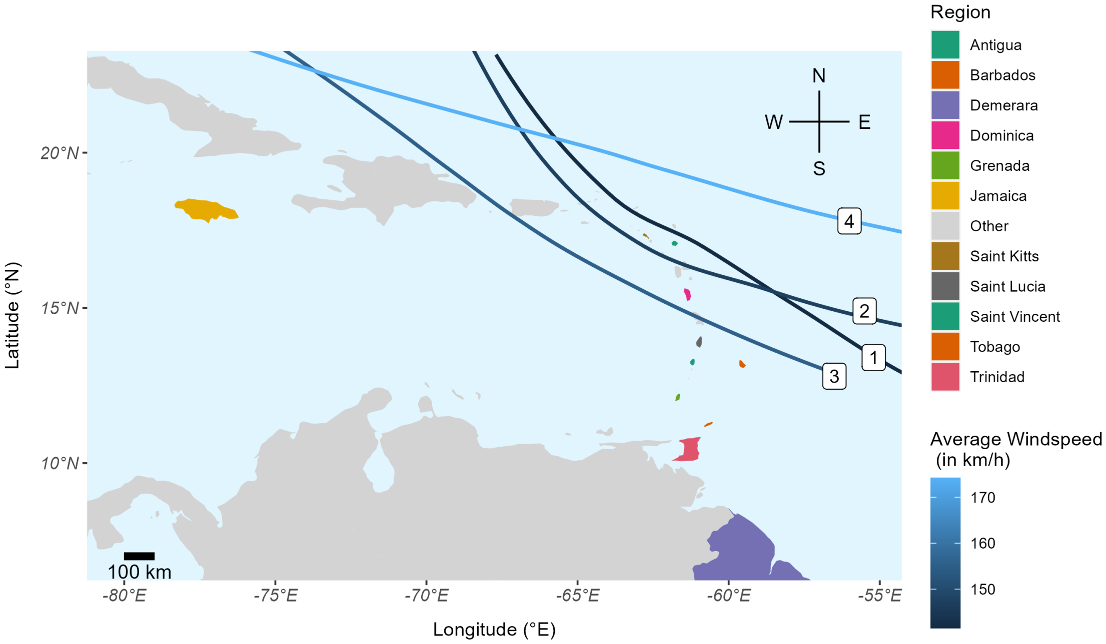

FIGURE 1.1: Spatial Distribution of the tropical storms, using different shades of blue for the wind speed and different colours for the regions. In the figure, the four tropical storms are indicated by numbers ranging from 1 to 4: 1) September 1922, 2) August 1924, 3) July 1926 and 4) September 1926.

In the specified time frame, the data set encompasses branch-specific data on various financial attributes: first, the aggregate balance across all clients' savings accounts (*SAV*) within a particular branch. Second, current account balance *(CAC)*, akin to checking accounts, indicates the funds available for transactions. As account holders may have positive and negative balances on their current accounts, *CAO* quantifies the total overdrawn sum or the extent of overdraft by clients. Hence, it is a proxy for

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[8] Therefore, the final data set only contains observations from Antigua, Barbados, Berbice, Demerara, Dominica, Falmouth, Grenada, Kingston, Montego Bay, Morant Bay, Port Antonio, Port Maria, San Fernando, Savanna la Mar, St. Anns Bay, St. Kitts, St. Lucia, St. Vincent and Trinidad.

short-term debt which might be used to smoothen consumption, which is expected to increase after a tropical storm as it was the case after Hurricane Katrina (Gallagher and Hartley, 2017). The variable *DEP* denotes the capital that clients have allocated to time-bound deposits that accrue interest. The primary distinction between *savings* and *deposits* lies in their functionality and purpose. Although the former provides a readily accessible avenue for clients to move funds, the latter represents a longer-term investment, typically earmarked for a specific duration and interest rate. Kass-Hanna, Lyons, and Liu (2022) show that access to savings and borrowing increases financial resilience in South Asia and Sub Saharan Africa and Jacobsen, Marshak, and Griffith (2009) highlight the importance of access to a sufficient lump-sum after a disaster. For this reason, I included both SAV and DEP in the data set, as proxies for savings.

1.3.2 Storm Data

The underlying storm data was created with the *HURDAT best tracks* from *National hurricane Centre's hurricane Database* which contains the position of the storm every 6 hours, as well as intensity measures (highest wind speed) dating back to 1851. This data base has been used in several papers focusing on the impact of hurricanes. Mohan and Strobl (2013) estimated the economic impact of hurricanes on sugar exports in the Caribbean between 1700 and 1960. Ortiz Royero (2012) used the data base to assess the exposure of the Colombian Caribbean coast to hurricanes. Strobl (2011) analyzed the impact of hurricanes on the economic growth of coastal US counties and Boose, Chamberlin, and Foster (2001) used $HURDAT$ to estimate the historical regional impact of hurricanes in New England. According to Elsner and Jagger (2004), the $HURDAT$ data are the most comprehensive and reliable record of hurricanes in the North Atlantic Ocean. To assess the impact of tropical storms on the local banking sector, a hurricane destruction index was created, based on a wind field model estimated using the *HURDAT best tracks* was created. The main assumption behind the estimated destruction is that I assume that the wind speed at the branch office is the same as at the places where the clients live or where their plantations or houses are.

To estimate wind speeds at the branch offices, I first interpolated the underlying six-hourly HURDAT-tracks to obtain more precise two-hourly locations of the underlying storms.

1.3.3 Summary Statistics

Table A.2 presents summary statistics for the banking variables and the wind speeds (denoted as *HURR*). During the study period, four storms with wind speeds exceeding 63km/h made landfall at a minimum of one branch, yielding 14 observations. The average wind speed of these storms was 104.3km/h, with the highest recorded wind speed being 142km/h. The tracks of these four storms are shown in Figure 1.1. Antigua, Dominica, St. Kitts and St. Lucia were the branches most affected by tropical storms, while branches in South America (Demerara) were typically unaffected by storms. The population density per km^2, *POPD*, also shows significant differences between areas with high and low population density. On average, 23.71 people live per km^2.[9]

Figure A.1 illustrates the evolution of average *current account balances (CAC)*, the amount of *overdrawn current accounts (CAO)*, *deposits (DEP)* and *savings (SAV)* over time (in logs). In general, savings increase over time, especially in 1923. The amount of current account balances is the most volatile variable and shows a seasonal pattern with higher current account balances in summer and lower current account balances in winter. This is consistent with the idea that plantations receive income from selling their crops, such as sugar, after the harvest season (January to May), leading to increased balances. As the plantations begin to plant again, the expenditures increase, resulting in lower current account balances. The other variables do not show similar seasonal patterns. However, the general trend of the amount of current account balances is similar to the amount of deposits. What further strikes out is that the amount

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[9] This is comparable to the population density of *Virginia* in the United States of America in the 21^{st} century

of overdrawn current account balances decreases sharply at the beginning of 1923 but recovers quickly at the end of the same year.

Spatial variations of these four banking variables are presented in Table 1.1. Two key observations surface: first, the distribution across branches is quite disparate. The branches in Kingston, Trinidad, Barbados, and Demerara collectively account for 70 to 90% of the total amount of current account and savings balances, as well as the amount of overdrawn current accounts and deposits. Most importantly, these branches represent more than 75% of the average total balance sheet of the Colonial Bank in the British Caribbean, which stands at approximately US$ 29 million.[10] On the contrary, the shares of Port Antonio, Morant Bay and Port Maria from the total balance sheet are only 0.49%, 0.58%, and 0.74%, respectively. Secondly, the amount of overdrawn current accounts generally constitutes less than 20% of the branch balance sheet[11]. For the four largest branches, the proportion of overdrawn current accounts ranges from 12% in Demerara to 30% in Tobago. Furthermore, Kingston clients hold significant amounts of deposits of the Colonial Bank, comprising 42% of the branch's balance sheet compared to Trinidad's 7%. In contrast, clients in Barbados and Demerara frequently use the bank for savings (48% and 47%, respectively). However, the balance sheet compositions of Barbados, Demerara and Kingston appear more homogeneous when considering deposits and savings collectively, comprising roughly 62% of the balance sheets. However, Trinidad's balance sheet diverges considerably, as evidenced by its high share of overdrawn current account balances (30%), lower combined proportions of savings and deposits (33%), and higher percentage of current account balances (37%), compared to Barbados (17%) or Demerara (27%). Therefore, Table 1.1 discloses significant heterogeneity, not only in terms of the size of the branches, but also in terms of how clients use Colonial Bank.

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[10] These branches contribute the following to the total balance sheet: Barbados (23%), Kingston (23%), Trinidad (18%), and Demerara (12.5%). For comparison, the fifth largest branch, St. Kitts, contributes just 3.2%.

[11] Notably high shares of overdrawn current accounts are seen in St. Lucia (41%).

TABLE 1.1: Banking Variables

Branch	CAC	CAO	DEP	SAV
Antigua	170,489.07	70,961.35	16,015.19	337,278.39
Barbados	1,129,358.85	1,468,460.22	942,627.27	3,236,564.06
Berbice	79,717.81	100,485.91	13,363.34	254,477.02
Demerara	975,666.36	418,314.81	529,395.02	1,692,078.36
Dominica	47,420.63	92,916.00	52,990.10	186,952.48
Falmouth	38,053.43	1,187.216	159,838.67	104,192.01
Grenada	132,960.37	72,721.768	19,481.56	278,334.73
Kingston	1,642,646.61	828,984.26	2,739,390.33	1,380,402.65
Montego Bay	70,420.26	42,482.95	27,787.45	190,874.28
Morant Bay	47,140.70	2,759.26	7,631.71	109,435.49
Port Antonio	30,521.53	2,861.19	2,032.67	105,022.74
Port Maria	60,337.86	2,574.14	520.78	151,227.54
San Fernando	286,488.73	110,964.41	0	418,015.25
Savanna la Mar	63,347.92	2,461.99	130,004.83	62,882.95
St. Anns Bay	50,494.38	18,097.40	12,606.43	135,961.03
St. Kitts	132,615.06	123,432.24	281,155.02	387,771.19
St. Lucia	65,669.38	305,686.21	6,665.72	375,787.33
St. Vincent	107,748.85	26,473.39	42,938.70	516,056.69
Trinidad	1,930,512.63	1,565,005.07	339,653.71	1,378,156.50

Notes: Branch-level summary statistics of the underlying Banking Variables: *CAC* are Current Account Balances (credit), *DEP* are Deposits, *CAO* are overdrawn Current Accounts and *SAV* are Savings Account Balances.

Almost one third of the Colonial Bank's branches are located in Jamaica. Although this share is rather high, the weight of all Jamaican branches, except Kingston, is only 5.6% of the total balance sheet of the Colonial Bank. Therefore, this also indicates that many of the Jamaican clients were not clients of one of the smaller branches of the Colonial Bank, but in Kingston.

1.4 Methodology

1.4.1 Population-weighted destruction index

The impact of hurricanes has been assessed in many different ways in the literature. Some of them included a dummy variable when a storm made landfall or used the maximum wind speed (Schüwer, Lambert, and Noth, 2019; Boustan, Kahn, and Rhode, 2012; Berlemann and Wenzel, 2018; Mohan and Strobl, 2013). However, these methods do not allow to estimate regional differences in the destruction. For this reason, I include a measure where the actual destruction of hurricanes depends on the windspeed.

I apply a population-weighted destruction index adapted from Strobl (2012)[12] to estimate the client's response to tropical storms. The index is constructed using localised wind speed estimates calculated from the actual paths of hurricanes using a wind field model. Specifically, the path of each hurricane is tracked in time and space and the Boose, Serrano, and Foster (2004) model is applied to determine the wind speeds experienced in the Caribbean. This model, which takes into account factors such as peak wind speed, movement speed, direction, and landfall occurrence, provides the localised wind speed experienced at each landfall location for each moment in a hurricane's life. Instead of only estimating the wind speed at a branch, the population-weighted destruction index allows me to estimate the potential destruction caused in

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[12] Which is based on the wind field model of Boose, Serrano, and Foster (2004) which uses the equation of Holland (1980) for cyclostrophic wind and sustained wind velocity

the area where the branch operates. To create the population-weighted destruction index, I utilised population data from 1920 that was obtained from the *History Database of the Global Environment (HYDE 3.2)* (Klein Goldewijk et al., 2017). This database provides population estimates at the level of a 0.083 x 0.083 degree grid, equivalent to 9.5 x 9.5 km.[13] Subsequently, I estimated the potential damage caused by storms at each grid cell. This damage is then weighted by its population in 1920 to give a population-weighted destruction index and thus the weighted destruction at each branch. Since these decadal population data predate all events of interest, endogeneity with regard to the population weights is arguably not a concern. Furthermore, the correlation coefficient between grid-level population data for the years 1920 and 1930 (post-event) is 0.999, suggesting the absence of any migration trends during the study period.

In order to create a population-weighted destruction index, I first use the two-hourly track data to estimate, according to Strobl (2012), the wind speed at every grid cell:

$$V = GF\Big[V_m - S(1 - sin(T))\frac{V_h}{2}\Big] \times \Big[\Big(\frac{R_m}{R}\Big)^B exp\Big(1 - \Big(\frac{R_m}{R}\Big)^B\Big)\Big]^{\frac{1}{2}} \tag{1.1}$$

Here, V_m signifies the maximum continual wind speed found anywhere within the hurricane, while T represents the angle formed by the hurricane's forward path and a radial line drawn from the hurricane centre to the point of interest, P (see Strobl, 2012). The forward speed of the hurricane is represented by V_h. The radius of maximum winds is denoted as R_m, whereas R is the radial distance from the centre of the hurricane to the point P (for more details see Strobl, 2012).

The population-weighted destruction index is calculated as follows and uses the wind speed $v_{j,t}$ in the grid cell j at time t, which was previously estimated in Equation (1):

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[13] In total, I used population data from 318 grid cells.

$$DESTRUCTION_{i,r,t} = \Big(\sum_{j=1}^{J} \int_{0}^{\tau} v_{j,t}^{\lambda} w_{i,j,r,t} \, dr\Big) \text{ if } v_{j,t} > 63\text{km/h} \quad \text{and 0 otherwise} \tag{1.2}$$

Whereas $DESTRUCTION_{i,r,t}$ is the total estimated destruction caused by a storm r during the lifetime of the storm τ in the area of a branch i at time t. If there exists only one branch on an island, the area of the branch is the entire island. In the case where there is more than one branch exists, the island gets divided[14]. Emanuel (2005) noted that there is a correlation between the financial damages and energy release of hurricanes, which increases proportionately to the cube of their maximum wind speeds. This argues that the destructive potential of a hurricane can be roughly estimated by its highest recorded wind speed cubed (Emanuel, 2005).[15]

For this reason, J, the set of grid cells in i and, according to Strobl (2012), λ is set to 3 (cubic). The population weight is $w_{i,j,r,t}$ and corresponds to the population in every cell of the grid in 1920 (Klein Goldewijk et al., 2017). Importantly, I include only wind speeds exceeding 63km/h (i.e., tropical storms) in the analysis.

1.4.2 Econometric Specification

In order to quantify the impact of the storms on the banking variables, I use the following econometric specification:

$$LOG(BANK_{i,t}) = \beta_0 + \sum_{k=0}^{p} \beta_{k+1} \cdot DESTRUCTION_{i,t-k} + \alpha_z + \delta_m + \theta_i + \epsilon_{i,t} \tag{1.3}$$

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[14] In the case of Barbados, I divided Barbados in two parts. The Speightstown-Branch covers the northern part, and the Bridgetown-Branch covers the southern part.

[15] This index was also applied by several other papers i.e. Strobl (2012, 2011); Bertinelli and Strobl (2013); Brei, Mohan, and Strobl (2019); Elliott, Strobl, and Tveit (2023); Mohan and Strobl (2017).

where α_z and δ_m are yearly and monthly fixed effects, θ_i are branch fixed effects, $LOG(BANK_{i,t})$ is the log of the banking variable and $DESTRUCTION$ is the population weighted destruction index at branch i at t, ..., $t - k + 1$. I use robust standard errors.

In this study, I also account for branch-specific immutable effects represented by θ_i and common shocks specific to the year and month denoted by α_z and δ_m. Monthly fixed effects allow me to capture seasonal variations, i.e. intensive rainfalls, price shocks of commodities, or seasonal patterns in labour demand/supply. The yearly fixed effects however capture year-specific impacts, i.e. years with extreme droughts, the introduction of tariffs or the incorporation of laws. One may also want to note that the econometric methodology is closely related to that used by Mohan and Strobl (2021) and Elliott, Strobl, and Tveit (2023). It as such posits that the local distribution of potential damage caused by tropical storms, or at least the perception thereof, remains constant over time. Given the relatively short time in the analysis this is likely to hold true. Thus, by accounting for both branch specific, time-invariant, and time fixed effects, equation (3) in the paper isolates the variation in destruction that can reasonably be considered as random, unanticipated realisations from the distribution of potential damages from storms (Mohan and Strobl, 2021; Elliott, Strobl, and Tveit, 2023). This allows a causal interpretation of the coefficients on $DESTRUCTION_{t-k}$.

In the underlying panel models, several half-monthly lags are included. This approach is similar to the approach applied in current papers which estimate the effect of environmental shocks on banking variable (Noth and Schüwer, 2023; Blickle, Hamerling, and Morgan, 2021; Walker et al., 2023). The motivation for using a model with several lags is due to the fact that lags are crucial as tropical storms might not immediately affect certain variables or even affect them over a longer period. Therefore, applying a certain number of lags helps to estimate the effect of a tropical storm on the banking variables. In the underlying specification, 18 lags (that is, nine months) were applied. However, different numbers of lags were applied to investigate whether the results are robust. As tropical storms are random exogenous shocks and no tropical storm warning systems were in place, people could not anticipate a tropical storm and try to mitigate damage. Moreover, as the econometric specification is similar to those of Mohan and Strobl (2021), it is worth mentioning that the estimated population weighted potential destruction index can be argued to be exogenously derived. Although clients of the Colonial Bank, in theory, might position assets within countries cognisant of which regions are more prone or less susceptible to storm damage, once we adjust for branch-specific fixed effects, what arguably remains are random manifestations from the local distribution of potential hurricane damage.

1.5 Results

1.5.1 Spatial Variation of the underlying Storms

As can be seen in table A.6, only four branches were affected by the underlying storms, indicating considerable spatial variation. The estimated wind speed at the branch for the first and second storms was significantly higher than for the third and fourth storms (both in the same year). For the first and second storms, the mean non-zero wind speed measured at the branches was 115.8 km/h, compared to 74.9 km/h for the third and fourth storms. The maximum wind speed was also much higher, 142 km/h compared to 83.4 km/h. More importantly, the first and second storms caused even more destruction because they hit more populated areas, so that the average destruction index was 9.5 compared to 0.86 (more than ten times higher). The maximum destruction is even 15 times higher (25.3 compared to 1.8, which is even lower than the average of the first and second storms). In general, it can be said that there were considerable differences between storms and branches.

The index shows heterogeneous destruction over the area. In the case of the second storm in the sample, I confirmed that the heterogeneity in the index was also found in the *Jamaican Gleaner*. The Jamaica Gleaner (1924a) shows that there was variation in damage so that the Virgin Islands were hit very hard and the storm caused significant damage. The storm also hit St Kitts (The Jamaica Gleaner, 1924b) and Dominica, but caused no damage to Jamaica (The Jamaica Gleaner, 1924c). Thus, the articles in the *Jamaican Gleaner* show that the variation in estimated destruction seems plausible.

1.5.2 Impact on Banking Variables

In the first step of the analysis, I estimate the effect of tropical storms on branch-level banking variables by using fixed effects panel regression models from equation (2). Table 1.2 shows the results from the effect of tropical storms on the banking variables. I focus on the effect on the log of the specific variable. Right after the storm, the amount of current account balances increases and becomes insignificant in the two to seven months afterwards. The intuition for the initial positive effect comes from the fact that clients might send money from accounts in other parts of the British Empire to their accounts at the affected branches. Subsequently, clients use their current accounts to pay for the immediate damages caused by the storm. These findings are in line with the current literature suggesting that after a tropical storm deposits decrease (Deryugina, Kawano, and Levitt, 2014; Brei, Mohan, and Strobl, 2019; Sawada and Shimizutani, 2008) or that withdrawals increase (Bayangos, Cachuela, and Del Prado, 2021; Do et al., 2021; Nguyen et al., 2023; Bos, Li, and Sanders, 2022; Brei, Mohan, and Strobl, 2019; Do, Phan, and Nguyen, 2022; Allen, Whitledge, and Winters, 2022). A further source to obtain liquidity was simply to overdraw current accounts. In fact, the results show that the clients did indeed overdraw their current accounts, which is consistent with Barth, Sun, and Zhang (2019); Barth et al. (2022); Bos, Li, and Sanders (2022); Berg and Schrader (2012); Koetter, Noth, and Rehbein (2020). As it might take some time to send money from other accounts to the account in the affected area, clients directly increase the amount of overdrawn current account as it might be an easy way to pay for the repair of damage caused by the tropical storm. However, the effect becomes insignificant one month after the tropical storm and becomes significant again three months after the tropical storm. Moreover, the results further show that both Client's deposits increase in the months following a tropical storm. On first glance, one would expect a different reaction. However, Barth et al. (2022), Barth, Sun, and Zhang (2019) and Cortés and Strahan (2017) emphasise that branches in affected regions increase interest rates on deposits, which in turn should attract more deposits to prevent the bank from a negative funding shock as the demand for loans increases. Therefore, the results show that the affected branches of the Colonial Bank were able to attract both, more deposits and savings, to prevent a funding shock. However, the effect on savings account balances becomes significantly positive 7.5 months after a tropical storm. The results are further illustrated in Figures A.4 and A.7.

TABLE 1.2: Effect of Tropical Storms on Banking Variables

Banking Variable:	CAC	CAO	SAV	DEP
Model:	(1)	(2)	(3)	(4)
Variables				
$DESTRUCTION_t$	0.0163^{***}	0.0138^{***}	0.0020	0.0185^{***}
	(0.0030)	(0.0032)	(0.0033)	(0.0046)
$DESTRUCTION_{t-0.5m}$	0.0089^{***}	0.0154^{***}	0.0025	0.0176^{***}
	(0.0023)	(0.0038)	(0.0030)	(0.0046)
$DESTRUCTION_{t-1m}$	0.0105^{**}	0.0118^{***}	0.0008	0.0183^{***}
	(0.0043)	(0.0045)	(0.0032)	(0.0065)
$DESTRUCTION_{t-1.5m}$	0.0086^{*}	0.0111^{**}	-0.0002	0.0159^{***}
	(0.0051)	(0.0048)	(0.0023)	(0.0050)
$DESTRUCTION_{t-2m}$	0.0081	0.0048	0.0008	0.0156^{***}
	(0.0053)	(0.0074)	(0.0022)	(0.0052)
$DESTRUCTION_{t-2.5m}$	0.0054	0.0093	0.0009	0.0149^{***}
	(0.0060)	(0.0066)	(0.0017)	(0.0041)
$DESTRUCTION_{t-3m}$	0.0028	0.0145^{***}	-0.0001	0.0147^{***}
	(0.0069)	(0.0047)	(0.0018)	(0.0042)
$DESTRUCTION_{t-3.5m}$	-0.0019	0.0252^{***}	-0.0008	0.0119^{***}
	(0.0067)	(0.0068)	(0.0020)	(0.0037)
$DESTRUCTION_{t-4m}$	9.51×10^{-6}	0.0321^{***}	0.0002	0.0138^{***}
	(0.0049)	(0.0054)	(0.0021)	(0.0034)
$DESTRUCTION_{t-4.5m}$	0.0005	0.0313^{***}	-0.0015	0.0147^{***}
	(0.0069)	(0.0052)	(0.0014)	(0.0033)
$DESTRUCTION_{t-5m}$	0.0038	0.0268^{***}	-0.0020	0.0177^{***}
	(0.0052)	(0.0060)	(0.0015)	(0.0031)
$DESTRUCTION_{t-5.5m}$	0.0007	0.0293^{***}	-0.0005	0.0154^{***}
	(0.0045)	(0.0048)	(0.0012)	(0.0044)
$DESTRUCTION_{t-6m}$	0.0038	0.0298^{***}	-0.0010	0.0136^{***}
	(0.0054)	(0.0038)	(0.0016)	(0.0039)
$DESTRUCTION_{t-6.5m}$	0.0035	0.0353^{***}	-1.65×10^{-5}	0.0123^{***}
	(0.0063)	(0.0095)	(0.0017)	(0.0038)
$DESTRUCTION_{t-7m}$	0.0055	0.0223^{***}	0.0010	0.0127^{***}
	(0.0087)	(0.0030)	(0.0012)	(0.0039)
$DESTRUCTION_{t-7.5m}$	0.0131^{**}	0.0195^{***}	0.0023^{**}	0.0125^{***}
	(0.0061)	(0.0040)	(0.0011)	(0.0039)
$DESTRUCTION_{t-8m}$	-0.0018	0.0144^{***}	0.0012	0.0159^{*}
	(0.0079)	(0.0045)	(0.0012)	(0.0096)
$DESTRUCTION_{t-8.5m}$	0.0115^{*}	0.0137^{***}	0.0034^{***}	0.0147^{***}
	(0.0064)	(0.0033)	(0.0012)	(0.0048)
$DESTRUCTION_{t-9m}$	0.0138^{*}	0.0091^{***}	0.0035^{***}	0.0148^{***}
	(0.0083)	(0.0033)	(0.0009)	(0.0050)

Continued on next page

TABLE 1.2: (Continued) Effect of Tropical Storms on Banking Variables

Banking Variable: Model:	CAC (1)	CAO (2)	SAV (3)	DEP (4)
Fixed-effects				
factor(month)	Yes	Yes	Yes	Yes
factor(year)	Yes	Yes	Yes	Yes
factor(Location)	Yes	Yes	Yes	Yes
Fit statistics				
Observations	1,650	1,650	1,650	1,650
R^2	0.97042	0.92876	0.98555	0.96921
Within R^2	0.01946	0.01690	0.00326	0.02415

*Heteroskedasticity-robust standard-errors in parentheses. Signif. Codes: ***: 0.01, **: 0.05, *: 0.1*

Continued on next page

The results of the econometric analysis indicate that the impact of tropical storms on the banking sector in the British West Indies during the early 20^{th} century was significant and multidimensional. In the aftermath of the tropical storms, clients overdrew their current accounts to finance the damages caused by the natural disaster or transferred funds to affected branches, which caused an initial increase in their current account balances. The affected branches of Colonial Bank also manage to attract additional deposits and savings to avoid funding shocks, although the effect on savings is generally insignificant. Therefore, the results suggest that initially clients overdraw their current accounts to pay for the immediate damages caused by the storm. At the same time, clients send money to the branches, which they in turn use to repay their negative current account balances in the month following the tropical storm. Therefore, the effect on current account balances becomes insignificant. To repair more severe damage, clients need more capital, which they obtain from two sources. First, after transferring money from other branches and banks causing higher deposits, they gradually decrease in the first three months by over US$ 17,000 for the average non-zero potential damage. Second, they increase the amount of overdrawn current account balances three months after the tropical storm.

In a further robustness check, six additional lagged values of $HURR$ (up to $HURR_{t-12m}$) were incorporated in Table A.3. By including up to 24 lags (12 months), the results slightly alter as the initial effect on the amount of current account balances and the amount of overdrawn current accounts gain more significance and become slightly higher. For the amount of current account balances, the amount of overdrawn current accounts, and savings account balances, the impact remains significant up to 12 months post-strike, suggesting that Colonial Bank's clients indeed escalated their lending over a more extended period, presumably for investments or repairs. In addition, it indicates that clients were engaging in precautionary saving, as evident from the increase in the balances of the savings account. In the case of deposits, the results remain unchanged. However, the inclusion of additional lags is problematic as storms from two seasons may overlap.

1.5.3 Economic Significance

The results are also economically significant. The direct impact of the average non-zero potential damage initially increases current account balances by 13.1%, although this effect dissipates in the following two months. Taking the average current account balance per branch, this can be translated into an initial increase in current account balances of roughly US$ 48,600, indicating that clients were able to send money from either other accounts at different branches of the Colonial Bank, accounts at other banks or to obtain loans from merchants, private individuals, or even banks located outside the British West Indies. The amount of overdrawn current account increases in the first month by approximately 8.9 to 12.4%, becomes zero before gradually increasing to 28.6% half a year after the storm. Afterwards, the effect becomes smaller, so that nine months after a tropical storm strikes, the amount of overdrawn current accounts is roughly 7.3% higher compared to before the storm. Therefore, this results in overdrawn current account balances of US$ 33,000 to US$ 46,000 in the first month and up to US$ 106,000 half a year after the storm and US$ 27,000 nine months after the storm. In the case of deposits, a tropical storm increases them by 9.5% (US$ 30,600) to 14.9% (US$ 48,000) over the first nine months. Therefore, the results suggest that the affected branches of the Colonial Bank were able to attract further deposits after disasters, which prevented them from experiencing a negative funding shock.

However, the banking variables are also mutually intertwined. Therefore, following the estimated value of average non-zero population weighted destruction, the direct aggregate inflow of client assets per affected branch is approximately US$ 80,000[16], while the amount of overdrawn current accounts increases by US$ 25,460, culminating in *net inflows* of US$ 54,600. *Net inflows* continuously decrease afterward and become negative 3.5 months after the hurricane strike. This comes from the fact that the amount of both current account balances and deposits steadily decreased, while clients increased borrowing through overdrawing current accounts. Hence, the results

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[16] The inflows are roughly US$ 40,300 from current account balances, US$ 0 from savings account balances and US$ 39,700 from deposits.

suggest that after an average tropical storm, clients amplified borrowing, in contrast to transferring assets from accounts at other branches or banks. Furthermore, it further implies that the additional inflows after the hurricane were directly used to repair damages caused by the hurricane.

Six and a half months after a strike, customers in affected branches have increased their debts by almost US$ 66,000 while the amount of assets increased only by US$ 26,000, culminating in *outflows* of almost US$ 40,000. Hence, the results suggest that roughly half a year after a strike, clients of an affected branch spent over US$ 40,000 on direct or indirect damage from tropical storms. However, eight months after a tropical storm, the amount of overdrawn current accounts is less than half of its value from 6.5 months after the storm. At the same time, clients increased their deposits by almost one third. Half a month later, clients increase their savings by over US$ 13,000, which slightly increases a further half month later. Therefore, nine months after the hurricane strike, overdrawn current accounts are almost US$ 17,000 higher compared to their values before the shock. However, this is only approximately the amount of the clients net inflows[17]. As *net inflows* increased by approximately US$ 63,000, clients from the Colonial Bank repaid their debts which they owed to the Colonial Bank and were, at the same time, able to increase their assets.

1.5.4 Robustness Checks

Fisher randomization test

To assess the robustness of the findings, I used a Fisher randomization test (Fisher et al., 1937). To this end, tropical storms were randomly assigned across banks and time, with the same model as mentioned above then estimated. This procedure was repeated 1,000 times, resulting in 1,000 *t-values* for each coefficient. These were then added to obtain the *Test Statistics*. The *t-statistics* of the 43 significant coefficients are presented in Table A.4, accompanied by the *t-statistics* from the Fisher randomization

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[17] Current account balances increased by US$ 34,000, savings by almost US$ 14,000 deposits by US$ 31,700.

test (CAC_f, CAO_f, SAV_f and DEP_f). Out of the 43 *t-values*, one *t-values*[18] from the Fisher randomization test have both the minimum magnitude to be deemed significant and also has the correct sign. Hence, the effects can generaly be determined to be causal rather than random. Especially in the case of the amount of current account balance, deposits and savings. In the case of overdrawn current account balances, I would generally say that the effects are causal, especially as out of the 19 coefficients of the Fisher randomization test only one is significant (5%) could have happened purely by chance.

Cubic Wind speed

An important concern might be whether the results from the population-weighted destruction index overestimate the impact of tropical storms of the clients from the Colonial Bank. For this reason, I additionally estimate the regression by using the cubic wind speed estimated at the branches, instead of using a a population-weighted destruction index. Therefore, the regression model becomes the following:

$$LOG(BANK_{i,t}) = \beta_0 + \sum_{k=0}^{p} \beta_{k+1} \cdot HURR_{i,t-k} + \alpha_z + \delta_m + \theta_i + \epsilon_{i,t} \qquad (1.4)$$

The results in Table A.3 show similar signs compared to the ones obtained in the baseline model in Section 2.4.1. The odd column number is always the model with 18 lags and the even column number represents the model with 24 lags. Taking the average estimated wind speed (104.3 km/h) causes current account balances to increase by 9.3 to 9.8% in the first 1.5 months after a storm and then becomes zero. Moreover, such a storm increases the amount of overdrawn current accounts by 10.1 to 12.5% in the same period, becomes zero, and increases again by up to 41.1% in the following five months, which is slightly less compared to the results from the baseline specification. Additionally, deposits increase between 10.5 and 18.4% in the following nine months, and savings increase up to 5.1% between 7.5 and 9 months after a storm.

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[18] The impact of a $HURR$ at $t - 4.5m$ on CAO. The remaining *t-values* are smaller than 1.96.

Therefore, the impact of $DESTRUCTION$ on savings and deposits is always slightly smaller compared to the results in the baseline specification. Therefore, the differences between the results in Table 1.2 are mostly caused by the differences in the distributions of the two underlying variables, as $DESTRUCTION$, compared to $HURR$, gives over-proportional high weights to tropical storms that affect a higher share of the population with a higher wind speed. Including further lags generally increases the size of the effect by up to 10% depending on the banking variable. However, the same pattern was already visible in the case of the population-weighted destruction index in section 2.4.1. However, the estimated effects obtained with the cubic wind speed are similar to the ones obtained with the population weighted destruction index. The initial estimated effect of the population-weighed destruction index (cubic wind speed) on the amount of current account balances is 13.1% (9.3 to 9.8%), on the amount of overdrawn current accounts is between 8.9 to 12.4% (10.1 to 12.1%) and on deposits is between 9.5 to 14.9% (10.5 and 18.4%). Furthermore, using the population weighted destruction index (cubic wind speed) estimates an increase in the amount of overdrawn current account balances by up to 28.6% (41.1%) and an increase in savings account balances by up to 2.3% (5.1%). As the magnitude of the results is generally comparable, it shows that the estimations are robust with respect to changing the functional form. More precisely the results are robust with respect to only using the estimated cubic wind speed at the branches instead of applying a population-weighted destruction index.

Changes in Banking System

As the focus is on a brief period, it is, as I am aware, unlikely that the banking system underwent significant changes within only five years. Table A.6 indicates that only a limited number of branches were impacted, therefore spatial variation across the branches exists. However, it should be noted that the attention is on the average impact of the hurricanes, rather than on the individual event studies. To nevertheless verify this indirectly, Table A.7 presents an additional regression analysis I conducted. It includes dummy variables indicating whether a particular branch had been impacted by the first *(STORM1 TREATED)*, second *(STORM2 TREATED)*, or third *(STORM3 TREATED)* storm. The baseline regression from the paper is also included. Furthermore, I introduced two interactions to illustrate whether a branch was affected by the first and second or the first and third storm. Overall, the results from Table A.7 do not significantly differ from those in the baseline specification. However, it is noteworthy that the first storm resulted in a decrease in CAC, the second storm led to a significant decrease in all variables, and the third storm had a positive impact on CAC, SAV and DEP, whereas it had a negative effect on CAO. Furthermore, the interaction terms suggest that the distinct storms had diverse effects on the banking variables.

As previously shown, the first and second storms had the highest estimated wind speeds and destruction. For this reason, I restricted the subsample up to October 1925 and re-estimated the baseline regression displayed in Table A.8. Findings demonstrated similarities with those from the baseline regression, and implied that the first two storms initially reduced CAC, increased CAO and DEP over a longer time span, and increased SAV roughly nine months after the landfall. Similarly, the magnitude values are less than those in the baseline regression, consistent with the outcomes exhibited in Table A.7.

Pre-Trends and 1910 population data

In Table A.9 I re-estimated the outcomes presented in Table A.7 by incorporating six pre-trends that encompassed the three months preceding the storm's landfall. When comparing the results in Tables A.7 and A.9 it is clear that there were no pre-trends in the variables before the storm hit. Moreover, the findings do not significantly deviate between the two models.

Additionally, I also ran the baseline regression with the 1910 population data, which did not change the destruction index much (as there was not much change in the population), and again did not change the results. I also used the average population per

9.5 x 9.5 km grid cell in 1920 across all branches, which corresponds to 4,845 inhabitants per grid cell[19]. With the average population across all branches I re-estimated the baseline regression so that the population weight is the same across branches. The results of this regression are shown in Table A.10 and only the effect size changes. The fall in size may not be surprising since the population in 1910 is less likely to reflect the exposure for our sample period then using the 1920 population, and hence would be introducing some attenuation bias in our damage index.

1.6 Conclusion

This study explores the role of banks in the aftermath of natural disasters by providing a historical perspective on the impact of tropical storms on clients of the British Caribbean banking system during the 1920s, an era when banks did not grant loans for long-term investments. Natural disasters, such as tropical storms, pose a significant threat to people's livelihood and cause substantial damage to private and public capital like infrastructure, homes, or plantations. After such disasters, individuals often require financial aid to repair damage or sustain themselves in the absence of income, especially if their crops are destroyed. In this context, banks serve as a pivotal institution where clients can save, store, invest money, or obtain loans and advances.

The methodology used in this research involved the creation of a unique dataset that incorporates high-frequency banking data from the 26 branches of the Colonial Bank in the British Caribbean between 1922 and 1927. This data set allowed for a detailed analysis of the bank's operations and their client's behaviour. The study's findings reveal a multifaceted and significant impact of tropical storms on the clients of the Colonial Bank. Tropical storms immediately influenced clients' financial behaviour, which in turn affected the Colonial Bank's balance sheet. Following a storm, clients would typically transfer money from other banks or branches and overdraw their accounts to finance repairs to their homes, plantations, or factories. Colonial Bank,

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[19] This corresponds to 54 people per squarekilometer, which is roughly the recent population density of Uruguay.

however, was able to attract additional deposits to prevent negative funding shocks. Approximately three months after a tropical storm, net money inflows turned negative, suggesting that clients borrowed and spent more than they initially transferred. Interestingly, around 7.5 months after the disaster, clients significantly increased their savings balances, indicating precautionary savings. The data also indicate that clients preferred to cover storm damage by borrowing money instead of using their deposits or savings. Given that the Colonial Bank was not permitted to offer long-term loans secured by property, damaged collateral did not directly influence the amount of loans granted. Furthermore, although the Colonial Bank did not provide its customers with long-term loans, the results reveal that clients transferred money from other banks or branches or were able to receive loans from financial institutions outside the British West Indies or private individuals. This study underscores the importance of the Colonial Bank in the British Caribbean, highlighting its role in helping clients recover from severe external shocks.

Chapter 2

The Creative-Destructive Force of Hurricanes: Evidence from Technological Adoption in Colonial Jamaican Sugar Estates

joint with Eric A. Strobl

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2.1 Introduction

Although Great Britain only colonised Jamaica in 1655, by the 18^{th} century sugar had become the most profitable crop in the British Empire and Jamaica its largest producer in the (British) West Indies (Higman, 1987), where the mode of apparatus was a heavy reliance on slave labour and the use of a fairly primitive technology for production, while also enjoying essentially a monopoly of the British market through protective measures (Schuyler, 1918). However, while profits in the industry had always been extremely sensitive to the inherent volatility of the price of sugar, over the following century slave emancipation in 1834, the gradual reduction of preferential duties with Britain starting in 1846 and final elimination in 1874 (Lobdell, 1972b), and the domination of the world market by European beet sugar producers by the 1880s through rapid technological developments and subsidies caused a large rise in production costs and a sharp drop in sugar prices (Lobdell, 1972b; Mintz, 1959). These fundamental changes in the nature of production, trade protection, and competition meant that sugar estates in the British West Indies for large stretches of the 19^{th} century were repeatedly faced with two main choices: either exit the market or find ways to substantially lower their costs of production (Cumper, 1954; Beachey, 1957). In this regard, Beachey (1957) estimates that of the approximately 2,200 estates operating in the British West Indies at the time of emancipation only between 750 to 800 existed by the end of the century. For those that remained in production, in many of the colonies greater cost efficiency was achieved by the amalgamation of smaller estates into larger ones to benefit from economies of scale and/or substantial capital investment in newer, more cost efficient technologies (Lobdell, 1972b).[1]

Once the jewel in the British crown of sugar production, Jamaica was particularly hard hit by the drastic changes in the market in the 19^{th} century. Of the 600 estates

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[1] For instance, amalgamation of estates was particularly noticeable in Antigua, where of the 107 that existed in 1865 the remaining 78 estates in 1900 had grouped into just 52 (Beachey, 1957), while the adaption of newer technology of surviving estates was most extensively seen in the newer colonies, such as British Guiana and Trinidad (Curtin, 1954).

in cultivation in 1832, by 1896 only 140 had survived (Beachey, 1957).[2] Moreover, although some amalgamation did take place, the large distances between estates generally made this an unfeasible option in many areas of the island (Britain et al., 1897; Lobdell, 1972b). However, curiously many of those estates that were still in production by the end of the 19^{th} century had still not undertaken much by way of technological upgrading to become more cost efficient, as compared, for instance, to Guyana or Trinidad (Norman, 1897a). In this respect Sheridan (1989) has argued that the investments necessary to replace existing with more modern sugar production capital would have been substantial, and thus for the average estate in Jamaica, small and heavily indebted, not feasible through self financing. Additionally, Jamaica at the time was characterized by a lack of access to foreign and public capital (Fe, 1984) and an underdeveloped local banking sector that generally only provided small, short-term loans (Quigley, 1989b; Callender, 1965; Huesler, 2024b).

It was not until well into the first half of the 20^{th} century that Jamaican sugar estates slowly became more cost efficient in line with international standards (Fe, 1984), so that there was a long period of co-existence of plantations with both uptodate and outdated technology. While it has been suggested that the high sugar prices caused by World War I were the primary cause (Callender, 1965), in reality adaptation was much more gradual, essentially implying a prolonged co-existence of technologically advanced and laggard sugar producers on the island. There may, however, have been another type of a large shock that played a role in the technologically inferior Jamaican sugar producers finally upgrading. More specifically, lying in the North Atlantic Basin, Jamaica is periodically subject to potentially very damaging hurricanes and these storms have been shown to historically have had large effects on sugar estates across the West Indies, resulting in significant losses by destroying sugar cane harvests and, more importantly, by damaging sugar production infrastructure (Mohan and Strobl, 2013; Smith, 2012b; Mulcahy, 2004; Schwartz, 2015). By the early 20^{th}

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[2] The average size of surviving estates increased from 495 to 706 Ha, indicating that it was relatively larger estates that survived (authors' own calculation).

century such destruction of vital capital stock arguably would have made the repair of outdated equipment no longer a feasible option for those Jamaican sugar estates that wanted to remain in production. This paper thus investigates whether hurricanes may have indeed acted as a creative-destructive force inducing technologically laggard Jamaican sugar producers to upgrade if they could afford to do so.

To motivate our empirical analysis we, as Dye (2011) did for technological adoption in the Cuban sugar industry, refer to Salter et al. (1969)'s vintage capital model, which allows for sugar producers with heterogenous technologies to coexist in equilibrium. More specifically, because technology is arguably capital embodied in sugar processing, the cost of purchasing new equipment will be subtracted from net per unit of production profits, unlike for the sunk cost of existing equipment. Thus, there can be a range of different vintages of technology in use, depending on the costs of financing, heterogeneities in variable costs, or different forecasts of future prices (Dye, 2011). Related to this, Atack, Bateman, and Weiss (1980) show that more advanced technologies, such as steam engines, produced both more and cheaper power. In our context, since plantation owners generally were able to avoid damage to crops by timing harvesting to take place between January and May while hurricane season generally runs from June to November (Satchell, 1990), we consider hurricanes as mainly inducing negative shocks to the processing equipment, resulting in its necessary repair if production is to continue. However, if the repair costs render per unit production unprofitable, then plantation owners may exit the market or instead choose to upgrade their technology, assuming it is not already at the frontier. Importantly, Bloch, Courvisanos, and Mangano (2011) shows, by combining Salter et al. (1969)'s analysis of capital-embodied technical change with Kalecki (1968)'s analysis of financing investment, that retained profits can induce such technological investment. In the context of Jamaica Sheridan (1989) has also argued that higher sugar prices provided the means to finance any technological upgrading. Feasibly then, once there was damage to equipment from a hurricane it may only be when sugar prices had previously been high that self-financing of such an investment was possible for many estates.

The empirical analysis of our study rests on combining an exhaustive geo-referenced database of Jamaican sugar estates over the period 1882 to 1930 with a local measure of destruction due to hurricanes. Importantly, for each sugar estate we have detailed information on the technology used for sugar production, allowing us to follow the estate level of sugar producing technology over time. To proxy hurricane damages we combine historical tropical storm tracks with a wind field model in order to differentiate likely estate specific damages across space and time. With these data at hand we first establish that hurricanes resulted in reduced sugar production and some estates to exit from the market. We then show that destruction increased the probability of surviving estates updating their capital stock, but that this crucially depended on having the finances to do so.

There already exists some quantitative evidence on the possibly beneficial effects of large environmental disasters in the past, such as for urban growth (Hornbeck and Keniston, 2017) or innovation (Noy and Strobl, 2023, 2022). More importantly, there are also a handful of studies that show that such events can induce surviving enterprises to upgrade to newer technologies after capital stock destruction. For example, for the case of the 1923 Kanto earthquake in Japan Okazaki, Okubo, and Strobl (2019) provide evidence that local damages induced some firms to shut down two years later, while others increased the level of technology, as proxied by horsepower of their machinery. These effects crucially depended on firm size, which the authors interpret as a proxy of access to finance. Looking at firm survival and post-performance after the 1959 Isle Bay Typhoon, Okubo and Strobl (2021) found rather hetereogenous experiences across sectors in Japan, in that in some the flooding caused by the storm decreased survival but also increased the value of the capital stock in survivors, while the opposite was true in others.

Our paper contributes to the existing literature on a number of fronts. Firstly, from a methodological point of view our data set spans enterprises producing essentially a fairly homogeneous product (sugar) over nearly 50 years. This is also a period in which 7 damaging hurricanes struck Jamaica, providing us with a setting of a series of quasi-experiments, rather than one single event, with which to explore the question at hand. We additionally have precise measures of sugar production technology in that we can identify the type of machinery employed and hence can clearly identify what constitutes upgrades. Secondly, while it has previously been shown that the development of financial markets have historically been an important factor for innovation and adoption[3], we here instead explore the role of self-financing in the absence of financial markets. In particular we investigate how the price of the product produced (sugar) as well as the price of the main other, and relatively capital non-intensive, agricultural product at the time (bananas) (Callender, 1965), determined estates' choices and timing of whether to upgrade. Finally, we explore how in such a limited capital market setting government intervention through providing loans may have been important for technological adoption.[4]

The remainder of the paper is organised as follows. The next section provides an overview of the historic background and general setting of Jamaica sugar production during our sample period, followed by an outline of the data in Section 3, methodology and the econometric analysis in Section 4. The last section contains a brief conclusion.

2.2 Historical Background

2.2.1 Jamaica's Sugar History

Sugar production in Jamaica is estimated to have started around the beginning of the 16^{th} century, when the island was still under Spanish rule (Woodward, 2008). However, it only became an important economic actor after the British took control of the island from the Spanish in 1655, and by the 17^{th} and 18^{th} centuries, under the British

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[3] For example, Mao and Wang (2023) provide evidence that the introduction of free banking laws across states in pre-Civil War America encouraged the development of labor-saving technologies, while Harley (2012) show that undeveloped financial markets limited greater technological adoption by textile producers during the early Industrial Revolution.

[4] Okazaki, Okubo, and Strobl (2023) show that in the case of the 1923 Kanto earthquake in Japan government loans helped firms survive, but were unable to examine whether this lead these also to upgrade technologies.

plantation system, Jamaica became the major producer and leading exporter of sugar in the British Caribbean (Deerr, 1950). An important feature of the sugar plantation system was its heavy reliance on slave labour. Thus slave emancipation in 1838 constituted a particularly large cost shock. Given Jamaica's relatively low population density, many former slaves moved away from the estates and were able to acquire their own land for agricultural production, and thus labor supply was limited or unreliable and wages consequently higher (Cumper, 1954). As a matter of fact, it has been estimated that wages of free labour accounted from anywhere between $\frac{1}{2}$ to $\frac{2}{3}$ of the total costs of producing sugar (Cumper, 1954; Beachey, 1957). One possible remedy would have been to become more cost efficient by investing in newer production technology. However, absentee ownership was a common feature of Jamaican sugar plantations, where many absentee proprietors enjoyed extravagant lifestyles, financed by additional mortgages on their often already heavily indebted plantations, hence resulting in limited access to finance for most plantations (Reid, 2016; Mintz, 1959; Mulcahy, 2004; Norman, 1898b). Moreover, they were generally not able to obtain loans from locally based banks[5], making it thus difficult for many owners to invest in modern machinery to increase production after emancipation (France, 1984; Britain et al., 1897; Lobdell, 1972b).

Beginning in 1825, with the entrance of Mauritian muscovado sugar into the global market, Jamaican sugar planters also saw the near monopoly of British West Indian sugar colonies of the British sugar market slowly eroding. This culminated with the Sugar Duty Act of 1846, which introduced the gradual elimination of preferential duties by 1854 within the British empire. In 1884, the price of sugar further declined due to the competition from cheap German and Austrian-Hungarian bountied beetroot sugar, which flooded the European market (Lobdell, 1972b; Mintz, 1959). Consequently sugar exports to Britain fell substantially, although this was partly dampened by increased consumer demand from the US market (Lobdell, 1972b). This in turn led

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[5] The main bank operating in the British Caribbean at the time was the Colonial Bank and it refused to loan money on the security of land (Lobdell, 1972b).

to the abandonment of unproductive lands and the restriction of cultivation on some plots (Handbook of Jamaica, 1880-1938). Falling, and uncertain, profits subsequently discouraged many planters from investing in modern machinery (Civil & Military Gazette, 1882). As cane cultivation stagnated and global demand for bananas rose, there was a significant shift towards banana cultivation. The export of bananas more than quadrupled between 1880 and 1884 in Jamaica, where a number of sugar estates switched to banana production. As noted by Lobdell (1972b), most of the shifting estates were also those unable to get the financial means to update their machinery for sugar production. In 1902, Jamaica's sugar industry was further severely affected by the Brussels Sugar Convention, which abolished both direct and indirect bounties benefiting the export of sugar (Taylor, 1909). This induced the passing of Law 43 of 1903, removing all sugar duties, so that sugar, rum, and molasses from other countries could be freely imported into Jamaica. It is nevertheless noteworthy that not all sugar plantations had decreased their production at this stage, as a few estates, like for example Bushy Park in the parish of St. Catherine, managed to increase their output by introducing state of the art technology (The Jamaica Gleaner, 1896).

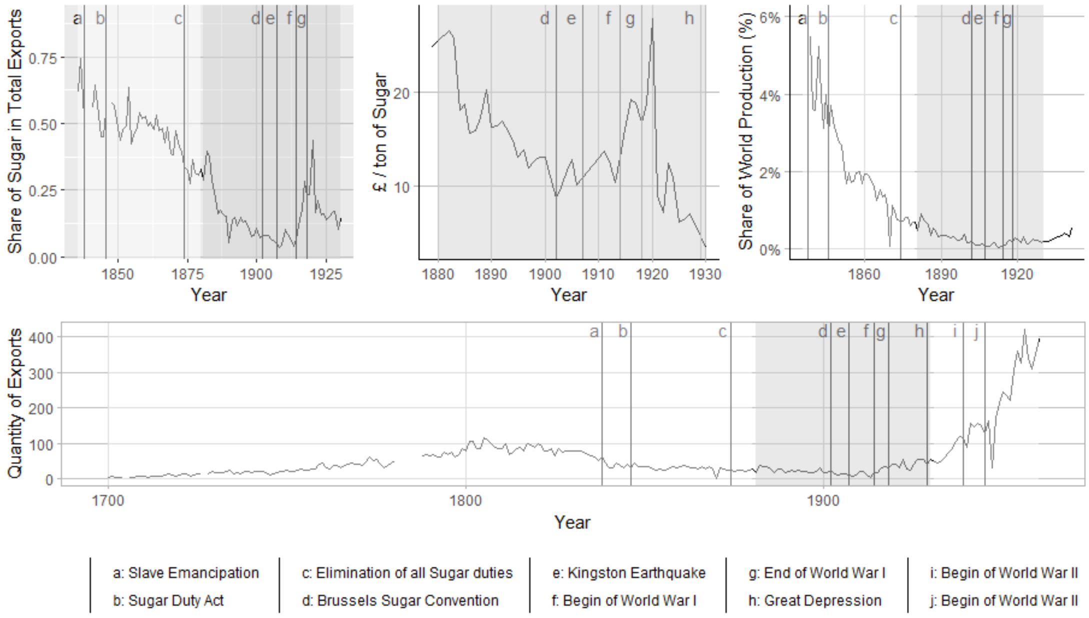
The end of the 1910s was marked by a significant increase in sugarcane cultivation and high prices for all crops, but especially for sugar, most likely due to the collapse of European beet sugar production and the sudden stark increase in British sugar tariffs, which had been gradually re-introduced in 1901, during WWI. However, the subsequent fall of the price of sugar from £75 to £12 per ton in 1921 after dismantling of the tariffs had a devastating effect on sugar estate owners, particularly those that had used the profits due to the prior high prices to upgrade machinery. More specifically, there had been a "... general conviction that high prices would last another season, and this included many planters to improve facilities and their factories. This meant the buying of machinery at abnormally high prices. Then, too, the planters did not sell the whole of their sugar on the top of the boom. This meant that planters instead of getting as they hoped £100 for a ton of sugar, they received anything from £40 to as low as £15 a ton. On the top of this came the bills for machinery to be paid when the planters' means were exhausted." (The Jamaica Gleaner, 1921, p.3).

The trends in Figure 2.1 demonstrate the changes just described in terms of Jamaican sugar exports, share of sugar in total exports, and the price of sugar. As can be seen, the total quantity of sugar exported rose steadily from 1700 to the early part of the 19^{th} century, and then experienced a prolonged decline until the early part of the 20^{th} century when there was a stark rise. In terms of the share of the value of sugar in total exports, one notices also a prolonged decline, and, although the share increases substantially as the per unit market value rose in the late second decade of the 20^{th}, never quite reached the heights of constituting over 50 per cent of total exports witnessed prior to second half of the 19^{th} century. One can also see that this decline in relative exports is also reflected in Jamaica's share of the world market, where this fell steadily from the mid-19^{th} until it plateaued in the beginning of the 20^{th} century.

2.2.2 Sugar Production Technology in the Late 19^{th} and Early 20^{th} Century

The first step in sugar processing was the extraction of cane juice, which was performed by a mill. In the earlier years mostly single roller mills were used to crush the cane and extract the juice (Beachey, 1957). However, over time improvements like applying multiple, heavier, or hydraulic rollers became crucial in maximising the amount of extracted cane juice (Beachey, 1957). The motive power of the mill varied as well, where the simplest were the animal (mostly cattle) and water or wind powered mills (when these power sources were available), and finally steam mills (France, 1984). The first attempt to use steam power was in late 18^{th} century Jamaica, roughly a decade after the first successful application in Cuba in 1797 (Deerr, 1950). Even after the successful application in Cuba, the spread of steam engines in Jamaica was still very slow despite first being used in 1808 (France, 1984). For instance, in 1871 almost all Jamaican Sugar Mills were moved by animal mills and only one out of over 5600 Sugar Mill was moved by steam power (Minutes of the Legislative Council, 1871). In the late 19^{th} Century upgrading mills, however, became much less costly as the production of steam engines was standardised, which also led to a higher adoption rate

FIGURE 2.1: The Evolution of the Jamaican Sugar Market



Notes: This graph illustrates how the sugar exports (1000 tons) evolved over time (lower). The two vertical lines show the start and end year of the observed period. The upper panels show the share of sugar from Jamaica's total exports (left)[6], the price per ton of sugar in £ (middle), which has been deflated with a composite price index from O'Donoghue et al. (2004) and the share of sugar produced in Jamaica relative to the total global sugar production[7]. The gray shaded area is the study period in each panel.

of steam mills on sugar estates (Tann, 2016). As a matter of fact, by 1900 almost all estates were using steam mills (Cumper, 1954).

After extraction, the cane juice was heated to 140 degrees Celsius, and a clarifying agent was added. This was followed by evaporation and concentration, during which the sugar was purified and glucose was obtained (Beachey, 1957). Evaporation of the syrup traditionally took place in a range of copper boilers over an open fire (Beachey, 1957). The major problem with this earlier technology was that evaporation required very high temperatures. Consequently the invention of the vacuum pan became one of the most crucial advances in the sugar industry, as it was able to boil syrup, in vacuo, at much lower temperatures than before (Beachey, 1957). Further improvements in the vacuum pan included triple, quadruple and multiple effects, which made the entire process much more efficient, as less energy was needed to evaporate sugar (Deerr, 1950; Minutes of the Legislative Council, 1887; Fuga, 1961). For example, it has been noted by Beachey (1957) that the vacuum pan could have reduced the costs of sugar production by as much as 50 per cent. Nevertheless, the adoption of the vacuum pan was generally slow in that it was first introduced in 1818 in Europe and only made its first appearance in Jamaica some 25 years later and remained uncommon for much of the 19^{th} century (Deerr, 1950). The fact that, in contrast, the adoption of the vacuum pan took place relatively earlier in some other colonies, such as Guyana or Trinidad, was likely due the fact that sugar estates in these tended to be larger and less indebted, and thus could afford the considerable financial outlay required (Beachey, 1957). Additionally, the relative labor shortage in Jamaica, as many former slaves moved away from the plantations, may have played a role (Beachey, 1957; Engerman, 1983).

After evaporation, the molasses was separated from the sugar crystals. Originally this was done by natural drainage, which required two weeks or more (see Beachey, 1957). The introduction of the centrifuge greatly accelerated this process and only took a few hours (see Beachey, 1957; Fuga, 1961). Additionally, they were easy to install in existing machinery, and second did not require any new skills (Cumper, 1954; Fe, 1984). Moreover, with a centrifugal present the most could be gotten out of a vacuum pan (Beachey, 1957).

Importantly, innovations in the processing of sugar, like the introduction of vacuum pans and centrifuges, also made sugar production less labour intense (Satchell, 1989). There was a clear awareness of this in the region at the time as "[t]he general consensus of opinion seems to show that sugar planting in the West Indies may again become a profitable industry. At present, however, things are in a very slovenly state. Methods of cultivation have been improved, but the old-fashioned machinery is inadequate to cope with the advance made in the sugar trade. Many of the old mills only got 60 per cent out of the cane, but with modern machinery, it would possible to get quite 80 per cent., if not more." (Bath Chronicle and Weekly Gazette, 1901, p.2). Nevertheless, the adoption of the new processing technologies was slow. For example, in the case on Worthy Park Estate in Jamaica acquiring a vacuum pan was recommended as early as 1875 (Craton and Walvin, 1970), but was instead postponed until 30 years later in 1906 (Craton and Walvin, 1970). Improvements of the underlying process were much more common after 1900, where a number of estates are known to have undertaken these improvements when sugar prices were high and some of the revenue generated could be added to cash reserves (Callender, 1965). For example, during the period 1919 to 1928, sugar estates used their savings to increase production and invested over £1’300’000 in new equipment (Callender, 1965).

Investment in sugar production technology by estate owners was not the only strategy for combating falling profits in the industry of the late 19^{th} century. Another solution proposed was to centralize sugar milling and processing at a central factory, as had been seen to be successful in, for instance, the French West Indies. (Beachey, 1978). This was an option strongly supported by the 1897 West Indian Royal Commission, specifically set up to examine the condition and prospects of the British West Indian sugar colonies. For example, in the parish of St. Catherine in Jamaica in 1882 it was argued that a central factory could purchase "[...] sugar canes from neighbouring proprietors and lessees and manufacturing the same into Sugar and Rum [...]." (The Budget, 1882, p.3). That is, as smaller estates were not able to process sugar inexpensively on their own, they could benefit from a central factory that purchased their cane at moderate rates (Beachey, 1978). In order to encourage the construction of central factories the colonial government in Jamaica in response passed a law in 1902 that guaranteed the interest on any capital manufacturing or or preparing any products of the island (Callender, 1965). Nevertheless, at the beginning of the 20^{th} century there were still only a few central factories in St. Thomas and St. Catherine (Handbook of Jamaica, 1880-1938), and it is only in starting in the 1930s that sugar production was dominated by central factories (Fe, 1984).[8] There were arguably a number of reasons for this. For example, as noted by Beachey (1957), only few sugar areas in Jamaica were believed to have enough cane grounds to make it profitable, where a minimum of 38 square miles was believed to be necessary.[9] Additionally, there was as a lack of suitable transport infrastructure in terms of both roads and railways. More specifically, central factories would have required a sufficient railroad network to transport the sugarcane quickly from the plantations to the factories. However, while there were some railroads in Jamaica this was not sufficient to support central factory production and metropolitan investors were unwilling to invest in any necessary expansion (Green, 1973). Moreover, even by 1920 zero per cent of roads in Jamaica had been paved (Maunder, 1954b). Other reasons for the lack of investment in central factories include a lack of financing available (Britain et al., 1897), worries by the merchants who held mortgages on the plantations that central factories would have prior claim on the sugar produced, as well as concerns by sugar plantation owners that relying on central factories would affect their image of independence (Beachey, 1957; Green, 1973).

2.2.3 Hurricanes and Sugar Production

The sugar industry in the Caribbean has a long history of being particularly vulnerable to damages induced by hurricanes (Mulcahy, 2004; Schwartz, 2015). In this regard, using colony sugar export data Mohan and Strobl (2013) estimate that a damaging hurricane could completely wipe out sugar production in the smaller islands, and substantially reduce that of the larger islands. In Jamaica, for example, the average reduction ranged between 20 and 25 per cent, depending on the proxy of damages used.

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[8] Some estates acted somewhat as a sort of small central factory by buying cane from nearby small agricultural settlers, as, for instance, Westmoreland's Cornwall and Shrewsbury estate, but this constituted only a very smal part of total production (see The Governor's Report, 1902, 1904).

[9] This is reflected in the fact that the average distance of estates outsourcing sugar processing to a central factor was less than half (3.5km) than the self processing estates (8.6km), as calculated from the data described in Section 2.3.

With regard to the period examined here, there were several damaging hurricanes in Jamaica that are well documented to have affected sugar production. For example, in 1880 Jamaica was hit by a hurricane that caused significant damage to some sugar estates and their machinery, as described, for instance, by The Saint Christopher Gazette and Caribbean Courier (1880): "Along the shore, the Estates of Lyssons, Retreat, and Leith Hall have had some of their buildings unroofed. At [R]etreat, a large chimney fell, carrying the roof of Engine and Mill House with it and damaging Machinery." (The Saint Christopher Gazette and Caribbean Courier, 1880, p.2). The agent from the estate of owner Alexander Crum Ewing described the destruction to the estates as follows: "The damage done is very great. [...] At Dawkins Caymanas the boiling-house roof is quite destroyed, half of the trash-house roof, the still-house chimney was blown from its foundation right across the tank and deposited on the roof the distillery, 25 feet off, showing the force of the wind. [...] Mr Verlay is one of the worst sufferers, the damage done to "Mona" he estimates at £3000. Then the mills are much injured, 14 out of 18 oxen destroyed-the roof of the mill fell down upon them-and his wharf is washed away." (Glasgow Weekly Herald, 1880, p.8).[10]

A few years later in 1886 Jamaica witnessed a tremendous storm that left the sugar industry in the parish of St. Thomas in dire straits (Minutes of the Legislative Council, 1886). Some estates, such as Ewings Caymanas, used the opportunity to upgrade their machinery (The Governor's Report, 1885).[11] Almost a decade later, in November 1912, there was a heavy storm which caused damage to the parishes of Portland's and St. Mary's cultivation. Some days later, a different hurricane ravaged the western parishes St. James, Hanover and parts of Westmoreland, resulting in a 30% loss

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[10] Similarly, The Jamaica Gleaner (1906) described the effect of hurricanes on sugar estates as such: "The usual result of a hurricane, therefore, is that the roof of the cattle pen, which is an open building, is taken off, and possibly there is some small damage to the roof of the main building, where the original shingle or slate roof has been replaced by galvanised iron. In the modern up-to-date factory the building is usually of steel columns covered in with galvanized iron." (The Jamaica Gleaner, 1906, p.5). The authors also emphasized that in the case of such a modern factory, which mostly exist only in Trinidad, the rain could damage the mill if the building loses the roof due to the wind (The Jamaica Gleaner, 1906).

[11] In 1903 Jamaica was hit by a strong hurricane that destroyed almost all cultivation in the parish of St. Andrew and caused a great economic shock and a stark increase in unemployment. As sugar cultivation and estate buildings were damaged, there was a movement of sugar settlers to either abandon their estates or switch to the cultivation of bananas (The Governor's Report, 1904, 1906).

of sugar production (The Jamaica Gleaner, 1913). These hurricanes caused extensive damage, as in the case of Fred L. Clarke's estate, where the storms destroyed large portions of crops as well as the estate's buildings and machinery. Importantly, hurricanes such as these, often forced planters to turn to creditors as they set out to rebuild their capital infrastructure (Mulcahy, 2004).

2.2.4 Financing

Cost of Advanced Sugar Technology

The cost of upgrading sugar processing technology was considered to be generally prohibitive, particulary in view of the volatile and uncertain market price of sugar (Britain et al., 1897). In terms of the cost, data from Norman (1897b), for example, show that in British Guiana the average sugar estate invested over £14'000 in new machinery between 1882 to 1895. Roughly 15 years later, George Carrington, an estate owner from Barbados, mentioned that updating machinery of an estate costs about £10'000 (Norman, 1897a).[12] Given that data on production and production costs on a select number of sugar estates in 1897 collected by the Sugar Planters Association (Britain et al., 1897) and sugar and rum prices in that year from Blue book of Jamaica (1897) suggests that the average annual profit for estates without a vacuum pan and centrifugal was £542, which implies that if such an investment were to be solely financed by savings at 1897 prices then this would take at least 20 years to repay. One should note that the potential increase in profits in upgrading suggested by the same data would be sizeable, as the average profits in estates with updated processing technology in the sample was £3,504, while the average per acre profit was more than double (£6.44 versus £3.07) and the average profit per ton of sugar was nearly double (£6.02 versus £3.34).

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[12] Unfortunately one can only find information on the costs of investing in a vacuum pan, but not the equivalent for a centrifugal. In this regard, Lock, Newlands, and Newlands (1888) estimates the cost of a small vacuum pan to be £2'000 in 1888, although this may be the price for a smaller unit as The Sugar cane (1883) notes the cost to vary approximately between £2'000 to £9'000. Additionally, it is noteworthy that have no information on installation costs, which also might have been high.

Access to Finance

As a large proportion of the sugar estate owners in Jamaica were absentee and heavily indebted, it was difficult for them to invest in new machinery or to expand cultivation (Sheridan, 1989).[13] But even for landowners without large debts, who often put all their assets into their estates, raising additional money for new technologies proved difficult (Minutes of the Legislative Council, 1873). In terms of private banking in Jamaica the British Colonial Bank held a monopoly until 1890, when a few Canadian banks entered the market (Quigley, 1989b). However, the Colonial bank was not able to provide long-term investment capital, as it was prohibited from lending against property (Monteith, 2003; Lobdell, 1972b), while the private banks were generally risk averse, only granting small, if any, loans. For example, in 1906 the Bank of Nova Scotia loaned only 15% of its deposits (Quigley, 1989b). Hence, arguably the banking system was not able to provide estate owners with the loans financing for large investments.[14] As a matter of fact, frustration in this regard was often voiced by the plantation owners. For example, in reporting to the West India Royal Commission one estate owner stated that "There is practically no credit [...] and I cannot borrow any money." (Norman, 1897a, p.256)

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[13] A reporter from The Mail (1902) wrote about the dire need for capital: "[...] [a] great deal of capital is needed to equip the sugar Industry of the West Indies with the modern machinery and appliances required for the economical cultivation of the cane and the economical production of sugar from the cane, and there is little or no capital In the islands available for the purpose. The local capital of the planters has, with rare exceptions, all been exhausted long ago, and the worst effect of the bounties has been to prevent the introduction of fresh capital from without. It is certain that with new machinery and appliances the present cost of sugar production in the West Indies can be very largely reduced." (The Mail, 1902, p.4).

[14] Another potential private source of financing for sugar estates could have been direct investments. However, while investors from the United States invested heavily in the banana industry, they did not undertake equivalent investments in sugar estates in Jamaica (Callender, 1965).

Government Financing

The Jamaican government generally did not provide direct financing to sugar estates except on three notable occasions over the period under consideration.[15] First, in response to the devastating hurricane of 1903, the Hurricane Loan Law of 1903 was passed, providing loans in aid of restoration of cultivation due to the hurricane (Hoyte, 1969). However, these loans were limited to no more than £3 per acre (Handbook of Jamaica, 1904), and thus even for the largest sugar producer at the time ($\approx$ 1000 acres) would have hardly provided sufficient funds to fully finance full investment in new processing technology, let alone for the average sized estate ($\approx$ 200 acres). In addition, the loans had to be repaid by 1905, i.e., relatively shortly after being received.

In response to the disastrous hurricane in 1912 the government established the Agricultural Loan Society Board with the Agricultural Loans Societies Law in 1912 (Laws of Jamaica, 1912). The Agricultural Loan Society Board was entitled to provide some money to the newly installed Agricultural Loan Societies (see Minutes of the Legislative Council, 1912). The Agricultural Loan Societies' shares were owned by its members, i.e., people and enterprises connected to agriculture or agricultural trade, which in turn entitled them to receive loans of up to £200, if either the 1912 hurricane or the drought during that period caused damage to their cultivated land (Laws of Jamaica, 1912). Again, this amount was unlikely to be enough to finance technological upgrading in sugar processing. However, one year later, in June 1913, £30'000 was allocated by the agricultural loan societies board for the relief of the sugar industry in Westmoreland and Hanover, who suffered losses from the hurricane (see Minutes of the Legislative Council, 1913, 1914). In addition, under Laws 36 and 37 of 1912, approximately £50'000 was appropriated to People's Co-operative Laon banks. These local agricultural loan banks were originally established in 1905 and were intended to provide small farmers with longer term loans, but had nearly all failed until the passing of the Agricultural Loan Societies Law of 1912, which established a board to support the

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[15] However, the government provided indirect support through the operation of Botanic Gardens that conducted research (Handbook of Jamaica, 1908), as well as through the system of indentured immigration which provided the plantations with a source of cheap labor (Roberts and Byrne, 1966).

Agricultural Loan Societies, through which public funds then could be made available to the local loan banks to lend to its members (Callender, 1965). As noted by Callender (1965), the subsequent primary recipients of such loans were the owners and lessees of sugar crops damaged by the hurricane. For instance, of the £50'000, 40% went to five local loan banks in St. Mary and 25% to six banks in Clarendon, St. Catherine, and St. James, whereas only a very small proportion, i.e., £115, went directly to cane farmers located in Hanover (see Minutes of the Legislative Council, 1914). Importantly, as these local loan banks were able to provide fast loans after natural disasters, like after the 1912 storms, they became valuable institutions (see Minutes of the Legislative Council, 1914). Moreover, the government decided to provide direct loans of £43'646, from which over half of it went to Vere in the south, which is now incorporated into Clarendon Parish (see Minutes of the Legislative Council, 1914). Three years after issuing the loans, almost half (The Governor's Report, 1916) and ten years later most of the loans were repaid (The Governor's Report, 1922).

A few years later, when sugar prices fell rapidly in 1920, many estates again found themselves in severe financial difficulties, the Jamaican government decided to help the sugar industry with the Sugar Industry Aid Loan Law of 1921, which provided a total amount of loans of up to £400'000 to the planters (see The Jamaica Gleaner, 1921; Minutes of the Legislative Council, 1924). As prices continued to fall in the 1920's, the Legislature of Jamaica additionally introduced an export bounty of £2.00 per ton of sugar in 1929, which led to a massive increase in sugar production in 1930 (The Governor's Report, 1929, 1930). The introduction of the export bounty was crucial, as it prevented many sugar estates from bankruptcy which would have destroyed the millions invested into updating the machinery and extending cultivation (Minutes of the Legislative Council, 1930).

Finally, one should note that there was generally little support from the British colonial government itself for the technological upgrading in the sugar industry in general (Lobdell, 1972b), or providing relief in response to damages induced by hurricanes.

With regard to the latter, Webber (2018) argues that "[...] colonial responses were ad-hoc, and fraught with anxiety due to the need to respond to shortages of food and materials." (Webber, 2018, p.0).

2.3 Data

2.3.1 Estate Data

Data on Jamaican sugar estates is taken from the annual Sugar Estates in Cultivation tables collated by the Institute of Jamaica in the *Handbooks of Jamaica*, which were first published in 1881 and provide information on the production, as well as various aspects of ownership, of all sugar estates in cultivation in Jamaica[16], as well information on their ownership and management, acreage, manufacturing technology, and output. We digitalized the data up to 1930.[17]

The Sugar Estates in Cultivation tables explicitly state the estate's name, owner's name, and, if applicable, the managing attorney, as well as its parish of location. This allowed us to match estates' observations over time. Linking the estate name with information collated by The University College London Department of History's Centre for the Study of the Legacies of British Slavery database[18] also enabled the identification of the exact geographic location of each estate, as well as their age. From these data we created a dummy for whether the estate was managed by an attorney (ATTD), the age of the estate (AGE), and the number of estates owned by each owner (OWNERSUM). The inclusion of OWNERSUM and ATTD as a control variables stems from the fact that some estate owners owned multiple estates in order to benefit from

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[16] *Estate* is the traditional term in Jamaica for the factory-farm complexes growing and processing cane (Fe, 1984). It has been estimated that around the turn of the 19^{th} century there were an additional 6000 small farmers with small mills who planted around 5,000 acres of sugar cane mainly for local consumption (Norman, 1898a).

[17] After 1930 the information recorded in the Handbooks became rather limited. In particular, it stopped reporting the type of technology employed. One may want to note that this does not appear to be related to a general decline in the industry. More specifically, while there was a slight decline in the production of sugar from 1931-1933, it almost consistently rose (except for 1940) from then onward until at least 1950 - see Cumper (1954) cited in the text.

[18] See University College London Department of History (2022).

economies of scale (Higman, 2008). It is expected that estate owners with multiple estates would be more productive and have greater financial resources to upgrade machinery. However, owning multiple estates is associated with higher costs for estate management. As a result, owners often hire attorneys to manage their estates. A professional attorney who is able to introduce innovations can have a positive impact on the estate business (Sheridan, 1957, 1960). Nevertheless, the presence of an attorney may also be an indicator that the owner was an absentee. AGE was introduced as a control variable due to intensified agriculture reducing soil quality (Cherubin et al., 2016; Cheesman, 2004) and, consequently, sugar production on the estate.

In terms of sugar production the tables provide the extent of area (in acres) under sugar cultivation and the amount of sugar (in hogshead[19]) produced. From this we calculated the annual sugar production per acre (HPRS), expressed in terms of its inverse hyperbolic sine in order to take account of occasional zero production years.[20] With regard to milling technology there is information on the type of mill employed, where there is a distinction between wind, water, cattle, and steam driven mills. Since the steam mill is the most up-to-date technology of these, but at times is used in conjunction with other mills, we simply define a dummy (MILL) of when a steam mill is employed. With regard to evaporation technology the data allows one to identify when aspinal, wetzel, or vacuum pans were used, and we thus create a dummy (TECHV) for the use of the latter, most advanced, technology.[21] For the separation of the molasses from the sugar crystals in the processing of sugar by estates one can also determine whether the more modern centrifugal apparatus was used, and we accordingly created an indicator variable (TECHC). Additionally, we generated a dummy for

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[19] One Hogshead of Sugar is roughly 750kg (Higman, 2008).

[20] One should note that the use of the inverse hyperbolic sine also comes with a number of disadvantages. Firstly, the subsequently estimated coefficients no longer capture marginal effects but instead can only be used to calculate elasticities (Bellemare and Wichman, 2020). Secondly, any estimated coefficient will capture a combination of both the extensive margin, i.e., the impact on moving from zero to a positive values, as well as the intensive margin, i.e., impacts on changing positive values, of the dependent variable. As noted by De Brauw and Herskowitz (2021) the estimated effect can thus in some circumstances be sensitive to the choice of units of the variable.

[21] Unfortunately, while at times it is also stated whether the vacuum pan includes triple, quadruple, and multiple effects, this does not appear to be consistent enough over time to use in the empirical analysis.

when both a vacuum pan and a centrifugal was in use (TECHCV) and, by examining the previous year's data whether either of these technologies or both of them were introduced for the first time, generating corresponding dummies fTECHV, fTECHC, and fTECHCV.

A sugar plantation's exit from the sugar producing market was identified when it no longer appeared in the tables.[22] The information given also allowed us to identify when an estate no longer produced sugar itself, but instead sent the canes to a central factory. Unfortunately, we have no information as to the production of the central factories itself, but do have the acreage planted from the supplying estates. We created dummies for both market exit (EXIT) and central factory production (CF) for the year prior to these.

2.3.2 Hurricane 1912 Loans

The Governor's Report (1926) compiled a list of all the local agricultural loan banks that extended loans under the Hurricane Law of 1912 and the corresponding total amount given, where there were a total of 38 of such lending establishments. We proxied the most likely relevant loan bank for each estate by identifying the one closest to the estate, using the geo-coordinates of the estate and the latitude and longitude of the town of the bank's location.[23] Loans per estate were then simply calculated as the total amount of loans of the corresponding bank divided by the number of estates for which the bank was the nearest (LOAN). One should note that this variable thus is constructed to vary across estates even within parishes.

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[22] For some there was the explicit remark that it had been abandoned, although this was not consistently recorded even when the estate was no longer included in subsequent years in the tables. Also, one should note that the fact that an estate no longer harvested sugar did not necessarily mean that the estate was completely abandoned. Rather many estates simply switched to banana production. Unfortunately, while in the later years of our sample period there are summary tables of estates producing bananas, the name of the estate often changed through ownership or amalgamation so that explicitly identifying switching sugar estates was not possible.

[23] For eight of these only the parish was provided, and we thus used the centroid of the parish instead as the bank's geographic location.

2.3.3 Hurricane Damages

In order to construct a proxy of damages to sugar estates due to hurricanes we use the historical storm tracks from the National Hurricane Center's North Atlantic Hurricane database (HURDAT) as inputs into a wind field model, as in Strobl (2012). HURDAT consists of the tracks of all known tropical storms in the North Atlantic since 1855, providing the six hourly position of the storm eye as well as the maximum wind speed at each point, as derived from ship sightings.[24] We interpolate these to hourly data observations. Using these within a tropical storm wind field model allows us to predict the maximum wind speed experienced during a storm's lifetime at any point relative to the eye of the storm, and we do so for the location of each Jamaican sugar estate for each storm. Following Strobl (2012), damages are assumed to have a cubic relationship to wind speed due to energy dissipation reasons (Emanuel, 2005), and that damages occur once wind speeds reach 119 km/hr, i.e., Saffir-Simpson Scale Level 1. As the consequent value of this variable (H) was large we normalized it by $10e^{-06}$. Additionally we created its mean ($\overline{H_i}$) and standard deviation (H_i^{σ}) for the period prior to 1880 to capture its estate specific pre-sample period distribution.

2.3.4 Price of Sugar & Bananas

In order to proxy the prices of sugar and bananas, denoted as PS and PB respectively, we use the unit value as taken from the Jamaican Colonial Blue Books. This is constructed by dividing the value of exports of each good by its quantity.[25] As these are in different units (tons for sugar and bunches for bananas), we generated their anamolies, i.e, deviations from the mean normalized by the standard deviation.

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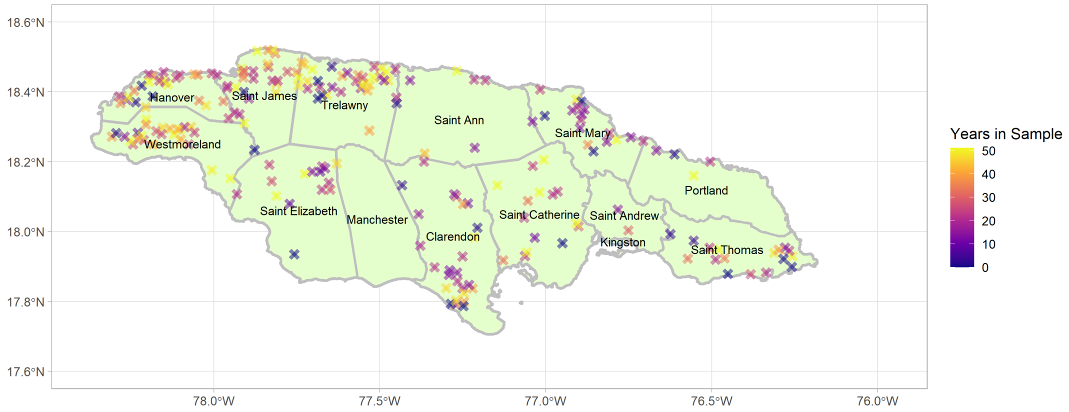
[24] One might be concerned that the reliability of the HURDAT database, particularly for the 19^{th} century. However, as noted by Chenoweth and Divine (2014), despite lower coastal populations, there were actually more registered ships at sea than in the 19^{th} compared to the first half of the 20^{th} century.

[25] One should note that there were no duties on sugar or bananas exports during our sample period. Our choice of using export unit values rather than average world market prices is to take account of any quality differences in the Jamaican products.

2.3.5 Summary Statistics

Figure 2.2 shows the spatial distribution of the 203 estates in our data, where the size of the dots indicates the relative number of years an estate was in the sample. Accordingly, most of the estates were concentrated in the western parishes of Westmoreland, Hanover, Saint James and Trelawny. The majority of estates remained for at least 20 years in the sample, but with large variations.

FIGURE 2.2: Distribution of Estates



Notes: This graph illustrates the distribution of the sugar estates in Jamaica during the observed period. The colours indicate the number of years, a specific estate was part of the sample.

Summary statistics of all our variables for the estates are provided in Table 2.1. As can be seen, the average (inverse hyperbolic sine) sugar production per acre is 0.92, corresponding to 2.4 hogshead per acre in levels, but with a variation of 80 per cent of the mean. Four per cent of the observations are estates producing right before they exit market, i.e., 173 of plantations ceased production within our sample period. The average age of estates is 131 years, where 68 per cent of these are run by attorneys and most plantations are part of a single ownership structure. The average use of steam mills is 86 per cent. For processing technology, the use of centrifugals (0.72) over the sample period is larger than that of a vacuum pan (0.48), where only 38 per cent of the observations constitute estates using both. In terms of first time adaptation of the processing technologies[26], their low value but high standard deviation indicates that much updating has taken place over the period in question. As a matter of fact, as can be seen from Figure B.2, the number of estates that already had the technology in place at the beginning of the period was only 27 and 45 per cent for vacuum pans and centrifugal, respectively, and 7 per cent for both. This rose to 100 per cent in terms of the centrifugal and 93 per cent for vacuum pan by 1930. One should note, however, that some of the increases in shares were due to exits of non-users and not just first time adoptions. The higher share of vacuum pan compared to centrifugal technology is likely due to the fact that the former required less skilled labor to operate (Cumper, 1954).

The use of the historical storm tracks within our wind field model and damage function identified 7 damaging storms in Jamaica during our sample period, namely in 1886, 1895, 1903, 1912, 1915, 1917, and 1928.[27] The variation of H for these storms is more than double its mean, which is in large part because for most years for most estates the damage due to hurricanes is zero. The average annual value of H across estates are depicted in Figure B.2. Accordingly, the highest average destruction was in 1903, followed by the storm in 1912. Comparing the trends in technology adoption to the occurrences of hurricanes any evidence of an increase in the share of the technologies, singly or together, seems rather mixed. One of the possible reasons may be that upgrading after a hurricane was conditional on available financing. For example, after the 1915 hurricane, when prices would have been on a rise due to WWI, the share of estates employing vacuum pans increased.

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[26] These variable is set to missing after they have taking on a value of one.

[27] In order to verify that our wind field model calculations did not miss any damaging hurricanes, we searched the digitalized *Jamaican Gazette* over our sample period using the search terms 'hurricane' and 'storm'. However, this did not unearth any other damaging hurricanes.

TABLE 2.1: Summary Statistics

	Def. (units)	Mean	St.Dev.	Min.	Max.	N
HPRS	Inverse Hyperbolic Sine of Sugar Prod.	0.92	0.75	0.00	7.92	3,676
EXIT	Exit Dummy	0.04	0.18	0.00	1.00	3,323
ftC	1^{st} Time Adoption of Centrifugal	0.05	0.22	0.00	1.00	1,095
ftV	1^{st} Time Adoption of Vacuum	0.03	0.17	0.00	1.00	1,959
ftC×ftV	1^{st} Time Adoption of Centrifucal & Vacuum	0.03	0.17	0.00	1.00	2,350
H	Hurricane Damage Index (Th=119km/hr)/ 10e-06 (km/hr)	0.52	1.30	0.00	7.35	3,676
H[178]	Hurricane Damage Index (Th=178km/hr)/ 10e-06	0.04	0.52	0.00	7.35	3,676
PS	Price of Sugar (Anomolies)	0.02	0.97	-1.75	5.92	3,676
PB	Price of Bananas (Anomolies)	0.05	0.99	-2.06	1.48	3,676
LOAN (t=1912)	£1000s	0.298	0.435	0.010	1.831	61
$\overline{H_i}$	Avg. H 1855-1880	0.28	0.09	0.08	0.46	3,676
H_i^{σ}	Std. H 1855-1880	0.83	0.17	0.44	1.14	3,676
MILL	Dummy for Steam Mill	0.86	0.35	0.00	1.00	3,676
V	Dummy for Vacuum Pan	0.48	0.50	0.00	1.00	3,676
C	Dummy for Centrifugal	0.72	0.45	0.00	1.00	3,676
C×V	Dummy for Centrifugal & Vacuum Pan	0.38	0.49	0.00	1.00	3,676
AGE	Age	131.09	23.65	64.00	254.00	3,676
ATTD	Dummy for Attorney Mgmt.	0.68	0.47	0.00	1.00	3,676
OWNS	# Estates Owner owns	1.71	1.09	1.00	9.00	3,676
LAT	Latitude (degrees)	18.28	0.19	17.79	18.52	3,676
LONG	Longitude (degrees)	-77.64	0.50	-78.31	-76.26	3,676
WAR	WWI Dummy (1917-1920)	0.05	0.21	0	1	3,676
DUTY	British Empire Duty	2.21	3.20	0	12.6	3,676

Notes: All variables are defined over the 1881-1930 period.

The average loan amount from local banks in 1912 (LOAN) was £890, but with a standard deviation of 1850, where the largest implied amount was slightly over 10'000 and the smallest less than 10. Finally, the statistics for PS and PB show that the anamolies in banana prices were larger than those of sugar.

2.4 Econometric Analysis

As a theoretical framework underlying our econometric analysis we follow Dye (2011)'s approach to technological adoption in the Cuban sugar industry and refer to Salter et al. (1969)'s vintage capital, where plantation owners, once their estate's capital stock is damaged by a hurricane, may continue as is, or, if the status quo is rendered unprofitable by the damage may either exit or instead choose to upgrade their technology, assuming it is not already at the frontier. To put this theoretical framework to the data we undertake a number of estimations. First, we seek to confirm that our hurricane proxy accurately captures damage done to sugar estates by examining its impact on sugar production. Secondly, we estimate the effect on the aforementioned choices for an estate once it is damaged, namely to either exit the market, remain as is, or, if this has not already been done, upgrade its technology.

2.4.1 Impact on Sugar Production

The impact of hurricanes on sugar production (per acre) is estimated with the following linear model:

$$PRS_{it} = \alpha + \beta_H H_{it-1} + \beta_{\mathbf{X}} \mathbf{X}_{it} + \lambda_t + \mu_i + \epsilon_{it} \tag{2.1}$$

where PRS is the inverse hyperbolic sine value of sugar (hogsheads) per acre for estate i in year t. H is the hurricane damage index described in Section 2.3 measured at $t-1$ since sugar harvesting season is generally in January to May and hurricane season May to November. $\mathbf{X}$ are a base set of control variables, including an estate's age (AGE) and its squared value (AGE^2), a dummy for whether the estate is managed by an attorney ($ATTD$), the number of estates the owner possesses ($OWNS$), and whether the estate runs on as steam mill ($MILL$). λ is set of year fixed effects, while μ are a set of estate fixed effects and ϵ is the usual error term. Standard errors are clustered at the estate level.

One should note that arguably the estimated coefficient on H_{it-1}, i.e., β_H, is exogenous and thus can be interpreted strictly causally. More precisely, while one may worry that estates make their location and other decisions with the knowledge of the local risk of hurricane wind exposure in mind, after controlling for the local distribution of such potential damages with estate fixed effects μ, one is left with unpredictable, random realizations from this wind exposure distribution. We can thus confidently interpret any estimated effect of H in 2.1 as causal.[28]

The results of estimating Equation 2.1 including H at time t-1 are shown in the first column of Table 2.2.[29] As can be seen, hurricane wind exposure acts to significantly reduce per acre sugar production. If one takes the average non-zero value of H, i.e., 3.4, then this implies a change in the elasticity of PRS of -13.6 per cent. In the second column of Table 2.2 we experimented with using a higher damage minimum threshold value, i.e., 178 km/hr for H. However, as can be seen the coefficient is substantially smaller and insignificant, indicating that such a functional form is not able to capture the damages incurred in sugar estates due to hurricane wind exposure. We also investigated in the third and fourth columns whether there might be lagged effects at $t-2$ and $t-3$, respectively, but their estimated coefficient are insignificant and this does not change the coefficient on H at t noticeably.

In terms of the other control variables ($\mathbf{X}$) one finds that only AGE, in an inverted u-shaped manner, significantly predicts sugar production. More precisely, as an estate ages there is first a reduction in production, but at a decreasing rate. Although in principle this decreasing rate would ultimately result in an increase in production, the rate of decrease, i.e., the coefficient on AGE^2 is extremely small, suggesting that such a turning point (355 years) is well beyond any observed lifetime in our sample. The ultimately decreasing relationship may have to due with soil exhaustion, where only older and established states have sufficient experience or financing enough to use techniques to counteract this erosion of quality of soil. However, one should note that the youngest estate in our sample is 64 years and thus that this relationship is estimated based on estates that have been in the market for many decades already. The fact that owning more than one estate does not translate into productivity gains is

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[28] Of course, if our proxy H is poor in capturing the actual damage incurred by estates, then there may be the possibility of attentuation bias caused by measurement error.

[29] One should note that for all regressions undertaken in the paper we investigated whether there were multi-collinearity issues, particular with regard to our main variables of interest by calculating the variance inflation factors after estimation. The results indicate that this was not an issue; detailed results are available from the authors.

TABLE 2.2: Impact of Hurricane Damage on Sugar Production

	(1)	(2)	(3)	(4)
$H_{i,t-1}$	-0.041*		-0.039*	-0.039*
	(0.016)		(0.016)	(0.016)
$H_{i,t-2}$			0.046	0.047
			(0.033)	(0.034)
$H_{i,t-3}$				0.000
				(0.000)
$H_{i,t}[178]$		0.001		
		(0.012)		
$AGE_{i,t}$	-0.067**	-0.067**	-0.067**	-0.068**
	(0.012)	(0.012)	(0.012)	(0.012)
$AGE^2_{i,t}$	0.000**	0.000**	0.000**	0.000**
	(0.000)	(0.000)	(0.000)	(0.000)
$ATTD_{i,t}$	0.056	0.056	0.055	0.054
	(0.039)	(0.039)	(0.039)	(0.039)
$OWNS_{i,t}$	0.003	0.002	0.003	0.003
	(0.014)	(0.014)	(0.014)	(0.014)
Obs.	3676	3676	3676	3676
R^2	0.203	0.200	0.197	0.193

Notes:(a) Linear panel model with estate fixed effects; (b) ** and * are 1 and 5 per cent significance levels; (c) Standard errors (clustered by estate) in parentheses; (d) Time dummies included but not reported.

perhaps not surprising as it has already been noted earlier that one of the reasons why establishing central factories to merge the processing of cane across estates was not appropriate for most of Jamaica was because of the large distances between estates. A similar reasoning may be applied in terms of not finding any economies of scale for multiple estate ownership. The result that attorney management does not have a detrimental effect on sugar production has already been shown by Higman et al. (2005) for Jamaica and for Saint Vincent by Smith and Forster (2018), although only for the first half of the 19th century.

2.4.2 Impact on Market Exit & Switch to Central Factory Production

Figure B.3 shows the number of sugar producing estates over our sample period. As can be seen these fell considerably from 176 to only 30 over our sample period. To explore whether hurricane damage induced estates to exit the processing market, broadly defined as complete abandonment or shifting to other types of production, such as bananas, we specify a simple probit model[30]:

$$P\Big(EXIT_{it}=1\Big)=\phi\Big(\alpha+\beta_H H_{it-1}+\beta_{\mathbf{X}}\mathbf{X}_{it-1}+\beta_{\mathbf{Z}}\mathbf{Z}_i+\gamma_K+\lambda_t+\epsilon_{it}\Big) \tag{2.2}$$

where $EXIT$ is the indicator variable of whether the estate is no longer in the market at $t+1$, P is the probability that $EXIT$ takes on the a value of one, and ϕ is the cumulative distribution function of the standard normal distribution. Since Equation 2.2 is a non-linear model so that one can no longer control for estate fixed effects that would capture all sugar estate time invariant unobservables. In particular one might be worried about not taking account of the local hurricane damage distribution, thus rendering the causal identification on H questionable. Thus we, in addition to the longitude ($LONG$) and (LAT) of the estate and a set of parish dummies (γ), also control for the mean ($\overline{H_i}$) and standard deviation (H_i^σ) of H as measured prior to our sample period, i.e., for 1855-1880, as denoted in $\mathbf{Z}$. Standard errors are clustered at the estate level and all coefficients are reported as marginal effects.

The results of estimating Equation B.2 are provided in the first column of Table 2.3. Accordingly, there is no apparent effect of hurricane damage on the probability that an estate exits the sugar production market. However, when we include H's lagged value in the second column one finds a significant positive impact on $EXIT$, where this exit inducing effect does not last beyond $t-2$ (Column 3). The estimated coefficient on H_{t-2} suggests that the average non-zero hurricane damage increases the probability

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[30] Employing a logit model instead made no difference qualitatively and produced very similar implied quantitative impacts. This was also the case for any subsequent probit models employed in the analysis.

of an estate ceasing production two years later by about 6.8 per cent, while the largest observed impact (7.4) over our sample period was 14.8 per cent.

TABLE 2.3: Impact of Hurricane Damage on Estate Exit & Central Factory Production

	(1)	(2)	(3)	(4)	(5)	(6)
Dep.Var:	EXIT	EXIT	EXIT	CF	CF	CF
$H_{i,t-1}$	0.002	0.002	0.002	-0.000	-0.000	-0.000
	(0.004)	(0.004)	(0.004)	(0.001)	(0.001)	(0.001)
H_{t-2}		0.021**	0.021**		-0.000	-0.000
		(0.006)	(0.006)		(0.001)	(0.001)
H_{t-3}			-0.000			0.000
			(0.000)			(0.000)
$\bar{H}_i$	-0.018	-0.019	-0.020	-0.020	-0.021	-0.020
	(0.083)	(0.080)	(0.080)	(0.047)	(0.048)	(0.046)
H_i^σ	-0.021	-0.020	-0.020	0.012	0.012	0.012
	(0.042)	(0.041)	(0.041)	(0.027)	(0.028)	(0.027)
$AGE_{i,t}$	-0.000	-0.000	-0.000	0.000	0.000	0.000
	(0.001)	(0.001)	(0.001)	(0.000)	(0.000)	(0.000)
$AGE^2_{i,t}$	-0.000	-0.000	-0.000	-0.000	-0.000	-0.000
	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)
$ATTD_{i,t}$	-0.008	-0.009	-0.009	0.000	0.000	0.000
	(0.005)	(0.005)	(0.005)	(0.001)	(0.001)	(0.001)
$OWNS_{i,t}$	-0.003	-0.003	-0.003	0.000	0.000	0.000
	(0.002)	(0.002)	(0.002)	(0.000)	(0.000)	(0.000)
$LATI_i$	0.016	0.015	0.015	-0.011*	-0.011*	-0.011*
	(0.021)	(0.020)	(0.020)	(0.025)	(0.025)	(0.025)
$LONGI_i$	0.018	0.019	0.018	-0.004*	-0.004*	-0.004*
	(0.010)	(0.010)	(0.009)	(0.010)	(0.010)	(0.010)
Obs.	3323	3323	3323	528	528	528
$Pseudo-R^2$	0.141	0.148	0.148	0.460	0.461	0.461

Notes: (a) Probit model; (b) Coefficients reported as marginal effects; (c) ** and * are 1 and 5 per cent significance levels; (d) Standard errors (clustered by estate) in parentheses; (e) Time and parish dummies included but not reported.

Figure B.4 depicts the share of sugar estates outsourcing processing to a central factory as well as their share in total sugar acreage. Accordingly, both the number as well as their acreage increased substantially in importance, where by 1930 these constituted nearly 20 per cent and 40 per cent, respectively. To see whether hurricane damage may have resulted in increased outsourcing we re-estimated Equation 2.2 but instead in terms of switching to central factory production. As can be seen, hurricane damage had no impact on switching to production to central factories, regardless of the time horizon considered. In terms of the other control variables, one finds that only the latitude and longitude are significantly significant. This may not be surprising since, as has been noted earlier, many plantations were geographically disadvantaged to produce for a central factory.

2.4.3 Impact on First Time Adoption of Modern Processing Technologies

The role of hurricane destruction in terms of the first time adoption of modern processing technologies is estimated via a set of probit models as follows:

$$P\Big(ft\mathbf{PT}_{it} = 1\Big) = \phi\Big(\alpha + \beta_H H_{it-1} + \beta_{\mathbf{X}}\mathbf{X}_{it-1} + \beta_{\mathbf{Z}}\mathbf{Z}_i + \gamma_K + \lambda_t + \epsilon_{it}\Big) \tag{2.3}$$

where $ft\mathbf{PT}$ is a vector of indicator variables indicating a first time adoption in the centrifugal (ftC), the vacuum pan (ftV), or both ($ftC \times ftV$), where the latter may be the simultaneous adoption of both at the same time, or one of these having already adopted the other. We include the same set of controls in Equation 2.3 as in Equation 2.2, calculated standard errors clustered at the estate level and report the coefficients as marginal effects. One should note that once an estate adopts a technology (or joint technologies) it falls out of the sample. Similarly, estates that already had employed both modern processing technologies at the beginning of our sample would not be included in the estimation. Finally, in our data set we observed estates that adopted both technologies at the same time, as well as sequentially, where in terms of the latter sometimes vacuum pans preceded centrifugals and sometimes it was in the reverse. These complexities meant that we were relatively limited in employing other types of choice models. More specifically, we were limited to modelling the choice of a adoption of either technology or the simultaneous adoption of both, where the latter could be either the simultaneous adoption of both at the same time, or one of these having already adopted the other. One may also want to note that essentially all estates by the beginning of our sample period in 1881 had adopted the steam mill this aspect of technology will not be part of our analysis.

TABLE 2.4: Impact of Hurricane on Process Upgrading

	(1)	(2)	(3)	(4)	(5)	(6)
Process:	ftC	ftC	ftV	ftV	ftC×ftV	ftC×ftV
$H_{i,t-1}$	-0.017	-0.017	0.015*	0.016*	0.009	0.010
	(0.016)	(0.016)	(0.008)	(0.008)	(0.007)	(0.007)
H_{t-2}		-0.009		0.013		0.011
		(0.017)		(0.009)		(0.010)
$\overline{H_i}$	0.225	0.222	-0.067	-0.068	-0.175	-0.179
	(0.279)	(0.280)	(0.142)	(0.138)	(0.135)	(0.133)
H_i^{σ}	0.027	0.029	0.088	0.087	0.154*	0.156*
	(0.130)	(0.131)	(0.059)	(0.057)	(0.058)	(0.057)
$AGE_{i,t}$	-0.003	-0.003	-0.003*	-0.003*	-0.003*	-0.003*
	(0.003)	(0.003)	(0.002)	(0.002)	(0.001)	(0.001)
$AGE_{i,t}^2$	0.000	0.000	0.000*	0.000*	0.000*	0.000*
	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)
$ATTD_{i,t}$	0.008	0.008	0.004	0.003	0.016	0.015
	(0.015)	(0.015)	(0.008)	(0.008)	(0.008)	(0.008)
$OWNS_{i,t}$	-0.006	-0.006	0.003	0.003	0.000	0.000
	(0.007)	(0.007)	(0.003)	(0.003)	(0.003)	(0.003)
LAT_i	0.102	0.102	0.009	0.012	0.007	0.007
	(0.061)	(0.061)	(0.029)	(0.027)	(0.032)	(0.032)
$LONG_i$	0.012	0.012	-0.005	-0.001	-0.003	-0.001
	(0.035)	(0.035)	(0.013)	(0.012)	(0.013)	(0.013)
$MILL_{i,t}$	-0.004	-0.004	0.007	0.007	0.012	0.011
	(0.020)	(0.020)	(0.010)	(0.010)	(0.010)	(0.010)
Obs.	713	713	1360	1360	1462	1462
$Pseudo-R^2$	0.190	0.190	0.172	0.177	0.161	0.164

Notes: (a) Probit model; (b) Coefficients reported as marginal effects; (c) ** and * are 1 and 5 per cent significance levels; (d) Standard errors (clustered by estate) in parentheses; (e) Time and parish dummies included but not reported. (f) The number of years covered are 18, 2, and 28 for the regression involving ftC, ftV, and $ftC \times ftV$, respectively.

Results for Equation 2.3 are given in Table 2.4. Accordingly, damages to an estate from a hurricane does not induce it to adopt a centrifugal for its the separation of molasses from the sugar in sugar production. Allowing for a lagged response similarly does not suggest that hurricanes can induce evaporation process upgrading.[31] One may also note that all controls are insignificant predictors of employing a vacuum pan. In contrast, an estate is significantly more likely to adopt a vacuum pan for evaporation once it has been damaged by a hurricane, at least in the year of the event. The estimate on the coefficient suggests that the average damage once damage occurs would increase the probability of adoption by 5.1 per cent, while the largest observed damage during out sample period induces the likelihood by 11.8 per cent. Older plants are also less likely to adopt a vacuum pan, although at a decreasing rate. The probability joint adoption, either at the same time or conditional on one being adopted, however, is not determined by hurricane damage. Age, in contrast, reduced joint adoption, but again at a decreasing rate.

2.4.4 Hurricanes, First Time Adoption of Modern Processing Technologies, & Access to Finance

As noted earlier, purchasing more modern processing technologies may have required significant financing both from a theoretical perspective, and in particular self-financing in our context. More specifically, once there was damage to equipment from a hurricane it may only be when sugar prices had previously been high that self-financing of such an investment was possible for many estates. At the same time one might also expect that some estates might consider instead a switch to the lower capital intensity production of bananas. To capture the two competing financing aspects of the sugar and banana markets and their role after hurricane damage we first generate the moving averages of the price of sugar, $\sum_{j=0}^{J} \frac{PS_{i,t-1-j}}{J+1}$) and the price of bananas, $\sum_{j=0}^{J} \frac{PB_{i,t-1-j}}{J+1}$), where J and then interacted these with H_{it-1} in Equation 2.3. One should note that since we continue to include time dummies in the regression we do not need to include the prices themselves as their effects are captured already through the time dummies (which also capture all other common time varying factors as well). Assuming that our geographical controls, i.e., latitude, longitude, and the

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[31] We also experimented with further lags, but these were always insignificant

pre-sample period hurricane damage distributional parameters, allow us to interpret the coefficient on H causally, then the identifying assumption for doing the same for its interaction with the sugar and bananas moving average prices is that there were no other time varying factors correlated with these that might have affected how hurricane damage impacted first time adoption of modern processing technologies. We are not aware of any potential candidates for such a violation.

The results of re-estimating Equation 2.3 with the hurricane damage price interaction terms are shown in Table B.1, where we for each first time adoption variable experiment with up to 3 year moving average definitions of prices. Examining the first time adoption of centrifugals in the first four columns shows that the upgrading effect of hurricanes does not depend on the price of sugar no matter how long (up to the previous three years) one allows for its impact. In contrast, when one defines $J = 1$, i.e., takes into account anamolies of the price of bananas over the last two years, the banana price interaction term is significantly negative. This suggests that once an estate is damaged by a hurricane if the price of bananas is high then the incentive to update the separation process technology is lower. Thus the hurricane induced adoption works is solely dependent on the price of this alternative crop. Intuitively, this may be because a higher price in bananas makes such a long term and costly investment less attractive as it may be more profitable to switch to bananas cultivation. Using the point estimates suggests that for average hurricane damage, the average observed anamoly (0.05) in the price of bananas relative to its sample mean reduces the probability of employing a centrifugal by 74 per cent.

In terms of the upgrading of the evaporation technology, one similarly finds that there is only an effect of hurricanes through the price of bananas, and not sugar. For this the significant interaction term is for $J = 2$, i.e., dependent on a slightly longer horizon of price development of three years. Its point estimate is, however, larger, suggesting that an average damaged estate is very unlikely to upgrade to a vacuum pan when the three year average price of bananas was at least as large at its average anomaly.

Both the price of sugar and bananas matters when one considers price movements over the longer term of three years ($J = 2$) for a complete process upgrading. Noticeably in this regard is not only that the estimated coefficient on the price of sugar interaction with H is positive, but also multiple times larger than that of bananas. Thus, sugar estates are particularly sensitive to the price of sugar after a damaging hurricane in terms of considering an upgrade. While the estimated coefficient on the interaction term with the price of bananas lies between that found for the centrifugal and vacuum pan only estimates, the point estimate on that of sugar indicates an unfeasibly (over 100 per cent) large probability response to increases in the price of sugar. This supports the general view of the general extreme own price sensitivity of technological investment in the Jamaican sugar industry (Sheridan, 1989), but within the context after hurricane damages were incurred. One may also note that the sensitivity of complete upgrading to hurricane damage and prices can be explained by the combined operation of these technologies, as they provide the most efficiency gains, as noted earlier.

As noted in Section 2.2.4, there was little private financing available for sugar estates to upgrade their technology during our sample period. The government did on two occasions provide loans to estates in response to hurricanes, and these funds may have been used to upgrade damaged, or perhaps even non-damaged, processing technology. In this regard, as noted earlier, the loan amounts available after the Hurricane of 1903 were very small and certainly not enough to finance such upgrading.[32] In contrast, the amount of funds available after the hurricane in 1912 and provided by local loan banks was potentially much larger. In Table B.2 we investigate whether these loans may have played a role in technological upgrading by including the estate level proxy (LOAN) and its interaction term with our hurricane damage index. One should note in this regard that as there were no upgrades to centrifugals in this year, we are unable to examine such upgrading on its own, but rather only in terms of how already

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[32] Additionally we were unable to find any data that would have allowed us to approximate estate specific loan provision to test this.

having a centrifugal affects upgrading to a vacuum pan. Our identifying assumption is that there are no other time varying estate specific factors that we do not control for that are correlated with the lending of their nearest agricultural societies' bank branch.

The first two columns in Table B.2 re-estimate columns three and four of Table 2.4 but including the 1912 hurricane loan proxy, where we, as with the price specifications, include our geographic controls, parish dummies, and cluster at the estate level. As can be seen, for vacuum pan upgrading while H continues to have a positive significant impact, the coefficient on $LOAN$ is negative and significant. One possible reason may be that when considering vacuum pan upgrading any loans obtained were instead used for repairs. Allowing for the effect of the latter to depend on hurricane damage, while not changing the significant effect of H, both the loan variable and its interaction term become insignificant (see Column 3). Including the price interaction terms (Column 5) does not alter these findings.

For a complete upgrading of processing technology (Column 2), $LOAN$ similarly display a negative impact when included on its own. Including the interaction term with H in the fourth column, however, changes the coefficient on $LOAN$ from significantly negative to significantly positive. Thus the direct effect of greater local bank lending increases the probability of adopting the newest processing technology. Moreover, the interaction term between the loan variable and the hurricane index is significantly negative. Thus, while the average loan amount per estate extended by the nearest local loan bank increases the likelihood of using modern processing technology, the higher the hurricane damage the lower this effect would be. This is robust to including the price variables, as shown in the last column. These results suggest that while the loans were used to upgrade, this was less so the greater the hurricane damage incurred. Possibly this may be because hurricanes caused a loss in production, as shown in Section 2.4.1, some of the loan funds had to be used to cover variable costs or cover other financial obligations, and/or were used for the repair or replacement of other production infrastructure. For the average loan amount (£298) the overall implied net impact on the probability of upgrading would still be negative (6.9 per cent) for the average level of hurricane damage. It is only when hurricane damage is rather small, i.e, less than the around 22^{nd} percentile of observed non-zero damage distribution, that there is an overall positive effect on upgrading. Finally, one may want to note that the fact that $LOAN$ is a significant predictor independent of hurricane damage is suggestive of the possibility that loan provision may not have been completely dependent on hurricane damage and/or that our proxy does not capture all hurricane damages relevant for loan provision.

2.4.5 Robustness Checks

We subject our preferred specification of technology adoption of the last column of Table B.2 to a number of robustness checks. Firstly, as noted earlier, our identifying assumption is that there were no other common time varying events that may have coincided with sugar price movements that may have also altered the relationship between hurricane damage and process upgrading. One possible culprit might be occurrence of World War I (WWI). In particular, the price of sugar increased substantially during WWI due to the fall in beetroot sugar production (Poggi, 1930). However, trade disruptions during WWI may have also reduced the imports of the sugar processing equipment, and thus the ability of plantations to upgrade. To investigate the role of these factors, we created, as in Dye (1994), a dummy for WWI and interacted this with the hurricane destruction index ($WAR_t \times H_{it}$) as well as the sugar price interaction term with the destruction index ($WAR_t \times \sum_{j=0}^{2} \frac{PS_{i,t-1-j}}{3} \times H_{i,t}$). As can be seen from the first column in Table B.3, these additional interaction terms are not significant and do not noticeably change the results on the impact of hurricane damages and its interaction terms with loans and sugar and bananas prices.

Another common time varying change that might undermine our identifying assumption are sugar duties. In particular, after serveral decades of zero tarrifs the British empire (re-) introduced a sugar duty of 4 shillings and 2 pence in 1901, further changing this to 1 shilling and 10 pence, 14 shilling, 25 shilling and 8 pence, 21 shilling and 4 $\frac{2}{3}$ pence, 9 shilling and 8 $\frac{2}{3}$ pence, 7 shilling 4 $\frac{2}{3}$ pence, and 4 shilling and 9 $\frac{2}{3}$

pence per CWT in 1908, 1915, 1916, 1919, 1924, 1925, and 1928, respectively. Interacting the deflated (to 1880 prices) value of the sugar duty with the damage index ($DUTY_t \times H_{it}$) and with the interaction term of the price of sugar and the damage index ($DUTY_t \times \sum_{j=0}^{2} \frac{PS_{i,t-1-j}}{3} \times H_{i,t}$) and including this in the specification does, however, not alter the original findings concerning financing and hurricane damage in any noticeable way; see the second column of Table B.2.

Another concern is whether the standard errors on our coefficients are appropriately estimated, where we have thus far assumed these to be clustered by plantation. As noted by Bertrand, Duflo, and Mullainathan (2004) in standard settings where there are clear treatment and control groups then it is important to allow for correlation the error term within the level of the treatment. In our setting, however, our treatment differs not only across units but also across time, as storms hit intermittently and each may affect different plantations. To nevertheless take account of the higher level treatment we re-ran the specification in the last column of Table B.2 clustering standard errors by storm and year. As Column 3 of Table B.2 shows this, if anything reduces the estimated standard errors, and does not change the conclusion when clustering is undertaken at the plantation level.

It could also be that technological upgrading is spatially correlated, which if not taken account of can lead to poorly estimated standard errors (McMillen, 1992). To explore this we allowed for spatial correlation of the error term of plantations within prechosen distance thresholds using the plantations geographic coordinates in the spirit of Conley (1999).[33] The estimated (standard) coefficients along with their standard errors are shown the last four columns of Table B.2 for thresholds of 0, i.e., no spatial correlation, and 20, 50, and 100km, respectively. Accordingly, allowing for spatial correlation over longer distances only reduces the standard errors compared to allowing for no spatial correlation and does not change our results qualitatively, except that

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[33] Since the latitude and longitude are used to calculate the spatial distances we exclude these as controls for all of these specifications.

with the 100km distance treshold there is now a direct impact of hurricane damages on technology adoption.

2.5 Conclusions

In this paper we investigated how hurricanes, although intrinsically destructive, may have been a creative force in terms of inducing the technologically laggard Jamaican sugar industry in the late 19^{th} and early 20^{th} to become more cost efficient. To this end we assembled an exhaustive sugar estate panel data set that, in addition to sugar production factors and ownership characteristics, contained detailed information in terms of the sugar processing technology employed. Combining this with an estate specific proxy of hurricane damage derived from historical storm tracks and a physical wind exposure model allowed us to examine whether hurricanes played a role in encouraging Jamaican sugar plantations to upgrade to modern machinery.

The findings show that hurricanes not only reduced sugar production, but encouraged some estates to exit the sugar production market. But, importantly, they also encouraged surviving firms to upgrade their processing machinery to technologically superior equipment after being damaged. However, this rather costly upgrading would have been dependent on access to substantial financial means, a challenge for the already generally heavily indebted estates. Moreover, at the time the financial market in Jamaica was largely undeveloped, and thus private external financing was generally not available to sugar estates. In line with this we show that upgrading after a destructive hurricane depended heavily on the price of sugar. Moreover, price increases in the main alternative export crop at the time, the banana, discouraged such upgrading even when damage was incurred. The government did on occasion provide some lending to the agricultural sector after hurricanes that feasibly could have also been used for upgrading. However, these loans were likely too insignificant to undertake the large investment in new machinery. As a matter of fact, the evidence for local lending after the destructive hurricane in 1912 indicates that only very slightly damaged estates might have been encouraged to use such financing to upgrade.

More generally, our study demonstrates that while the sometimes hostile natural environment in the British West Indies was unquestionably destructive to local economies, it may at the same time also have been a blessing by acting as a catalyst for surviving plantations to adapt technologically to a changing market. Crucial for the latter to happen was access to adequate financing, a factor that still today appears to play an inhibiting role for developing countries facing environmental disasters (see, for example, McDermott, Barry, and Tol (2014) Zhang and Managi (2020)). Finally, whether any benefits arising from historical natural disasters such as hurricanes may have persisted to aid local long-term Caribbean economic development, as has already been demonstrated in US contexts of the 1872 Boston fire (Hornbeck and Keniston, 2017) and the 1927 Mississippi flood (Hornbeck and Naidu, 2014), is a question that as of date remains unaddressed.

Chapter 3

Impact of Natural Disasters on School Attendance: A Comparative Study from Colonial Jamaica

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3.1 Introduction

The educational history of Jamaica is a complex narrative deeply intertwined with its colonial past. Since the 17th century, the island's colonial masters largely overlooked the educational needs of the local population (Mulcahy, 2008). The abolition of slavery in the 19th century marked a transformative phase, introducing elementary schools established by missionaries for the descendants of emancipated slaves (Moore and Johnson, 2004). These missionary efforts were later bolstered by the British government's investment in building schools and providing financial grants (Board of Education, 1901). However, the primary intent behind these efforts was to cultivate 'civilized citizens' from the descendants of the enslaved (Moore and Johnson, 2004). While the government financed the construction of educational facilities, the burden of school fees persisted until their removal in 1892 (Laws of Jamaica, 1892). The enforcement of compulsory elementary education in 1912 marked a significant milestone in Jamaica's educational history (Moore and Johnson, 2004). During this period, school attendance in Jamaica experienced fluctuations but remained comparable to other regions in the Caribbean, Central, and South America (Frankema, 2009).

The 19th and 20th centuries in Jamaica were also characterized by devastating hurricanes, which severely impacted infrastructure, including educational institutions, and disrupted student attendance. For example, the 1912 hurricane caused extensive damage; The Governor's Report (1912) documented that *"[t]he parishes of Westmoreland and Hanover, and in rather less degree, St. James were the principal sufferers. Out of 126 schoolhouses in these parishes, 57 were completely destroyed and 41 more or less seriously damaged: 19 teachers' houses were destroyed and 26 damaged."* (The Governor's Report, 1912, p.431). Despite the historical significance of these events, there is a paucity of research on the impact of natural disasters on school attendance during this period. One notable exception is Naylor et al. (2022), who investigated the impact of extreme weather events on school attendance in the Outer Hebrides during the latter third of the 19th century.

The damage to school infrastructure and the disruption to attendance caused by hurricanes in Jamaica are particularly significant within the context of the island's colonial history. During the colonial era, education was a critical tool for social control and economic advancement, aimed at cultivating a disciplined and proficient labor force to support the plantation economy and broader colonial interests (Moore and Johnson, 2004). As Jamaica transitioned from a labor-intensive, slave-based agricultural economy to one increasingly reliant on mechanized agriculture (Huesler and Strobl, 2024a), the importance of education became even more pronounced. This shift necessitated a more technically skilled workforce to manage and operate new machinery, thereby elevating the role of education in fostering the necessary competencies (Higman et al., 2005). Given the weak establishment of the Jamaican school system during this period, the economy's need for a technically skilled workforce was particularly vulnerable to disruptions caused by hurricanes. These disruptions likely hampered children's educational outcomes, thereby impeding the economy's ability to transition smoothly and converge to its real growth path. This underscores a critical gap in understanding how natural disasters influenced Jamaica's efforts to transform its society through education.

This paper aims to fill this gap by examining the impact of hurricanes on school attendance in Jamaica from 1892 to 1942, a period characterized by several significant hurricanes. This period saw Jamaica experience four category two hurricanes, including the *1903 Jamaican hurricane*, the hurricanes of 1912 and 1915, and the *1917 Nueva Gerona hurricane*. To quantify the impact of these hurricanes on school attendance, monthly data on elementary school attendance across the fourteen Jamaican parishes was combined with a measure of potential storm destruction. This measure integrated storm tracks with a wind field model to estimate wind speeds at parish centroids, serving as proxies for potential destruction.

The findings of this paper confirm that hurricanes significantly reduced average monthly school attendance in affected parishes. On average, a category two hurricane[1] caused a 9.1% decrease in attendance during the hurricane month, an 8.6% decrease the following month, and a 7.2% decrease two months after the hurricane. Therefore, the findings suggest that on average nearly 400 children are absent from school for one month, more than 375 for two months, and upwards of 310 children for three months following the impact of a hurricane. Furthermore, mediation analysis indicates a decline in school performance on average of 2.77% to 3.23% due to hurricanes, which is indirectly caused by decreased school attendance. These findings underscore the importance of maintaining school attendance and the role of trained teachers in mitigating the educational impacts of tropical storms.

This paper provides new insights, enhancing two distinct strands of literature. First, it underscores the substantial effects of hurricane strikes on school attendance. With an expansive panel consisting of 80 countries, Cuaresma (2010) demonstrate that natural disasters affect global education outcomes by decreasing secondary school enrolment. Furthermore, in Nigeria, more than 40% of the respondents reported a decrease in school attendance due to floods and local windstorms between 2009 and 2013 (Adeagbo et al., 2016). Similarly, rural Haiti saw nearly half of the children abandon school attendance in the aftermath of Hurricane Matthew (Cook and Beachy, 2018). Comparable results have been reported for natural disasters in Indonesia Rush (2018), rainfall shocks in Uganda Agamile and Lawson (2021) and cyclones in Fiji Takasaki (2017). However, focussing on agricultural shocks, Baker, Blanchette, and Eriksson (2020) show that Boll Weevil increased school attendance by lowering the opportuinity costs of attending school. This paper further contributes by using monthly parish level data which spans over 50 years. Moreover, during this period of time, I analyse how multiple hurricanes with different wind speeds, also across parishes, affected school attendance. The findings align with these studies, showing a significant decrease in school attendance in Jamaican parishes affected by hurricanes.

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[1] With wind speeds exceeding 154km/h.

Secondly, this paper highlights the potential long-term implications of these short-term disruptions. Although I do not directly measure long-term impacts, the observed declines in attendance and performance suggest adverse effects on students' future educational attainment and economic growth. This aligns with the broader literature on the role of education in economic development, as discussed by Barro et al. (2013), Long (2006), and Hanushek and Wößmann (2007). Research by Deuchert and Felfe (2015) that inspected the aftermath of Super Typhoon Mike in 1990 on the educational progress of children in the Cebu Islands (Philippines) confirmed that natural disasters have a profound and long-lasting impact on educational outcomes, leading to a decrease in exam scores, an increase in grade repetitions, and an overall decrease in educational attainment over time. Regular school attendance, as shown by Lamdin (1996) and Roby (2004), plays a key role in improving student performance and mitigating learning losses even from minimal absences. Thus, natural disasters, such as hurricanes, which historically disrupt school attendance, have far-reaching implications on education and, consequently, economic growth.[2] This was confirmed by a study conducted by Sala-i Martin, Doppelhofer, and Miller (2004) that involved nearly 90 countries from 1960 to 1999, revealing a direct correlation between economic growth and primary school enrolment rates.[3] Moreover, Spencer (2017) and Spencer, Polachek, and Strobl (2016) further demonstrated the adverse impact of hurricanes on student performance in Jamaica (1993-2010). Recently, Arceo-Gomez and López-Feldman (2024) show that increased temperature decreases school performance in Mexico. This paper, therefore, underscores the importance of maintaining school attendance in the face of natural disasters to support educational performance of students, which is likely to impact long-term economic growth.

Moreover, this paper makes a contribution to the existing literature by applying a wind field model to estimate the impact of hurricanes on educational data in the late

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[2] However, it must be mentioned that school attendance is not only important for economic growth but also for *nation building* as in Imperial Germany (Cinnirella and Schueler, 2018).

[3] Similar results were obtained by Ogundari and Awokuse (2018) and Artadi and Sala-i Martin (2003) in their studies conducted in (sub-Saharan) Africa.

19th and early 20th centuries. In addition, two distinctive datasets are employed: a monthly dataset on school attendance spanning 50 years at the parish level in Jamaica and a yearly dataset from 1880-1892 that is even more detailed, providing school-level data for 1060 schools, including yearly test scores and the number of teachers (both trained and untrained). Both data sets are archival in nature and were digitised specifically for the purposes of this study. The extensive and detailed nature of the data allows for a more precise estimate of the immediate effects of hurricanes on educational infrastructure and attendance, providing valuable insights.

The remainder of the paper is structured as follow. Section 3.2 provides a historical background on education and hurricanes in Jamaica, followed by a discussion of the data in Section 3.3. Summary statistics are presented in Section 3.4, with results in Section 3.5. The paper concludes in Section 3.6.

3.2 Historical Background

3.2.1 Education

Early Development of Formal Education (1834-1837)

The development of formal education in Jamaica, beginning in the pre-emancipation period of 1834, catered primarily for the children of free parents, served primarily by seven Church of England schools scattered across the island (Board of Education, 1901). As Holt (1991) notes, by 1837, a significant portion of the student population comprised children of apprentices or those who gained freedom post-1834, indicating the initially limited access to education. However, by 1837, Holt (1991) shows that *"[...] 8,321 children of apprentices were attending day school, which means—given that approximately 20,000 of the 38,754 freed children of apprentices were of school age by 1837—that just three years after abolition over 40 percent were in school."*(Holt, 1991, p.152).

Expansion and Policy Initiatives (1865-1908)

Following the Morant Bay Rebellion in 1865, the administration of Governor Sir John Peter Grant saw a significant expansion of public services, including primary education (Jeffrey, 1980). A significant policy initiative was the introduction of the ’payment by results’ system, which linked financial grants to schools to the performance of students in core subjects and the efficiency of teachers (Jeffrey, 1980).

Education during the 19^{th} century in Jamaica transcended mere transmission of knowledge. As Moore and Johnson (2004) highlights, it played a pivotal role in reshaping the mindset of the majority black population. The primary objective was to cultivate compliant, civilized, and loyal British colonial subjects, especially targeting the lower classes. This educational approach was designed to provide basic literacy and numeracy skills while instilling an ideology that maintained their subservient roles within a socio-political system dominated by a white minority (Moore and Johnson, 2004; Holt, 1992). This was especially visible with the introduction of the ’payment by results’ system in the 19^{th} century, which tied school funding to student performance in core subjects and teacher efficiency (Jeffrey, 1980). The ultimate objective of this reform was accordingly to Jeffrey (1980), to produce a literate labour force capable of serving the colonial economy while simultaneously preventing the emergence of individuals capable of challenging the existing social order. The post-emancipation period saw a significant shift in Jamaica’s educational landscape. The British government’s investment of £50,000 for schoolhouse construction and a matching grant initiative for colonies led to an increase in educational opportunities (Board of Education, 1901; Holt, 1991). By 1837, over 12,000 children attended one of the 183 elementary schools, and by 1908, despite some reductions due to amalgamations, the number of schools was still substantial at 690 (Board of Education, 1901; Moore and Johnson, 2004). This is illustrated graphically in Figure 3.1 with data from Moore and Johnson (2004). Education during this era was heavily influenced by a Victorian religious and moral order, contrasting starkly with local Afro-creole beliefs (Moore and Johnson, 2004).

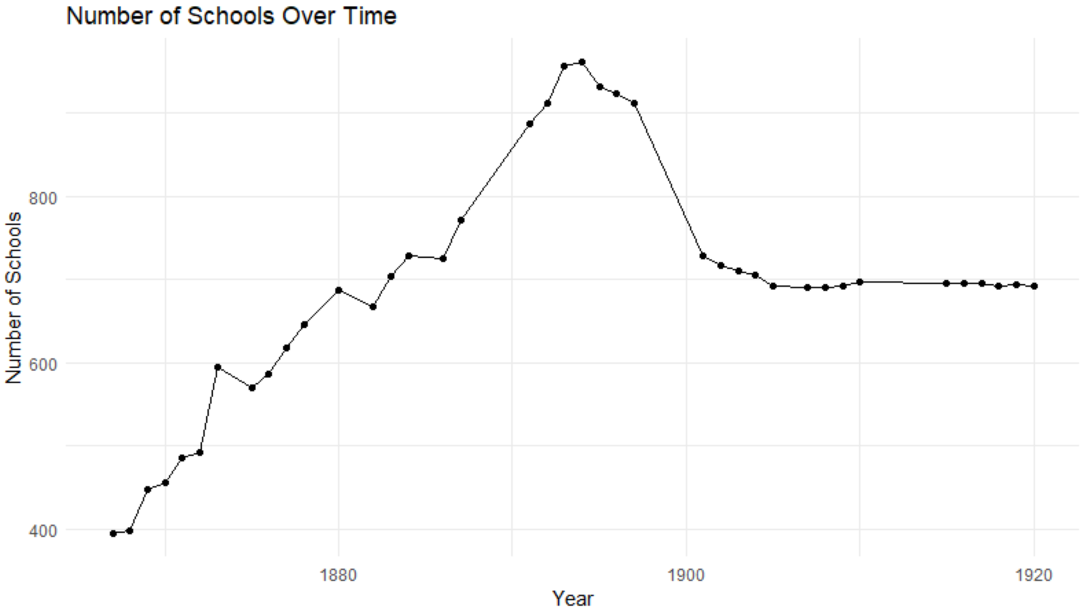

FIGURE 3.1: Number of Schools over time. The data for this graph is obtained from Moore and Johnson (2004). Moore and Johnson (2004) used data from the Blue book of Jamaica (1867-1905), The Governor's Report (1882-1920) as well as from various letters.

Implementation of the Education Code

A significant enhancement was the implementation of the Education Code in 1867, which established a system of grants-in-aid contingent on school performance (Handbook of Jamaica, 1883, p.129). Annual inspections played a crucial role in maintaining educational standards. Inspectors assessed various aspects of school management and student performance. The results were documented, schools were classified into three levels based on their efficiency, and schools were provided with detailed feedback to improve their teaching methods and overall educational quality. These categorisations determined the amount of government aid they received (Handbook of Jamaica, 1883, p.129). The inspection process revealed that a significant proportion of schools failed to meet the required standards. However, it also prompted improvements in management and teaching practices over time (Handbook of Jamaica, 1883, p.129). By 1875, there was a growing demand among parents for enhanced educational opportunities for their children, and the number of efficient schools gradually increased, reflecting a notable improvement in student performance and attendance (Handbook of Jamaica, 1883, p.130). The introduction of standardised examinations and performance-based grants provided an additional incentive for schools to enhance the quality of their education (Handbook of Jamaica, 1883, p.131). Schools were required to meet specific standards in various subjects, with marks awarded to determine the relative merits of the work submitted for examination. This system facilitated the identification of schools that were performing well and those that required improvement (Handbook of Jamaica, 1883, p.131). According to (Handbook of Jamaica, 1883, p.131). schools were annually inspected by the School Inspector, whereas she/he examined the following subjects: Reading, Writing from dictation, Arithmetic, Scripture knowledge, General knowledge, Grammar and Composition, Geography and History, Handwriting, Singing as well as Organization. In total, a maximum of 84 points is obtainable whereas most schools were not able to obtain even 2/3 of the maximum (Handbook of Jamaica, 1883, p.131).

Role of Mission Societies and Churches (1838-1910)

Mission societies and churches were instrumental in shaping the educational system following emancipation in 1838, establishing elementary schools for freed slaves, ensuring that their influence permeated the education sector (Moore and Johnson, 2004). Their influence remained strong even after the inception of the crown colony government in 1866 (Moore and Johnson, 2004). Although the government did support the education sector, its role was largely supplementary[4], unlike other colonies such as Trinidad where the government was a significant provider of primary education (Moore and Johnson, 2004). This church-led education system was characterised by a specific ideological orientation. According to Moore and Johnson (2004), the ultimate aim was to produce a new kind of Jamaican citizen, someone who would rise above the ignorance propagated during slavery and emerge as a "civilized citizen" (Moore and Johnson, 2004). Despite the ideological focus, the state still sought to establish a comprehensive and universal education system, in line with the goal of state-sponsored education to not only teach skills, but also educate workers about their societal roles and obligations (Holt, 1991). During the late 19th and early 20th centuries, the government's role in education was minimal, contributing mainly through financial grants to support the schools operated by these religious groups. This system created a framework where education was accessible primarily through church-affiliated institutions, which shaped the curriculum and moral outlook of the students (Board of Education, 1901).

Legislative Reforms (1892-1914)

The Elementary Education Law of 1892 Laws of Jamaica (1892) laid the foundation for public elementary schools. A *Public Elementary School* was defined as an institution primarily providing elementary education, where tuition fees did not exceed sixpence

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[4] Even in 1910, only roughly 10% of the elementary schools were indeed government schools, while the rest of the schools were church schools (Moore and Johnson, 2004).

per week (Laws of Jamaica, 1892). The 1899 amendment Laws of Jamaica (1899) further detailed the duties of the Board of Education, which included advising on matters related to public elementary schools, recommending changes to the Code of Regulations, and managing the establishment and closure of schools. The amendment set age limits for school attendance, specifying that children could attend public elementary schools from ages six to fourteen, with special provisions for kindergarten education for those aged four to eight (Laws of Jamaica, 1899).

However, the path to educational reform was far from straightforward. Despite the theoretical support for an enhanced education system, the actual implementation was sluggish due to the lack of appropriations (Holt, 1991). The primary advocates of educational reform were coloured assemblymen who, as Holt (1991) highlighted, championed the cause of increased educational budgets, the establishment of more schools on the island, the creation of local professional schools for doctors and lawyers, and technical training schools. However, this agenda faced opposition from planters who generally resisted measures to expand education (Holt, 1991).[5]

Challenges and Government Interventions (1910-1914)

As the education system evolved, various challenges emerged. For example, irregular attendance due to agricultural commitments and the need for children to contribute to household labour was a significant problem, as pointed out by Underhill (2010) and Board of Education (1901). The government sought to address this by implementing compulsory education in certain areas, but the impact was minimal. The 1910 amendment Laws of Jamaica (1910) established School Boards for towns and districts, which were responsible for managing government elementary schools within their jurisdictions. These boards were empowered to enforce compulsory school attendance and could create by-laws to regulate their proceedings. The law mandated

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[5] In this manner Holt (1991) mentions that "[...] planters generally opposed all measures to expand education. Very likely the idea of spending money primarily for the benefit of the black majority did not appeal to most planters. Most of the white estate managers had no family or children, at least none they chose to recognize officially [...]." (Holt, 1991, p.196).

that school managers render accounts and vouchers for all expenditures related to grants received. The role of the "Superintending Inspector of Schools" was pivotal. This officer, later titled "Director of Education" in 1911 Laws of Jamaica (1911), was responsible for overseeing the administration of education funds and ensuring compliance with educational standards. The law mandated the appointment of inspectors by the Governor to inspect and examine schools, thus maintaining quality and adherence to regulations. The exact number of school inspectors was not fixed by the laws; instead, the Governor was given the authority to appoint as many as necessary to fulfill the duties required (Laws of Jamaica, 1911). In 1912, schooling was made mandatory in Kingston, Falmouth, and Lucea, but this move had limited success due to various societal and financial constraints (Moore and Johnson, 2004). To increase school attendance, the government implemented stringent measures, such as laws that allowed school boards to declare persistently absent children as "incorrigible truants", and the use of corporal punishment (Moore and Johnson, 2004)[6]. Parents were also held accountable if their children failed to attend school, they could face fines or even imprisonment (Moore and Johnson, 2004).[7] The consolidated Elementary Education Law of 1914 Laws of Jamaica (1914) reinforced compulsory education. It mandated that children attend school from ages six to fourteen, with penalties for parents or guardians who failed to ensure compliance. The law also provided for scholarships to encourage continued education beyond elementary school (Laws of Jamaica, 1914).

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[6] By 1913 a new law allowed school boards to declare persistently absent children as incorrigible truants and authorized the use of corporal punishment under court orders (Laws of Jamaica, 1913).

[7] It should be noted that the enforcement of these penalties, particularly fines and imprisonment, varied and faced challenges, as highlighted by Moore and Johnson (2004). The enforcement of these penalties was already provided for in Law 31 of 1892 (Laws of Jamaica, 1892).

Efforts to Improve School Attendance and Funding

Despite these obstacles, Jamaica has made impressive progress in promoting school attendance. By 1900, the island's gross enrolment rate in primary schools was significantly higher than in other Latin American and Caribbean countries, such as Argentina, Chile, the Dominican Republic, Brazil and Bolivia (Frankema, 2009). However, the financial burden of education continued to challenge full school attendance (Moore and Johnson, 2004). The cost of school fees, writing and reading materials, and proper clothing were significant barriers for many families (Moore and Johnson, 2004). In an attempt to address this, the Jamaican government abolished the mandatory school fee in 1892, which led to a significant increase in school attendance (Board of Education, 1901).[8]

Subsequently, schools were funded through an additional house tax, which proved to be a more successful financing strategy, generating an increase in revenue of more than 50% compared to previous school fees (Laws of Jamaica, 1892). In 1892 government expenditure on education was more than £56,000, which was about 8% of total government expenditure (The Governor's Report, 1895). This proportion has remained relatively constant over time, although in absolute terms it has increased considerably. In 1944, education expenditure was £568,000 and total expenditure £7.4 million (Blue book of Jamaica, 1945).

School Terms and Vacations

As the education system continued to evolve in the 19^{th} and 20^{th} centuries, the term and vacation dates began to take shape. Although specific data for Jamaican primary schools is scarce, records for three high schools in Handbook of Jamaica (1895) and for primary schools in Barbados provide some insight. For example, the Rectory School in Port Maria, York Castle High School, and Kingston Collegiate School typically allotted five weeks for Christmas, one week for Easter, and six weeks for the midsummer

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[8] Similar have been found for the 19^{th} century U.S. (Go and Lindert, 2010).

holidays (Handbook of Jamaica, 1895, p.336). In Barbados, primary school students typically had a week off for Christmas, a week off for Easter, and a one month summer break in August (Board of Education, 1905).

Secondary Education Reforms (1892)

In response to the necessity for an enhanced level of education, the government enacted the Secondary Education Law in 1892. This legislation facilitated the establishment of secondary schools in major urban centres and provided scholarships for high-performing students to pursue their studies at the secondary or post-secondary level (Handbook of Jamaica, 1892). The objective of this law was to address the discrepancy between the elementary and secondary levels of education, thereby establishing a more comprehensive and unified educational system (Handbook of Jamaica, 1892). The secondary education system in Jamaica during the late 19th and early 20th centuries was initially driven by missionary societies and the colonial government, with the objective of producing a middle-class cadre imbued with British cultural and moral values (Moore and Johnson, 2004). Despite the initial limitations of early efforts being confined to expensive private institutions, government interventions, such as the enactment of Law 34 of 1879 and Law 32 of 1892, resulted in the establishment of national grammar schools and the provision of public funding to facilitate broader access to secondary education (Moore and Johnson, 2004). Notable educational establishments such as Jamaica High School (subsequently renamed Jamaica College) were based on the British grammar school model, offering a challenging curriculum that included classical languages, sciences, and moral education (Moore and Johnson, 2004). These schools aimed to educate future leaders for public service and instill loyalty to the British Empire. By combining religious and academic education, institutions like York Castle High School and Calabar Institution also played a significant role. The overarching objective of secondary school was to create an educated class capable of supporting colonial administration and advancing the civilising mission of the British Empire (Moore and Johnson, 2004).

Summary of Educational Reforms

In conclusion, the evolution of Jamaica's education system from the late 19th to early 20th centuries was characterised by significant reforms and challenges. The shift from a predominantly church-led education system to a more integrated approach involving both voluntary and government schools reflected the island's commitment to expanding educational access (Board of Education, 1901). The introduction of compulsory education, the elimination of school fees, and the restructuring of the school calendar were pivotal steps in this process, despite the ongoing challenges of irregular attendance and financial constraints (Board of Education, 1901). The efforts to enhance education during this period established a foundation for future advancements and a more inclusive educational landscape in Jamaica.

3.2.2 Hurricanes

Historically, hurricanes caused great damage in many parts of Jamaica. Between 1892 and 1942. The famous 1903 Jamaican hurricane struck Jamaica in August 1903 with wind speeds exceeding 170km/h, causing great damage. In fact, it caused so much damage to the railway system that the Jamaican railway was unprofitable in the following two years (Satchell and Sampson, 2003). The The Jamaica Gleaner (1903a) wrote the following about the impact of the hurricane on Port Royal schools: *"Four of our teachers have been hard hit during the recent hurricane, their school houses having been blown down [...]."*(The Jamaica Gleaner, 1903a, p.5). Hence, teachers were often also directly affected by the storms.[9] In the parish of St. Catherine the impact of the hurricane was even more severe as *"[a]ll the churches and school houses have either been completely demolished [or] badly damaged. Hundreds of houses have been destroyed, and the peasantry are homeless."* (The Jamaica Gleaner, 1903b, p.10).

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[9] *"The Union would not be worth its existence, if at a time as this it did not make some efforts to afford tangible help to those members who need it. Teachers as a rule have very little money laid by, it is with them in nine cases out of ten a hand-to-mouth existence, therefore to those who have lost schoolhouses, residences, books, furniture, cultivation, etc., it is like mockery to talk of sympathy without extending a helping hand."*(The Jamaica Gleaner, 1903a, p.5).

A few years later, the 1912 hurricane made landfall in Jamaica with winds up to 170km/h. As a result, crop yields decreased rapidly as many plants were destroyed (The Governor's Report, 1912). In the parish of Westmoreland, the hurricane caused even more damage, as *"[t]here has been a loss of about 30% on the cane crops and the buildings on some of the estates suffered severely. A considerable amount of damage was also done to cocoanut trees, breadfruit and other valuable trees, while house property was destroyed and many people left homeless. The wharves were all washed away and a considerable amount of goods lost."* (The Governor's Report, 1912, p.117). Similarly, in Manchester, more than 150 houses were destroyed and in many parishes several school buildings were damaged, indicating how severely the population was directly affected by the storm (The Governor's Report, 1912). However, the hurricane also destroyed almost half of the school buildings in Hanover, Westmoreland, and St. James (The Governor's Report, 1912). In Grange Hill, Westmoreland, the hurricane destroyed school buildings, so the school was not kept until temporary buildings were put up in the following year (The Jamaica Gleaner, 1912).

The *1915 Galveston hurricane* hit Jamaica in mid-August with more than 157km/h before making landfall in Galveston. In parishes such as Portland or Trelawny, the hurricane directly affected crop production, so losses of up to 65% occurred (The Governor's Report, 1915). However, the hurricane also affected schooling. *"During the past year there has been a general, if slight, falling off in the attendance [...]. It is thought to be due to the hard time induced by the war and by the hurricane of last autumn. The poorer peasants whose ground crops were badly damaged, if not destroyed, and who in consequence have to produce their food from the shops cannot provide their children with food and decent clothes to go to school."* (The Governor's Report, 1915, p.341). Therefore, the reason for the decrease in school attendance is not only due to damaged buildings, but also to the lack of food or income of parents. But not only school buildings were destroyed, but also school materials and furniture so that *"[t]he storm, besides destroying many desks, presses and benches, has left the roof in such a condition that makes the building unsafe to work in."* (The Jamaica Gleaner, 1915, p.14). Moreover, hurricanes also cause great destruction to roads and bridges, as mentioned by The Governor's Report (1915) for the parishes of Hanover and St. Thomas, where *"[...] during the hurricane, the roads themselves being rendered impassable in some cases for weeks."* (The Governor's Report, 1915, p.453).

Only two years later, the *1917 Nueva Gerona hurricane* hit Jamaica in September with wind speeds up to 160km/h. In the parish of Port Maria, the hurricane caused considerable damage to school buildings and teachers' houses. However, as mentioned in The Governor's Report (1917) *"[i]n only one or two cases was the school work suspended for any great length of time. Where the schoolrooms were completely wrecked, the managers, teachers and people of the district quickly met together and erected a temporary booth or shed under which the school could assemble."* (The Governor's Report, 1917, p.187). In the following ten years, there were no major hurricanes.

Hence, there were several channels on how hurricanes affected school attendance. First, hurricanes destroyed school houses, the furniture (e.g., desks or chairs), or teachers' houses so that no education could have been provided. Second, by destroying transportation infrastructure such as roads, which hindered children to be able to arrive at school. Third, hurricanes might have caused great damage to the homes of the students or their families' crops, causing students to help at home. Furthermore, some parents were unable to buy clothes or food for their children, as hurricane damages were costly, causing children to not attend school.

However, schools were not only affected by tropical storms. In 1907, the Kingston Earthquake destroyed numerous schools in Jamaica (Handbook of Jamaica, 1925). In addition, epidemics contributed to reduced school attendance. For example, the influenza epidemic in 1918 led many schools to close during November and December, resulting in the average attendance across all parishes dropping to only one third compared to the previous year (The Jamaica Gazette, 1919; Moore and Johnson, 2004).

3.3 Data

3.3.1 Educational Data

The empirical analysis of this paper is based on an exhaustive geo-referenced database of all Jamaican government elementary schools over the period 1892 to 1942. The primary data source for elementary school attendance in this study is drawn from two significant publications: The Jamaica Gazette and The Jamaican Bluebooks, covering the period from 1869 to 1942 (The Jamaica Gazette, 1942; Blue book of Jamaica, 1892).

The Jamaica Gazette is the official weekly newspaper of the Jamaican government, providing detailed monthly records of school attendance per parish, compiled by the superintending inspector of schools from 1892 to 1942. *The Jamaican Bluebooks* offer information on school attendance from 1869 to 1892 (Blue book of Jamaica, 1892). The data in *the Jamaica Gazette* is monthly and at the parish level, whereas the data in the *Jamaican Bluebooks* is annual and at the school level. The Bluebooks data is more granular compared to the Gazette data but contains variables that are not homogeneous over time, making the analysis challenging. For this reason, only data on attendance, school marks, and the number of trained and untrained teachers were used. Additionally, the data on school grades is at the annual level for each school, and all 1,060 distinct schools were georeferenced for the analysis.

The annual data in the *Bluebooks* provide valuable information on the structure and outcomes of the educational system during the study period. The primary examinations analysed were standardised tests administered annually in a variety of subjects (Handbook of Jamaica, 1883, p. 131). The curriculum typically included subjects such as reading, writing from dictation, arithmetic, scripture knowledge, general knowledge, grammar and composition, geography and history, handwriting, and singing. School inspections played a crucial role in maintaining educational standards, with inspectors assessing various aspects of school management and student performance. The exams were graded on a point system, with a maximum of 84 points obtainable. The results of these inspections were documented, and schools were classified into three levels based on their efficiency, which determined the amount of government aid received (Handbook of Jamaica, 1883, p. 129). However, most educational institutions struggled to achieve even two-thirds of the maximum score, reflecting the challenges in maintaining high educational standards (Handbook of Jamaica, 1883, p. 131).

In addition, I calculated the monthly share of children attending school from the total population from the Jamaican Population Census of 1871, 1881, 1891, 1911, and 1921 which were taken from Handbook of Jamaica (1881, 1925). In the absence of census data for 1901 and 1931, estimates from *The Jamaica Vital Statistics* were used (The Governor's Report, 1901, 1936). To obtain monthly estimates, the population data was linearly interpolated. Subsequently, the monthly share of children attending school was calculated by dividing the school attendance figures for a given month by the interpolated population estimate from the preceding months. Additionally, these population data were used to determine each parish's share of the total population.

Furthermore, I incorporate the impact of the 1907 Kingston, a pivotal moment in Jamaica's history, earthquake on school attendance patterns. The Rossi-Forel scale, used to measure the intensity of the earthquake, is incorporated from Cornish (1908). For each parish, an average value of the Rossi–Forel scale was calculated, with intensity levels ranging from 6 in parishes such as Hanover and Westmoreland to the maximum level of 11 in Kingston. It is important to note that the original Rossi-Forel scale goes up to 10, but Cornish (1908) extended it to 11 for areas that experienced the most severe damage (Cornish, 1908, p.255). This inclusion is vital to understanding the potential fluctuations in school attendance due to this major natural disaster.

Additionally, an influenza dummy is introduced into the model. Historical records indicate a significant drop in school attendance during the influenza (or Spanish Flu) epidemic, largely due to the widespread closure of schools in November and December 1918 (The Jamaica Gazette, 1919). Therefore, the influenza dummy variable is set to one for the months of October, November and December in 1918, as well as for

January and February in 1919.

3.3.2 Hurricane and Climate Data

To assess the influence of hurricanes on school attendance, this paper uses a model to estimate the wind speed at the centroids of Jamaican parishes. The methodology follows Strobl (2012), utilizing a wind field model[10] developed by Boose, Serrano, and Foster (2004), which incorporates Holland (1980)'s equation for cyclostrophic wind and sustained wind speed. This model involves tracking the trajectory of each hurricane in both time and space and applying the model of Boose, Serrano, and Foster (2004) to determine the wind speeds experienced in the Caribbean region. By taking into account important factors such as speed of movement, direction, maximum wind speed, and landfall, this model then provides us with the localised wind speeds at each landfall location throughout the hurricane's lifetime. Using the six-hourly *HURDAT best tracks* data from the *National Hurricane Centre's Hurricane Database*, I estimated the wind speeds at the centroids of Jamaican parishes, following the method recommended by Strobl (2012). This approach allows for a nuanced assessment of storm exposure variability across different regions. According to Emanuel (2011)'s recommendation on power dissipation, I proceeded to cube the local wind speeds obtained. This step is crucial because it has been observed that the monetary damage caused by hurricane strikes increases cubically with the wind speed. As the obtained number becomes very large, I divide it by 1 million. For the purposes of this analysis, only wind speeds greater than 119km/h were considered, corresponding to tropical storm conditions. The wind speed at every parish centroid is estimated in the manner of Strobl (2012):

$$V = GF\Big[V_m - S(1 - sin(T))\frac{V_h}{2}\Big] \times \Big[\Big(\frac{R_m}{R}\Big)^B exp\Big(1 - \Big(\frac{R_m}{R}\Big)^B\Big)\Big]^{\frac{1}{2}} \tag{3.1}$$

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[10] This wind field model has been applied to various papers (see e.g. Huesler and Strobl, 2024a; Ouattara and Strobl, 2013; Del Valle et al., 2020; Noy and Strobl, 2023; Mohan and Strobl, 2017; Del Valle et al., 2018).

In this formula, V_m represents the maximum sustained wind speed within the hurricane. The angle between the forward trajectory of the hurricane and a radial line from the centre of the hurricane to a specific location, denoted as P, is indicated by T. The forward velocity of the hurricane is expressed as V_h. The radius at which maximum winds occur, R_m, and the radial distance from the centre of the hurricane to point P, R, are also integral components of the equation (Strobl, 2012).

3.3.3 Population weighted destruction index

In addition to assessing the influence of cubic wind speeds on school attendance, I incorporate a population-weighted hurricane destruction index derived from Strobl (2012). This index is constructed using the same windfield model employed in the previous section. Instead of only estimating the wind speed at a parish centroid, the population-weighted destruction index allows me to estimate the potential destruction caused in the entire parish. The intuition behind the destruction index is that a hurricane with the same wind speed would cause greater damage in a parish with higher population density compared to a parish with lower population density. Therefore, population statistics are used from the *History Database of the Global Environment (HYDE 3.2)* (Klein Goldewijk et al., 2017). This database provides population approximations on a 0.083 x 0.083 degree grid, equivalent to a 9.5 x 9.5km area. An estimation of the wind speed in each grid cell, when combined with the corresponding population, serves as an indicator of potential damage. Thus, a grid cell with higher wind speed and larger population would yield greater destruction than one with a lower wind speed and population. Importantly, there are no endogeneity concerns with respect to population migration, since the (decadel) population data predate hurricanes. After reestimating equation (1) at the grid cell level, one obtains an estimated wind speed $v_{j,t}$ for every 9.5 x 9.5km cell j at time t. Subsequently, the population-weighted hurricane destruction index is calculated in the manner of Strobl (2012):

$$DESTR_{i,r,t} = \Big(\sum_{j=1}^{J} \int_{0}^{\tau} v_{j,t}^{\lambda} w_{i,j,r,t}\, dr\Big) \text{ if } v_{j,t} > 119\text{km/h} \qquad \text{and 0 otherwise} \tag{3.2}$$

$DESTR_{i,r,t}$ is the estimated total destruction caused by a storm r during the lifetime of the storm τ in a parish i at time t.[11] Furthermore, J is the set of grid cells in parish i and, according to Strobl (2012), λ is set to 3. The time depending population weight is $w_{i,j,r,t}$ and corresponds to the population in every cell of the grid in the previous decade.[12] As Jamaica is a rather small island (approximately 250 x 80km), I interpolated the 6-hourly *HURDAT best tracks* to obtain more precise, two-hourly, wind speeds vj, t.

3.4 Summary Statistics

Between 1892 and 1942, Jamaica experienced 28 tropical storms, ten of which had wind speeds exceeding 119km/h. As can be seen from Table 3.1, the average wind speed of these storms was roughly 87.4km/h. Among these, four were categorized as category two hurricanes (with wind speeds surpassing 154km/h). Table 3.1 shows that the highest estimated wind speed was 173.8km/h, which is just below the threshold for a category three hurricane. During the 50 years observed, each parish experienced at least one tropical storm. The frequency of category two hurricanes varies significantly. Portland, St. Ann, and St. Thomas did not experience any category two hurricanes, while St. Catherine and St. James were hit by three. Figure C.1 shows the tracks of storms with wind speeds above 119km/h, indicating that northern Jamaican parishes were more frequently and severely affected by powerful hurricanes. Moreover, the summary statistics further show that the average parish had around 60,000 inhabitants, with the smallest being Trelawny (31,696 inhabitants) and the largest St.

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[11] I divide $DESTR$ by $10^{1}0$ to get more feasible numbers.

[12] Hence, for 1892-1900 $HYDE$ data from 1890 is used, 1900 for 1901-1910, 1910 for 1911-1920, 1920 for 1921-1930 and 1930 for 1931-1940 and 1940 the years after 1934.

Catherine (130,274 inhabitants). The Rossi-Forel scale for the Kingston earthquake varied significantly across parishes, with a low of 6 in Westmoreland and Hanover and highs of 10 in St Andrew and 11 in Kingston.

TABLE 3.1: Summary Statistics

Statistic	N	Mean	St. Dev.	Min	Max
Monthly & Parish-Level: 1892-1942					
Windspeed	931	87.37	24.78	62.1	173.8
Population	8,989	63,546.84	20,928.27	31,70	130,274
Attendance (post 1892)	8,989	4,362.92	1,881.61	132	12,588
Earthk	8,989	0.013	0.326	0	11
Yearly & Parish-Level: 1872-1892					
Avg. Attendance	266	2,258	1,130.88	341	5,641
Share: Teachers Trained	266	0.57	0.16	0.12	0.92
Avg. Mark	263	38.37	5.39	26.33	58.15
Yearly & School-Level: 1880-1892					
Windspeed	1,310	136.8	32.53	90.3	178.9
Avg. Attendance	9,322	50.68	23.61	1	320
Pupils on Books	9,322	89.15	40.36	0	536
Avg. Mark	9,322	41.92	10.10	1	89

Windspeed represents the average wind speed of tropical storms in kilometers per hour, *Population* denotes the average population of parishes, *Attendance (post 1892)* refers to the average monthly school attendance after 1892, *earthquake* represents the Rossi Forel scale of the Kingston earthquake, *Avg. Attendance (pre 1892)* is the average monthly school attendance before 1892, *Share: Teachers Trained* is the share of trained teachers among the total, *Avg. Mark* Represents the average academic performance mark.

School attendance figures show an average of 4,363 children attending school per parish, with the range spanning from 2,441 in Trelawny to 6,018 in St. Elizabeth. Figure C.2a illustrates the spatial distribution of the average monthly school attendance, highlighting higher attendance in southern parishes such as St. Elizabeth, Manchester, Clarendon, and St. Catherine, compared to northern and eastern parishes. However, this changes when analysing the spatial distribution of average school attendance as a share of the total population, illustrated in Figure C.2b. Now, southern parishes still have higher attendance rates, but the dispersion decreased considerably.

Temporal variations in school attendance are also evident. In Figure 3.2 the evolution of monthly school attendance (log) by parish is illustrated. The figure provides some information on school attendance in Jamaica. First, there exists a positive trend with respect to school attendance. Therefore, more children were able to attend school over time. Second, there exists considerable seasonality. On average, in February, school attendance is highest, with 5,264 children attending school per parish on average, and lowest in December, when only 3,173 children attend school. Furthermore, school attendance is more than 20% higher in the first half of the year compared to the second half. Third, there was a pronounced drop in school attendance during the Spanish Flu in late 1918, when many schools closed.

For the period 1872 to 1892, where data was collected annually, average school attendance per parish was considerably lower (2,258) compared to post-1892 (4,363). The data also reveal that an average of 57% of teachers were trained, with significant variation between parishes, from 34.3% in Kingston to 78% in Hanover, and an increasing trend over time. Academic performance, measured as *Avg. Mark*, averaged 38.37 across parishes, with a range from 35.7 in St. Thomas and St. Mary to 43.7 in Manchester. Moreover, there is not only a spatial variation but also a temporal variation in *Avg. Mark*. In general, the value increases from 30 in 1869 to almost 45 in 1892. For the period 1880-1892, the annual data is more granular than in previous years, as it is not at the parish level but at the school level. During that period, the average attendance was 50.68, with an average of 89.15 pupils enrolled in each school. The average mark

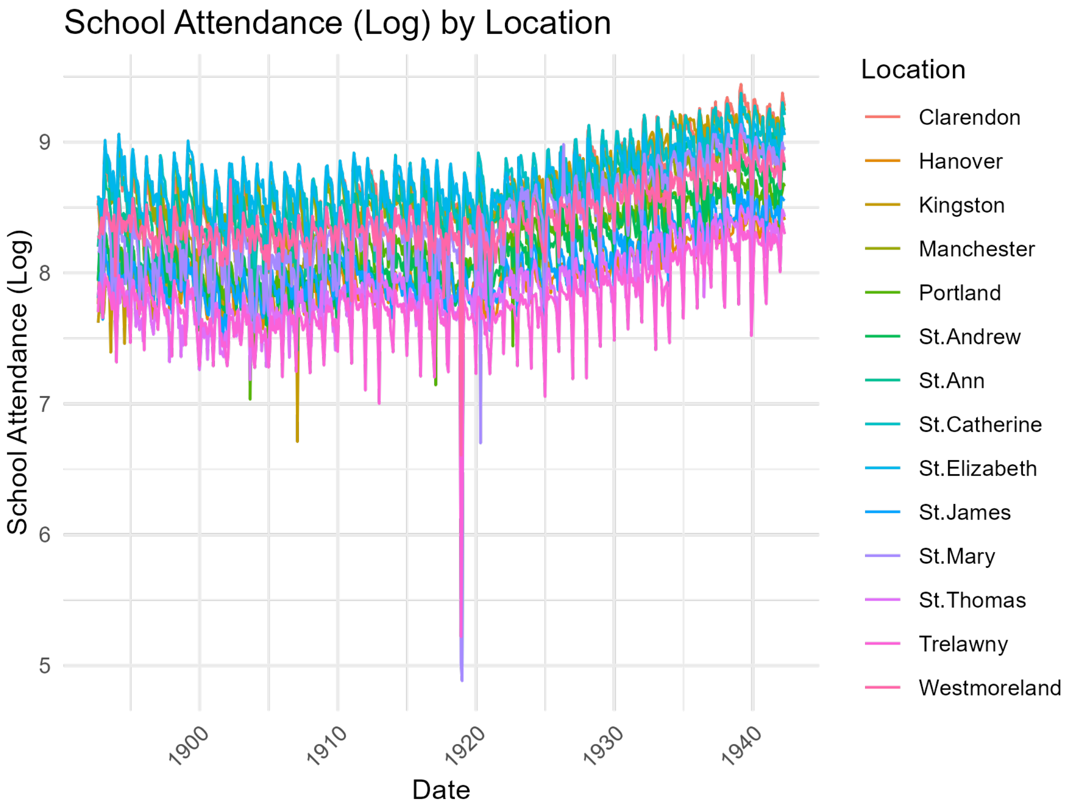

FIGURE 3.2: School Attendance (LOG) over time

was also slightly higher at 41.92.

In addition to examining the evolution of school attendance over time, it is also crucial to consider the proportion of children attending school in relation to the total number of school-aged children. For this reason, I estimated the number of school-aged children with ages between six and fourteen years for the years between 1892 and 1942 using data on births from Handbook of Jamaica (1883-1930) and The Governor's Report (1904-1938). Furthermore, the mean annual attendance was calculated for each parish and aggregated to obtain the mean annual school attendance in Jamaica. Figure C.3 illustrates the proportion of school-aged children who are attending school. The figure demonstrates a U-shaped form, with a high proportion of children attending school during the initial years (1892-1893), a lower proportion attending school between 1912 and 1920, and a gradual increase to the highest proportion attending school at the beginning of the 1940s. This is consistent with the historical development of education in Jamaica. The high proportion of children attending school in 1892-1893 can be attributed to the abolition of school fees. The decline in attendance between 1918-1920 was caused by the influenza pandemic. The subsequent increase in the number of students attending school was due to the stricter enforcement of compulsory education.

3.5 Effect of Hurricanes on School Attendance

This section analyses the relationship between hurricanes and school attendance in Jamaica. Using a fixed-effects panel regression model, the potential decrease in monthly school attendance due to hurricanes is examined:

$$\begin{aligned} LOG(ATT_{i,t}) = \beta_0 + \sum_{k=0}^{p} \beta_{k+1} \cdot HURR_{i,t-k} \\ + \alpha_z + \delta_m + \theta_i + \epsilon_{i,t} \end{aligned} \tag{3.3}$$

where α_z and δ_m are yearly and monthly fixed effects, θ_i are parish fixed effects, $LOG(ATT_{i,t})$ is the Log of school attendance and $HURR$ is the cubic wind speed divided by 1 million in parish i at time t, ..., $t + k$. Moreover, I cluster the standard errors on parish level. As hurricane strikes are random and exogenous events, using time- and entity-fixed effects isolates, according to Elliott, Strobl, and Tveit (2023); Huesler (2024b); Mohan and Strobl (2021), the random, unanticipated realisations from the distribution of potential damages from hurricanes.[13] This in turn allows me to estimate their effect on $ATTEND$ causally.[14]

Controlling for seasonality is achieved by using monthly fixed effects, while yearly fixed effects account for year-specific common effects. The analysis incorporates multiple control variables to provide a comprehensive understanding of the influence of the hurricane on parish-level school attendance. First, a linear trend at the parish level in school attendance is taken into account. This control is designed to capture inherent patterns within individual parishes that might result from a variety of factors not explicitly incorporated into the regression model. Next, the analysis takes into account the population share of each parish in the previous year. This approach allows for the evaluation of the potential influence of hurricanes in a comparative context. For instance, if a hurricane strikes a parish with a significantly larger population relative to other parishes, the hurricane's consequences are hypothesised to be more pronounced than in a less populated parish. Furthermore, since influenza caused school closure (The Jamaica Gazette, 1919), the influenza dummy is set to one for the months of October, November, and December in 1918, as well as for January and February in 1919. Lastly, the Rossi-Forel scale, along with two of its lags, is integrated into the model

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[13] Yearly fixed effects account for events such as World War 2 or price shocks that affected all parishes equally. Monthly fixed effects account for seasonal patterns, and parish fixed effects account for parish-specific differences that could affect school attendance, such as varying education policies or differences in the average distance to the nearest school.

[14] The estimated effect can be interpreted as causal for several reasons. First, there were no official warning systems which could have caused anticipation of hurricanes. Second, the geographical location choices of schools μ_i capture local distribution $f_{H_i}(H_i)$. Therefore, $H_{it} - \mu_i$ are random realisations from $f_{H_i}(H_i)$. Finally, information in *Departmental Reports* and *Jamaican Gazettes* indicate that schools affected by hurricanes were rebuilt and not abandoned which also aligns with the fact that no migration occurred after shocks as agricultural production and sugar-estate-level production recovered after shock.

to account for the potential impact of the Kingston Earthquake. The Rossi-Forel scale provides an estimate of an earthquake's intensity, thereby enabling the potential influence of seismic activity on school attendance to be captured.

The results of the estimation of the effect of Category One (two) hurricanes, where wind speeds exceed 119km/h (154km/h), on school attendance are in the first (third) column of Table 3.2. In the first column and third column, only the effect of $HURR_{t,..,t-7m}$, $EARTHK_{t,...,t-6m}$ as well as the location and time fixed effects are included. However, the results already indicate that hurricanes lead to significantly lower school attendance in the month of and the months after a hurricane. In column (2) and (4), I further control for $INFLUENZA$ which severely reduced school attendance in the end of 1918 and for $LINTREND$, which are parish-level linear trends and control for the underlying temporal trends specific to each parish. Incorporating $LINTREND$ allows me to account for any systematic time-dependent patterns that might influence school attendance, but are not related to hurricanes.

TABLE 3.2: Effect of Hurricanes on School Attendance

Model:	(1)	(2)	(3)	(4)	(5)	(6)
	119km/h	119km/h	154km/h	154km/h	119km/h	119km/h
Variables						
$HURR_t$	-0.0182***	-0.0163***	-0.0215***	-0.0209***	-0.0182***	-0.0151***
	(0.0053)	(0.0050)	(0.0069)	(0.0065)	(0.0053)	(0.0048)
$HURR_{t-1m}$	-0.0151***	-0.0106**	-0.0238***	-0.0199***	-0.0151***	0.0014
	(0.0058)	(0.0054)	(0.0068)	(0.0064)	(0.0058)	(0.0035)
$HURR_{t-2m}$	-0.0163***	-0.0091*	-0.0238***	-0.0165***	-0.0163***	-0.0007
	(0.0056)	(0.0051)	(0.0068)	(0.0064)	(0.0056)	(0.0028)
$HURR_{t-3m}$	-0.0077*	0.0011	-0.0117***	-0.0024	-0.0077*	0.0077***
	(0.0040)	(0.0037)	(0.0043)	(0.0043)	(0.0040)	(0.0030)
$HURR_{t-4m}$	-0.0052	0.0038	-0.0046	0.0039	-0.0052	0.0053*
	(0.0040)	(0.0037)	(0.0048)	(0.0047)	(0.0040)	(0.0031)
$HURR_{t-5m}$	-0.0033	0.0067	-0.0003	0.0080*	-0.0033	0.0046
	(0.0046)	(0.0042)	(0.0049)	(0.0047)	(0.0046)	(0.0035)
$HURR_{t-6m}$	-0.0035	0.0082	0.0007	0.0098	-0.0035	0.0051
	(0.0057)	(0.0053)	(0.0074)	(0.0072)	(0.0057)	(0.0043)
$HURR_{t-7m}$	0.0003	0.0003	0.0006	0.0026	0.0003	-0.0017
	(0.0060)	(0.0055)	(0.0075)	(0.0062)	(0.0060)	(0.0048)
$EARTHK$	-0.0244	-0.0467**	-0.0248	-0.0469**	-0.0244	-0.0409*
	(0.0184)	(0.0223)	(0.0184)	(0.0223)	(0.0184)	(0.0218)
$EARTHK_{t-1m}$	-0.0076	-0.0297**	-0.0080	-0.0298**	-0.0076	-0.0055
	(0.0083)	(0.0123)	(0.0083)	(0.0123)	(0.0083)	(0.0071)
$EARTHK_{t-2m}$	-0.0024	-0.0232**	-0.0027	-0.0233**	-0.0024	-0.0088
	(0.0064)	(0.0109)	(0.0064)	(0.0109)	(0.0064)	(0.0067)
$EARTHK_{t-3m}$	-0.0038	-0.0247**	-0.0042	-0.0248**	-0.0038	-0.0131*
	(0.0056)	(0.0104)	(0.0056)	(0.0104)	(0.0056)	(0.0068)
$EARTHK_{t-4m}$	-0.0012	-0.0221**	-0.0016	-0.0222**	-0.0012	-0.0097
	(0.0051)	(0.0101)	(0.0051)	(0.0102)	(0.0051)	(0.0069)
$EARTHK_{t-5m}$	-0.0058	-0.0266***	-0.0061	-0.0268***	-0.0058	-0.0155**
	(0.0043)	(0.0098)	(0.0043)	(0.0098)	(0.0043)	(0.0067)
$EARTHK_{t-6m}$	-0.0025	-0.0234**	-0.0028	-0.0236**	-0.0025	-0.0101
	(0.0038)	(0.0096)	(0.0038)	(0.0096)	(0.0038)	(0.0067)
$INFLUENZA$		-0.5483***		-0.5454***		-0.2375***
		(0.0886)		(0.0893)		(0.0851)
$LINTREND$		-14.80***		-14.57***		-5.602***
		(0.7770)		(0.7460)		(0.8874)
$Attendance_{t-1m}$						0.5335***
						(0.0386)
$HURR_{t-8m,\ldots,t-12m}$	No	Yes	No	Yes	No	Yes

Continued on next page

TABLE 3.2: (Continued) Effect of Hurricanes on School Attendance

Model:	(1) 119km/h	(2) 119km/h	(3) 154km/h	(4) 154km/h	(5) 119km/h	(6) 119km/h
$EARTHK_{t-7m,...,t-12m}$	No	Yes	No	Yes	No	Yes
Fit statistics						
Observations	8,807	8,807	8,807	8,807	8,807	8,807
Within R^2	0.00797	0.11368	0.00466	0.11145	0.00797	0.37787

Continued on next page

*Heteroskedasticity-robust standard-errors in parentheses. Signif. Codes: ***: 0.01, **: 0.05, *: 0.1.* Parish level, yearly and monthly fixed effects are included in all models. $HURR$ represents the cubic wind speed divided by 1 million, $EARTHK$ represents the Rossi Forel scale of the Kingston earthquake, $INFLUENZA$ is an Influenza dummy for October, November, and December in 1918, as well as for January and February in 1919 and $LINTREND$ are parish-level linear trends.

In column (6) ATT_{t-1m} is included. As expected, the effect of $HURR$ remains highly significant. The results from column (4) are further illustrated graphically in Figure 3.3. As is visible from Figure 3.3, $HURR$ decreases school attendance in the beginning but the effect becomes zero after three months. Moreover, the effect is also economically significant. Taking the average category two hurricane in the underlying data set (163km/h), one can conclude that $HURR_t$ reduces the average school attendance by 9.1%, $HURR_{t-1m}$ by 8.6% and $HURR_{t-2m}$ by 7.2%. Taking the average school attendance per parish (4,363 children), these results indicate that on average almost 400 children miss school one month, over 375 two months, and over 310 children miss three months of school after a hurricane strike. Nevertheless, the effect becomes insignificant after $t-2m$. In general, the mechanism behind the decrease in school attendance could be related to the resilience of educational attendance in the face of domestic infrastructure damage. Children, due to their limited ability to contribute to reconstruction efforts, might continue attending school despite damage to their home. Additionally, mandatory schooling laws could require attendance unless the school facilities themselves are compromised or the infrastructure is severely damaged, preventing children from reaching school.

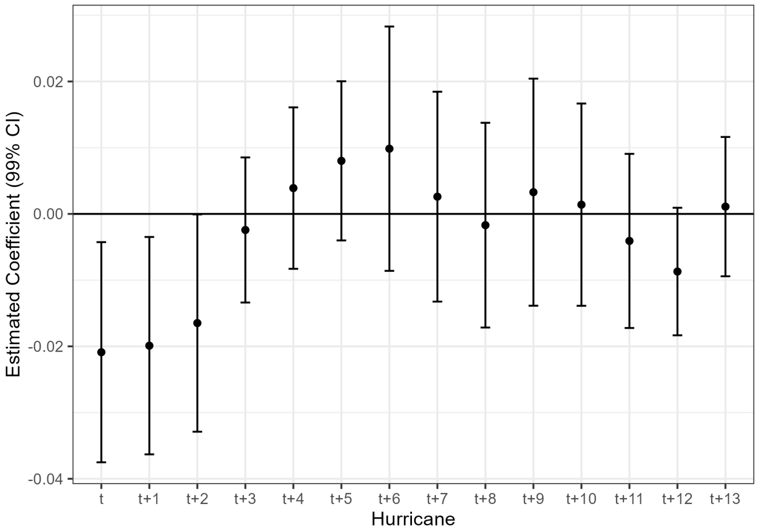

FIGURE 3.3: Impact of hurricanes (95% CI) on school attendance (154km/h)

In Table 3.2 columns (1-2) and (5-6) and Figure C.5[15], the same estimates have been carried out, but including category one hurricanes (wind speeds exceeding 119km/h). The results are comparable in significance, although slightly lower in magnitude. The results in column (2) indicate that taking the average hurricane (142km/h) reduces school attendance by 4.7% in t, 3.0% in $t - 1m$ and by 2.6% in $t - 2m$. However, the results increase when taking the average category two hurricane (163km/h) so that it reduces school attendance on average by 7.1% at t, 4.6% at $t - 1m$ and by 3.9% in $t - 2m$.

To test the robustness of the results, the same models are applied but include a lead in Table C.2, which controls for pre-Trends. As the effect of the lead is insignificant, the results show that there are no pre-existing trends or expectations. Therefore, the results of the paper capture the effect of hurricanes on school attendance. Furthermore, the effect of $HURR_t$, $HURR_{t-1m}$ and $HURR_{t-2m}$ in Table C.2 is similar[16] compared to those where no lead is included.

In Table C.1, I estimate the baseline model in columns (1) and (3) but also include $LOG(ATT_{i,t-1})$ in columns (2) and (4). Columns (1) and (2) show the results for wind speeds exceeding 119km/h and (3) and (4) for wind speeds exceeding 154km/h. In general, including $LOG(ATT_{i,t-1})$ increases the impact of $HURR_t$ but leads to an insignificant impact of $HURR_{t-1}$. Therefore, the results imply that average school attendance decreases by 6.3% points to 9.2% points when the average wind speed of category two hurricanes in the data set was taken. Furthermore, the positive significant effect of $LOG(ATT_{i,t-1})$ implies that there exists a positive path dependency with respect to $ATTEND$. Since the results in Table C.1 do not differ too much from those of the baseline specification, it can be interpreted as further evidence of the robustness of the results.

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[15] This figure contains the result from column (2) of table 3.2.

[16] The estimations with one additional lead are slightly higher when taking a threshold of 119km/h and slightly lower with a threshold of 154km/h.

3.5.1 Population weighted destruction index

To further illustrate the robustness of the results, a population-weighted hurricane destruction index is applied in the manner of Strobl (2012), which is based on the windfield model used in the first part of the results. The effect of $DESTR$ on $ATTEND$ is estimated as follows:

$$LOG(ATT_{i,t}) = \beta_0 + \sum_{k=0}^{p} \beta_{k+1} \cdot DESTR_{i,t-k} + \alpha_z + \delta_m + \theta_i + \epsilon_{i,t} \tag{3.4}$$

In general, the signs and significance of the results in Table C.3 are similar to those of the baseline model. The results in column (4) suggest that taking the average non-zero destruction, $ATTEND$ decreases by 1.81% in t. This is approximately one-quarter of the results from the baseline specification. Similarly, I estimate a population-weighted hurricane destruction index with a threshold of 154km/h. The results in Table C.4 suggest that taking the average non-zero destruction, $ATTEND$ decreases by 2.7% (compared to 8.6% in the baseline specification). Due to population weighting, areas with higher population densities are expected to experience more destruction compared to those with lower population densities. As a result, the destruction index generally underestimates the damage caused, reducing the impact on school attendance. It is worth noting that Jamaica was still a plantation economy at the beginning of the 21^{st} century. Therefore, since a significant portion of the population lived outside of the major urban centres and many schools were located in sparsely populated regions, the findings from using the population-weighted destruction index may underestimate the actual impact of storms on school attendance. Thus, the results of taking the population-weighted hurricane destruction index can be seen as a lower bound.

3.5.2 Fisher randomization test

To further assess the robustness of the findings, a Fisher-type randomization test is applied for the estimates of the hurricane impact on school attendance (Fisher et al., 1937). To this end, the hurricanes were randomly distributed across parishes and over time and were subsequently evaluated using the baseline model in column (5) of Table 3.2. This process was carried out 1,000 times (while keeping the control variables fixed), generating a total of 1,000 t-values for each respective coefficient.

Figure C.7 illustrates the distribution of t-values for the coefficients of $HURR_t$ in model 5 of Table 3.2, with the t-value from the initial baseline model indicated by a red dotted line. Moreover, the same process has been done for $HURR_{t-1m}$, which is presented in Figure C.8. As the distribution of t-values from the Fisher randomization test is in both cases not centred around the t-value obtained from the initial model, it can be concluded that the impact of hurricanes on school attendance is unlikely to be a result of chance. Therefore, the impact of hurricane strikes on school attendance can be interpreted as causal, reinforcing the conclusions drawn from the baseline model.

3.5.3 Population weighted destruction index

Figure C.4 illustrates the temporal evolution of marks. As evidenced by Figure C.4, there is a general increase in marks, irrespective of whether the average, the upper and lower 10% or the upper and lower 25% are considered. However, this increase is not linear, with some years exhibiting a significant decrease in marks. Two good examples are the drops in marks after the hurricanes in 1880 and 1886.

In addition to the fixed effect OLS results presented in the previous sections, it is possible that school attendance acts as a mediator. Hence, tropical storms may affect the marks obtained both directly and indirectly through school attendance. To investigate this possibility, I conducted a mediator analysis following the approach of Imai, Keele, and Tingley (2010); Imai et al. (2011). Figure C.6 provides a graphical illustration of the mediation analysis. The mediation analysis is estimated with yearly data for the subsample from 1872 to 1892 as data on marks is unavailable for more years. The mediation is estimated using the following two equations, as described in Gunzler et al. (2013):

$$SchoolAttendance_{i,t} = \beta_0 + \beta_{xz} \times HURR_{i,t} + \alpha_i + \delta_t + PTT_{i,t} + \epsilon_{z,i,t} \tag{3.5}$$

$$Marks_{i,t} = \gamma_0 + \gamma_{zy} \times SchoolAttendance_{i,t} + \gamma_{xy} \times HURR_{i,t} + \alpha_i + \delta_t + PTT_{i,t} + +\epsilon_{y,i,t} \tag{3.6}$$

These models are then estimated using the yearly data from 1880-1892 for which I also have a dummy variable indicating whether a teacher was trained or not. In both models I control for location fixed effects α, year fixed effects δ and I control for whether a school has a trained teacher (PTT). The mediation analysis is carried out in *R* by using the *mediation* library (Tingley et al., 2014) with robust standard errors bootstrapped over 1,000 simulations allows for investigating three effects. These comprise the direct effect (ADE) of $HURR$ on academic performance ($MARKS$), the indirect mediation effect (ACME), and the total effect of $HURR$ on $MARKS$. The analysis delves into the heterogeneity of these impacts, examining not only the average but also the distributional changes in academic marks due to tropical storms.

Table 3.3 presents the analysis findings on the impact of tropical storms on academic achievement within parishes, considering two minimum wind speed thresholds, namely 119km/h and 154km/h, across six distinct models. The results reveal a consistent and significant mediating effect of school attendance, as indicated by the average causal mediation effect (ACME). This suggests that school attendance is a crucial factor in mitigating the negative impact of tropical storms on academic performance.

TABLE 3.3: Mediation Analysis

	(1)	(2)	(3)	(4)	(5)	(6)
Variables						
$ACME$	-0.109 ***	-0.673***	-0.595 ***	-0.100**	-0.213**	-0.166*
ADE	0.081	0.005	0.030	0.133 *	0.243	0.226
Total Effect	-0.028	-0.668*	-0.489	0.033	0.031	0.060
Location FE	Yes	Yes	Yes	Yes	Yes	Yes
Yearly FE	No	Yes	Yes	No	Yes	Yes
Teacher Trained	No	No	Yes	No	No	Yes
Observations	9322	9322	9322	9322	9322	9322

Robust standard-errors in parentheses. The mediator in all regressions is Average Attendance (in log), dependent variable is $MARKS$, the independent variable is $HURR$, whereas the threshold is set at 119km/h (columns 1 to 3) or 154km/h (columns 4 to 6). Location-fixed effects are included in all regressions. Yearly-fixed Effects are included in columns (2), (3), (5) and (6) and a variable indicating whether the teacher is trained or not is included in columns (3) and (6). $ACME$ is the average mediation effect and ADE is the average direct effect. Signif. Codes:***: 0.01,**: 0.05,*: 0.1

For models that use the 119 km/h threshold (columns 1 to 3), the ACME values range from -0.106 to -0.666, all significant at the 1% level. For models employing the 154km/h threshold (columns 4 to 6), the ACME values range from -0.108 to -0.670, significant at the 1% levels. This indicates that increased wind speeds from tropical storms significantly reduces academic performance through affecting school attendance.

The direct effect of tropical storms on academic marks (ADE) is generally not significant, except in columns (2) and (4), where it is significant at the 10% level. This finding implies that the primary pathway through which tropical storms affect academic performance is through reduced attendance rather than a direct impact.

Therefore, a typical non-zero Category 1 (and above) Hurricane, with an average wind speed of 160.9km km/h, leads to a decrease in academic marks by 2.77% when the ACME is -0.673, by 2.30% when the ACME is -0.553. Similarly, using a higher storm threshold of 154km/h shows that a typical non-zero Category 2 Hurricane, with an average wind speed of 168.9 km/h, results in a decrease in academic marks by 0.52 to 4.23%. However, as the estimated $ACME$ decreases between column (2) and (3) and (5) to (6) when *Teacher Trained* is included, it must be noted that having a teacher with training reduces the negative impact of hurricane strikes on academic performance. In summary, the results consistently demonstrate that tropical storms have a detrimental impact on academic performance in all categories. Furthermore, I emphasise the crucial role of school attendance in mitigating these adverse consequences.

Table C.5 contains the results from the first and second stage. The results from the first stage, in Panel A, indicate a statistically significant negative effect of hurricanes on the average yearly school attendance rate. In particular, the coefficient for $HURR_t$ is consistently negative in all models, demonstrating that hurricane exposure has a substantial negative impact on school attendance. To illustrate, in columns (1) and (4), the coefficient for $HURR_t$ is -0.009, which is significant at the 5% level. The effect is even more pronounced in columns (2) and (5), where the coefficients are -0.056 and

-0.052, respectively, both significant at the 1% level. These findings are robust and confirm that hurricane events have a significant disruptive effect on average yearly school attendance on school level. The second stage results demonstrate a positive and highly significant relationship between school attendance and academic performance. The coefficients for $Attendance_t$ are positive and significant at the 1% level across all models, indicating that increased school attendance is strongly associated with improved test scores. The statistically significant mediation effect demonstrates that reduced school attendance is a crucial channel through which hurricanes alter academic outcomes.

The results show that hurricanes with higher wind speeds cause more damage, which may result in pupils receiving disproportionately lower grades because they have to help repair the damage at home. Stronger storms may destroy more of the harvest, such as sugar and bananas, which could force children to help with reconstruction efforts instead of studying, resulting in a decrease in academic performance. Hence, similar results have been found for the impact of natural disasters on academic performance in the 21^{st} century (Thamtanajit, 2020; Sapkota and Neupane, 2021; Khalid et al., 2024).

The paper also illustrates alterations in the distribution of marks. Not only did I notice a reduction in average marks, but also an increase in the variability of marks between schools, suggesting a broader range of academic results after storms. This raises concerns about the worsening of academic inequality in the aftermath of environmental disasters, especially as, depending on the model, between one-third and almost half of the effect of tropical storms on school performance is mediated by average school attendance.

3.6 Conclusion

This study provides a comprehensive analysis of the relationship between natural disasters and educational results, focussing on the impact of hurricanes on school attendance in colonial Jamaica from 1872 to 1942. By combining parish-level school attendance data with historical hurricane tracks, the research highlights the significant consequences of these natural events in a primarily agrarian society. The findings indicate substantial educational disruptions due to hurricanes, with category two hurricanes causing an average attendance drop of 9.1% in the hurricane month, followed by declines of 8.6% and 7.2% in the subsequent two months. The mediation analysis reveals that tropical storms significantly reduce academic performance, primarily through decreased school attendance. The average causal mediation effect indicates that school attendance is crucial in mitigating these adverse impacts, with trained teachers further reducing the negative effects. Stronger storms lead to greater academic declines and increased variability in marks, raising concerns about worsening academic inequality post-storm. These findings highlight the importance of maintaining school attendance and teacher training to mitigate the educational impacts of natural disasters.

The broader implications of these findings are manifold. First, they contribute to the growing literature on the impact of natural disasters on educational outcomes, complementing existing studies that examine similar dynamics in different contexts (Cuaresma, 2010; Bustelo, Arends-Kuenning, and Lucchetti, 2012; Adeagbo et al., 2016). This paper also enriches historical research on the socio-economic impact of natural disasters (Naylor et al., 2022), especially in agrarian societies that rely on vulnerable sectors such as agriculture, which is particularly prone to the impact of hurricanes (Cook and Beachy, 2018; Baez and Santos, 2007).

Furthermore, this paper underscores the potential long-term implications of these short-term disruptions. Although I do not directly measure long-term impacts, the observed declines in attendance and performance suggest adverse effects on students' future educational attainment and economic growth. This aligns with broader literature on the role of education in economic development, as discussed by Barro et al. (2013), Long (2006), and Hanushek and Wößmann (2007). The historical context of Jamaica, which was dependent on plantations during the period under study, provides a crucial lens through which to understand these dynamics. Thus, the historical disruptions caused by hurricanes likely had far-reaching implications for education and economic growth in Jamaica. This paper therefore emphasises the vulnerability of such agricultural-dependent economies like Colonial Jamaica to environmental shocks.

Chapter 4

Flooding Away the Economic Gains from Transport Infrastructure: Evidence from Colonial Jamaica

joint with Eric A. Strobl

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4.1 Introduction

Once the jewel of the British Empire, the sugar colony of Jamaica saw its prosperity consistently diminish over the late 19^{th} century due to the abolition of the trade and use of slavery, the elimination of favourable sugar duties, and falling sugar prices (Satchell and Sampson, 2003). To stem this decline it was thought that large transport infrastructure investments, by reducing costs of internal trade and population movements, might be the solution (Maunder, 1954a; Eisner, 1961; Will, 1970). While the first railroad was built as early as 1845 and jurisdiction over major roads was granted to the colonial government in 1865, the strategy of investing in transportation infrastructure only seriously took foothold when Joseph Chamberlain became Britain's Colonial Secretary and implemented a policy of increased government spending on large-scale infrastructure projects, especially railway and road extensions (Maunder, 1954a; Eisner, 1961; Will, 1970). Importantly, however, Jamaica's topography and climate presented a considerable challenge in terms of where to place and in using these internal transportation modes. More precisely, with a central mountain ridge that runs from east to west and steep valleys containing rapidly flowing rivers, the plausible locations of railway lines and roads was limited and often necessitated the use of bridges. At the same time the island's tropical climate was characterised by frequent localized heavy rainfall, which tended to severely damage bridges, and flood and deposit debris on roads and railway lines, often making these impassable for prolonged periods of time (House of Commons, 1900). In this paper we set out to explore to what extent such climate shocks impeded any local economic benefits of the considerable investment in transport infrastructure undertaken in colonial Jamaica.

There is a long history of trying to quantify the impact of early investments in transport infrastructure, arguably starting with the seminal study by Fogel (1964). More specifically, Fogel (1964) showed that while some areas in the United States benefited greatly from the tremendous growth in the railways in the 19th century, the national impact was relatively small. It then took nearly forty years for a significant resurgence of interest in empirically studying the effect of transport mode expansion, examining its impact in many different historical contexts. For example, also for the United States, Atack and Margo (2009) show that cropland increased as a result of the railroads. Outside of the North American continent, Cermeño and Caballero (2020) provide evidence that the development of roads in 18^{th} century Spain led to the integration of the wheat market, while Groote, Jacobs, and Sturm (1999) demonstrate that investment in both railway and waterway infrastructure played a significant role in the economic growth of the Netherlands. For India railway construction during colonial rule has been shown to have decreased trade cost and inter-regional price differences, increased regional and international trade, reduced resilience to local productivity shocks, and raised literacy levels (Burgess and Donaldson, 2012; Donaldson, 2018; Chaudhary and Fenske, 2023). Another example are the investments in transport infrastructure in Italy as a result of the Marshall plan that led to increases in agricultural production, advances in labour-saving equipment, and expansion in the service and industry sectors (Bianchi and Giorcelli, 2023). Nevertheless, the effects of infrastructure investment may differ depending on the type of infrastructure and local institutional setting, as has been the case for Spain (Herranz-Loncán, 2007).

One of the key ways in which transport infrastructure can benefit local economies is through access to other markets, as first quantified by Donaldson and Hornbeck (2016). More specifically, Donaldson and Hornbeck (2016) calculate the reduction in transport costs between US counties due to additional railway lines laid between between 1870 and 1890 and interpret such lower costs as enabling greater 'market access' to other counties. Their results show that the increase in market access from railway construction significantly raised local land values as regions became more connected. The authors' innovative least cost path of transportation approach of identifying market access has now found widespread use in many contexts of early transport investments. For example, within the same US railway network expansion market access has additionally been shown to have raised productivity in manufacturing (Hornbeck and Rotemberg, 2019), increased farming and the size of the rural population (Chan, 2022), increased better banking provision (Chan, 2023), and sparked entrepreneurial activity (Perlman, 2015).[1] Similarly, market access measured in this manner indicated that early investments in railways infrastructure have led to larger city size in late 19th and earlyt 20th century India (Fenske, Kala, and Wei, 2023), more population growth in 19th century England and Wales (Bogart et al., 2022), greater population density, higher land values, increased emigration and less labour intensive farming in post-famine Ireland (Fernihough and Lyons, 2022), and greater innovation in 19th century France (Tsiachtsiras, 2022), to name a few. It has also been employed to demonstrate positive more long term impacts, such as through the Italian colonial roads built during the 20th century Africa (Bertazzini, 2022) or the introduction of the US Interstate Highway system (Herzog, 2021).

The existing literature generally appears to leave little doubt as to the at least net local economic benefits arising from historical investments in transportation infrastructure, particularly through increased market access. However, one aspect that has as of date been neglected is the likely accompanying greater susceptibility of connected regional economies to negative transport network shocks, in particular through extreme weather damage. More precisely, while of course disruptions to transport infrastructure due to negative climate shocks continue to be a problem today (Diakakis et al., 2020; Palin et al., 2021; Loreti et al., 2022; Ochsner et al., 2023), and particularly so for developing countries with lower quality infrastructure (Brooks and Donovan, 2020; Schweikert et al., 2020; Dube, Nhamo, and Chikodzi, 2022; Andreasen et al., 2023), this is likely to have been substantially more of an issue in the early days of transport investment when transport technology was still far from the current state of the art. For instance, hand in hand with the substantial investments in interior transportation made in Australia in the late 19th century with the gold rush (Lay, 1984;

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[1] There may, however, been some losers as response of regions opening to trade (Winters and Martuscelli, 2014). For instance, Chan (2024) finds that US railways market access in the first half of the 20th century reduced literacy among boys in the short-run and subsequently decreased their income in the long-run.

Campbell, Brougham, and Caldwell, 2009; Blainey, 2010), Callaghan (2020) describes the extensive damage and interruptions to roads and railway traffic because of flooding. Also, Brett (2019) describes in detail New Zealand's steep learning curve with its early railway system in the late 19th century, as frequent flooding from rivers swept away bridges, blocked tracks with debris, and submerged the tracks, thereby substantially increasing operational and repair costs and interrupting traffic. Perhaps most exemplary of the slow adaption of transport technology to deal with the effects of excessive rainfall is the long evolutionary path of road pavement techniques, where simple rocky roads started being used in 2500 BC Egypt, cement paved some roads in Mesopotamia and found widespread use in the Roman empire, cement experienced a renaissance and the asphalt emerged in Britain and France in the 17th and 19th century, respectively, and only in the mid 20th century concrete became the superior technology for resisting flooding (Lay, Metcalf, and Sharp, 2020). As noted by Lay, Metcalf, and Sharp (2020), each of these technological developments, congruent with the ebb and flow of the importance of inland trade and transport, were in large part due to the need for a well functioning transport system to be able to better handle periodic extreme climate shocks.

Using the case study of colonial Jamaica we here explicitly quantify for the first time what role climate shocks may have played in reducing any market access benefits accrued from early investments in inland transportation networks. More specifically, our starting point is that by enabling greater market integration across space, an expanded and integrated transport system also meant that interruptions to the infrastructure due to the frequent flooding, even if locally remote, would have spatially dissipated by changing the optimal routes between places, and thereby temporarily impeding any local economic gains. To explore this we geo-referenced Jamaica's evolution of the railway and road network during the height of its investment (1881-1925), as well as identified the parts of the network affected by floods. This allows us to construct a market access measure *à la Donaldson (2018)* that takes into account the likely change in use of the network system, and hence increased transport costs, when segments of it were temporarily impassable due to flooding. To determine the economic consequences of the climate shocks we digitalized various measures of local economic activity, as captured by regional (parish level) tax data. Combined, this provided us with a thirty five year regional panel data set with which we estimate the impact of flood induced reductions in market access on various aspects of the local economy, including its service, housing, and agriculture sectors.

The remainder of this paper is structured as follows. In the next section we provides an overview of the relevant historical setting. Section 3 describes our data, while Section 4 outlines the construction of the market access variables as well as the econometric strategy. In Section 5 we provide summary statistics and discuss the results of our economic analysis. Concluding remarks are given in the final section.

4.2 Historical Background

4.2.1 Geography

The geography and climate of colonial Jamaica posed a considerable challenge to the provision of an adequate internal transport network (Eisner, 1961). Long and narrow in shape, the island is traversed by mountain chains that rise steeply from fairly narrow coastal plains and are separated by numerous valleys across its fourteen parishes; see Figure D.1. The principal range runs east to west, with a summit at Blue Mountain Peak ($\approx$ 2,256 meters) near the eastern end, while the central mountain ranges form the main watershed for rivers that drain either to the north or to the south coasts. As a matter of fact, areas that can be considered flat only constitute 14.5% of Jamaica's geography (HBJ, 1928). While Jamaica's main 22 rivers, located in 12 of the parishes, constitute over 700 kilometers, most of these are not navigable.[2]

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[2] One exception is Black River, located in the parish of Saint Elizabeth, where 40 of its 53 kilometers are navigable for small vessels (WRA, 2001). Additionally, 3 of the 36 kilometers of Milk River in the parish of Clarendon can be traversed by smaller boats.

4.2.2 Climate, Rainfall, & Flooding

Jamaica has a maritime tropical climate, with an average annual rainfall of close to 2000 millimetres, but with considerable variation both seasonally and spatially (WRA, 2001). The heaviest rainfall ($\approx$ 5,080 millimeters) can be found over the Blue Mountains in the parish of Portland, while the parish of Kingston experiences the lowest ($\approx$ 760 millimeters). Most of the southern coast is located in the rain shadow of the Blue Mountains and thus receives much less rain than the northern coast. Maximum rainfall occurs in May and October, whereas February and March tend to receive the least amount. Between July and November Jamaica is subject to tropical storms and hurricanes, which are often also accompanied by considerable rainfall (Collalti and Strobl, 2022). Jamaica's extreme precipitation events are known to be amongst the greatest point measurements of rainfall globally (Burgess et al., 2015). This heavy rainfall tends to cause fluvial (Mandal and Maharaj, 2013), as well pluvial flooding (Collalti, Spencer, and Strobl, 2023), the latter resulting in flashfloods and landslides (Miller, Brewer, and Harris, 2009).

4.2.3 Jamaica's Economy in the late 19th and early 20th Century

Despite the steady decline in the sugar industry over the 19th century, Jamaica's remained predominantly agriculturally based. More precisely, agriculture as a share of total output (employment) only fell from 60.4% (71.5) in 1832 (1844) to 56.2% (62.8) in 1890 (1891) (Eisner, 1961). This predominance continued over our period of interest, where by 1921 the share of agricultural employment was still 55.3% and output by 1930 was 50.8% (Eisner, 1961).[3] Importantly, however, the composition of agriculture changed had changed substantially since emancipation. More precisely, while sugar, as well as to some extent coffee and by the 1890s also bananas, dominated exports, agricultural production intended for local consumption and internal trade grew substantially. More specifically, ground provisions, which just before emancipation had

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[3] If one additionally considers manufacturing, which largely consisted of the manufacturing of agricultural inputs, as part of the agricultural sector then a further about 10 percentage points would be added to both the output and employment shares; see Eisner (1961).

been only 27% of agricultural output[4], grew to 55% by 1890 and still stood at 49% by 1930 (Eisner, 1961).[5] Similarly, farmers involved in the cultivation of ground provision in the Jamaican economy constituted 66% and and 69% of agricultural employment and 43% and 41% of the total working age population in 1890 and 1920, respectively (Eisner, 1961). It is noteworthy that ground provisions were almost exclusively grown by small scale farm peasantry and constituted their primary income earner by selling anything not consumed in internal markets.[6] For example, in 1890 (1930) 83% (69%) of peasantry production was due to ground provisions (Eisner, 1961). However, the small scale peasantry also played a non-negligible role in the production of export crops, i.e., including sugar, bananas, coffee, citrus fruits, and coconuts, during our period of interest, constituting 23% ((27%) of peasantry output and 39% (41%) of total exports in 1890 (1930).[7]

4.2.4 History of Transport Infrastructure Investment in Colonial Jamaica

When slave emancipation was completed in 1838, the transportation network within Jamaica was fitted to mainly serve the peripheral settlements of slavery times in that goods were conveyed by coastal boats, pack animals, and carts drawn by animals, and the majority of the population travelled on foot (Cumper, 1956; Satchell and Sampson, 2003). The exodus of a large part of the plantation population after emancipation resulted mainly in independent peasantry settlements, sustained on subsistence agricultural production, on marginal land within the estate system, which had been either sold or abandoned under the economic pressures of the 1840's. The use of roads for transport from the estates was costly and generally dangerous, and during heavy

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[4] During slavery many slaves grew ground provisions, consisting mainly of yams, cocoes, and sweet potatoes, for personal consumption and sale on local markets on small plots on or near the sugar estates (Higman, 1995).

[5] Although low in caloric content, one advantage of ground provisions was that they could be grown virtually anywhere on the islands, and thus allowed former slaves to continue their cultivation even after many left the sugar estates after emancipation.

[6] The importance of small scale farming in Jamaica during this time can also be gauged from tax data where in 1890 (1930) 86% (83%) of landholdings under 50 acres were due to those less than 5 acres (Eisner, 1961).

[7] The remaining share of peasantry production was in animal products.

rainfall often came to a standstill. As a matter of fact, it was usually cheaper to carry goods by boat from one extremity of the island to another rather than between even neighbouring parishes, making coastal boats the preferred means of transport (Eisner, 1961).[8] As noted by Satchell and Sampson (2003), this led to the development of a new road and railway system in order to break down the barriers between these new settlements and create markets for their produce.

Railroads

A proposal to construct the first Jamaican railway was made in 1843 by William Smith, a local landowner originally from Manchester, and his sugar planter brother David Smith. This was enthusiastically supported by planters who thought that a railway system would not only revitalise their plantations but also encourage the establishment of a central sugar factory system (Satchell and Sampson, 2003). Construction promptly started in 1844 under the Railway Company, a private entity. While the original plan was to build a line from Kingston to Spanish town as well as three branches to other parts of the parish of St. Catherine (Angels, Port Henderson, and Caymanas), costs only allowed for a branch to Angels, constituting a total of 14.5 miles of railroad, completed in 1845 (Handbook of Jamaica, 1895). The continued decline of the sugar plantation economy and the lack of funds for further railway investment meant that only an additional 11.5 miles were added to the system, connecting Old Harbour, also in St. Catherine, in 1869. Moreover, train services became irregular and the quality of railway infrastructure deteriorated substantially (Satchell and Sampson, 2003). This only changed some thirty years later when Sir Anthony Musgrave became governor in 1877, who strongly believed that the Jamaican economy would substantially benefit from a well managed railway. Subsequently in 1879 the government purchased the existing 26 miles of railroad from the private company and instigated an extensive repair and modernisation program, as well as extending it 24.5 miles to Porus

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[8] This was reflected in the fact that prices of produce could vary between contiguous areas by as much as 100 per cent (King, 1850).

(Manchester) in the west and 14.5 miles to Ewarton (St. Catherine) in the north in 1885 (Sewell, 1863).

Although there were calls to further extend the system, in part due to the growth of the bananas and citrus industry[9], this was originally resisted as the expected returns were not expected to meet the costs (Satchell and Sampson, 2003). Further extensions finally came to fruition when the then governor Sir Henry Norman induced the sale of the railways to an American consortium in 1890, leading to lines from Porus (St. James) to Montego Bay (St. James) in 1894 and to Port Antonio (Portland) in 1896, i.e., a further 62 and 54 miles, respectively. Nevertheless the profits were not sufficient to even cover the first mortgage bondholders, and after two years of default if paying the interest on the loans it had received the company fell into receivership and in 1900 the railway once again became property of the government (Eisner, 1961). Over the next twenty-five years only two further extensions were made, namely a 13 mile extension in 1913 from May Pen to Chapelton in the parish of Clarendon, and 9.25 miles linking Chapelton to Frankfield in 1925. At the end of 1925 the total railway network thus was of 185 miles in length.

Roads

One of the first acts passed after Britain captured Jamaica from the Spanish was *An Act for the Highways (1681)*, which placed the financial responsibility for the upkeep of highways upon the parishes through which they ran rather than the central colonial government (Handbook of Jamaica, 1881; Maunder, 1954a). But, as economic activity and population expanded to the interior of the island, the parochial funds became insufficient and financing was supplemented by annual grants from the legislature and highway tolls. Additionally in 1836 financing was changed in that each parish could raise money for repairs at its discretion. However, in response to overtaxation the

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[9] Access to railways was particularly important for the bananas industry as the fruit quickly reduced in quality if not transported with care and within two days of cutting. As a matter of fact, Satchell and Sampson (2003) argues that the economies of scale of the bananas industry was likely in part due to the extension of the railway system in the 1890s. Similarly, it is also likely to have a played a role in the expansion of the production of citrus, coconut, and cacao.

road financing had to be supplemented by government grants as well as the creation of private turnpike enterprises in 1838 (Fontanilla, 2023).

While the redistribution of large parts of the population after emancipation did result in a fairly integrated road network connecting the interior of Jamaica with the towns and coastal ports, the roads especially in the interior were even by 1840 in an appalling state. Additionally, there were few bridges to cross the numerous rivers traversing Jamaica and these were poorly constructed (Cumper, 1956; Satchell and Sampson, 2003). As a matter of fact, the widely held view was that the road system was "...a disgrace to a civilized community and militated considerably against the agricultural prosperity"(Phillippo, 1843, p.32). Thus, in 1851 a new system of road management was introduced, placing the responsibility of roads in the hands of a Board of Commissioners of Highways and Bridges, except for the turnpikes. With still little subsequent progress achieved, the *Major Road Act of 1857* was passed, which transferred the most important sections of roads to a body of Main Road Commissioners and established a main road fund to be financed by a land tax and tolls. However, the power to redeem the land-tax was repealed in 1862 and and the Main Road Commissioners replaced by a Director of Roads in 1863.[10] With the main roads fund insolvent and the roads still in poor state, the government finally assumed the entire debt in 1870 and all expenditure for main roads were borne in the annual expenditure estimates to be chargeable to the general revenues of the Colonial government. This led to a considerable expansion of the main road work over the next decades (Maunder, 1954a; Satchell and Sampson, 2003).

In terms of the sample period of our analysis (1895 to 1924) there are two other aspects about the Jamaican road system that need to be highlighted. Firstly, apart from the main roads there was also a large parochial road network under the authority and financing of the parishes. For example, in 1891 there were 3,300 miles of parochial roads compared to the 764 miles of major roads (Royal Commission, 1884). However, these

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[10] Additionally, the widely unpopular private turnpike tolling system was abolished the same year (Maunder, 1954a).

were in "...a very bad state", (Royal Commission, 1884, p.20), where about 60 per cent were "little better than bridle tracks" (Royal Commission, 1884, p.20) and unsuitable for carts or carriages.[11] As a matter of fact, while many new main roads were constructed, generally a lot of the additions to the main road network were takeovers of parochial roads in order to improve their quality (Handbook of Jamaica, 1925). Secondly, at the end of our sample period in 1925 no portion, or at best a very small one, of the road network was asphalted.[12] Unsurprisingly then, few vehicles were motor driven (Maunder, 1954a),[13] so that the majority of transportation of people or goods by roads was by animal drawn or by foot even by 1925 (Handbook of Jamaica, 1925).

Internal Transportation System as a Whole

It is also important to consider the internal transport system as a whole in terms of its components and how they interacted. In essence there were only three possible modes of transport for travel of goods and people, i.e., coastal boats, roads and railways, since most rivers were not navigable. While, as noted earlier, in the early colonial days the most reliable one was along the coast by boat since essentially all roads were in poor condition and there were not railroads, by the time of the period being studied in this paper, maritime transport as a means of transporting goods and people internally had become rather limited. For example, during our time period there were just two steamers leaving Kingston every week, one going eastward and one westward, leaving on Tuesdays and returning on Saturdays, stopping at 14 ports along the coast, at a cost of 17 and 75 shilling for a round trip for deck and cabin travel, respectively (Cundall, 1920). Additionally, the coast was not navigable for extended periods during the rainy season, and thus acted as a rather imperfect and unreliable substitute for either road or railway travel (Satchell and Sampson, 2003).

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[11] The difference in quality between the main and parochial roads was also reflected in the amount spent on repairs and maintenance, with, for instance, about £40 per mile on the former and £7 per mile on the latter (Royal Commission, 1884).

[12] Figures from Maunder (1954a) show that in 1920 zero per cent were asphalted and that this only increased to 5 per cent by 1930.

[13] As of 1924 there were only 3,554 motor driven registered, in contrast to 28,345 of other vehicles licensed, i.e, a little over 12 per cent (Handbook of Jamaica, 1925).

Importantly for the purpose of our analysis, prior to the 1930's the road and railway networks should be considered compliments rather than substitutes given the latter's limited coverage across the island (Satchell and Sampson, 2003). More specifically, large agricultural estate owners, primarily producing sugar or growing bananas for export, generally needed to use roads for at least part of the transport of their goods to the ports.[14] Similarly, small scale farmers required almost always the use of roads to get their products to internal markets (Satchell and Sampson, 2003). In this regard, much of the internal marketing was done by either professional higglers, usually women, who travelled from farm to farm and then sold goods on the market, or the farmer her/himself or his/her relatives (Bryan, 2000).

Cost of Using Major Roads relative to Railways

An important difference between transporting goods by railways and roads in their role in integrating the Jamaican regional economies was their relative cost. Given that in particular for small scale farms the transport of goods to their point of sale involved an intermediary, or somebody from the farm, who would travel from the point of production to the point of sale, it is important to consider both the cost of passenger travel as well as goods transport. In this regard, travelling by railway was generally quicker and cheaper for passengers along the routes where the latter was available. For instance, in 1895 going the 74.5 miles by railroad from Kingston to Port Antonio took a little over 4 hours and cost 6 shilling for the lowest class type, and went three times daily. In contrast, one could hire a livery buggy to go by road, but this would cost 120 shilling for the same trip and take about 10 hours (Handbook of Jamaica, 1896a). Alternatively, persons could also travel by road with a mail coach for 40 shillings, but trips from Kingston to Port Antonio were limited to three times a week and, as the railways, only included a limited number of stops along the way (Handbook of Jamaica, 1896a). Thus, given that the average daily wage rate was between 1 and 1.5 shillings

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[14] One should note that all coastal parishes had at least one major operating port during our sample period, although they differed in use and purpose.

per day at the time, certainly travelling by rail was by far the most affordable transportation option for passengers with little goods to transport (Satchell and Sampson, 2003).

In terms of using roads or the railways for transporting goods as a passenger, for railways the lowest class ticket included up to 28 lbs of baggage with an additional cost of 6 shilling for every extra 7 lbs above this limit. Mail coach passengers were allowed to carry up to 20 lbs of baggage for free and were limited to an additional 10 lbs for 3 shilling per pound, and thus this remained a limited option for carrying goods personally. Assuming that the time opportunity cost was equal to the average daily wage and people worked eight hours a day, then in order for a person to be indifferent between taking the railway or travelling by road by hiring a buggy from Kingston to Port Antonio they would need to be carrying 44 lbs of goods. By 1925 the relative cost of carrying goods personally by railway had only fallen marginally. For example, travelling by rail from Kingston to Port Antonio increased in cost to 7.8 for the lowest class type, with a free personal allowance of 56 lbs and any additional baggage at roughly 10 shillings per pound (Handbook of Jamaica, 1925). In contrast, travel by road with a livery buggy for the same route had risen to 160 shilling.[15] Thus, in order for a passenger to be indifferent between railway or road travel on this route they would need to have 71 lbs goods to carry.

Unfortunately for most of our sample period there is very little information in terms of the cost of sending freight on its own by railway compared to by road, although in a public meeting in Mandeville in 1901 a coffee producer argued that "people could send their produce by dray [a strong cart or wagon], which would be much cheaper" than by railways (The Jamaica Gleaner, 1901, 7). In contrast, the Government Jamaican Railway regularly advertised its freight rates by the 1920s. For instance, in 1923 sending a ton of ground provisions, sugar, and coffee by freight from Kingston to Richmond[16]

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[15] By 1925 mail coaches were no longer running.

[16] Richmond lies 36 miles from Kingston and is in the parish Saint Mary and during our sample period the trip would have taken about 2 and 4 hours by railway and livery buggy, respectively (Handbook of Jamaica, 1896a).

would cost 13.4, 25.6, and 33.3 shillings, respectively (The Jamaica Gleaner, 1923, 16). In contrast, hiring a livery buggy would run about 75 shilling for the same trip (Handbook of Jamaica, 1925). To be indifferent between either mode of transportation along this route would have meant shipping 5.6, 2.8, or 2.3 tons of ground provisions, sugar, or coffee, respectively, by freight. Of course, there would have been limits to how much a livery buggy would have been able to transport. While we have no information for this in the Jamaican context, one may want to note that for late 19th century Britain country carrier wagons could carry up to 2 tons of goods (Everitt, 1976).

4.2.5 Inland Transport Infrastructure & Flooding

The damaging effect of flooding for roads has plagued Jamaica since its early pre-emancipation colonial days where roads "...for hauling heavy goods of produce to shipping ports were...in a deplorable condition...cut up and impassable after rains" (Long, 1774, p.52). This susceptibility of roads to extreme precipitation continued well into the early 20th century in that they were "liable in times of excessively heavy weather to severe damage from flooded rivers and landslips, and from the heavy scouring of the rains on the surface of the roads, especially those on steep gradients" (Handbook of Jamaica, 1925, p.590). Sometimes such floods only affected individual parishes, as for instance in 1902 when there were continuous heavy rains during the first eight months of the year in St. Mary so that "nobody could remember such a year as this had been for rain, and heavy rainfall was just what the St. Mary's roads could not stand" (The Jamaica Gleaner, 1902, p.14), and "consequently many of the important main roads were from time to time rendered impassable" (Departmental Reports, 1916, 496). On other occasions there were island wide impacts, as was the case for the flood rains in September and November of 1915 which "with one or two exceptions damaged roads in all the parishes" (Departmental Reports, 1915, 452), or in 1916 when "the main roads, with few exceptions suffered severe damage on several occasions from repeated spells of Flood Rains" (Departmental Reports, 1916, 453). Moreover, flooding tended to be a problem for both the along coast, such as when in

"January 1915 the coast roads suffered considerably damage from scour due to heavy rains" (Departmental Reports, 1914, 268), and non-coastal areas when, for instance, in 1912 "very great damage was done to the interior roads in St. James by the floods consequent on an extremely heavy rainfall, and throughout the island generally" (Departmental Reports, 1912, 234). Damage to railroads after heavy rains was also a common, although much less well documented since the network was only for some of the period under government control. For example, in 1915 "during the seven months of the year heavy flood rains damaged the Railway considerably in various districts" (Departmental Reports, 1915, 176).

One should note that the damage to roads and railways as a result of floods took several forms. Firstly, there was temporary flooding, such as when in Westmoreland in 1916 "flood rains fell in May and again in August inundating the roads for about a fortnight" (Departmental Reports, 1916, 500) or when the "flooding of the Buff Bay river in December caused extensive damage to the Buff Bay River Road at Red Hills and at Kildare, and a temporary deviation...had to be opened so as to accomodate traffic" (Departmental Reports, 1916, 467). Additionally, both roads and railways could be affected by erosion arising from floods. More precisely, "by scour of the surface, by erosion of the roadway, and by carrying away of retaining walls in many cases where the roads lay along rivers, by washing away culverts, and by landslides"(Departmental Reports, 1912, 234). Similarly, there were times when "over 2,500 cubic yards of sand and gravel had to be cleared off the [railway] tracks due to heavy rains" (Departmental Reports, 1918, 71). Perhaps most importantly, floods tended to affect road and railway transport through their impact on bridges by making "any of the river crossings or fords...impassable from the abnormally flooded state of the rivers" (Departmental Reports, 1916, 496) and damaging the bridges themselves. Examples include, amongst many others, St. James in 1914 when "flood rains considerably damaged the Leyden Bridge carrying away one abutment and a portion of the wing wall" (Departmental Reports, 1914, 268) or when the "Cokely Bridge on the Annoty Bay Junction Road was severely damaged by a heavy flood in January, which caused the superstructure and one abutment with its windfalls to collapse" (Departmental Reports, 1902, 147), as well as when "during the heavy flood rains at the end of November, the Sandy River Bridge (22 ft. span) on the Junction Road, Stony Hill to Annotto Bay...suffered destruction necessitating a temporary deviation of the roadway until a new bridge should be built" (Departmental Reports, 1916, 466). Also, in 1921 "damage was done to the...rail bridges by the heavy flood rains of January 15-21 of 1921" and "...these heavy rains caused numerous earth slides between Riversdale and Richmond, blocking the line against traffic" (Departmental Reports, 1921, 352-353).[17]

There was a general awareness of the impeding economic impact of flooding on internal transportation. This included the disruptions to transport, such as in 1881 when the "frequent floods Jamaica has of late been subjected to have cut up the roads and swollen the rivers...and caused great interruptions to the inland communication with Kingston" (Handbook of Jamaica, 1881, p.61). Additionally the repair of the road and railway network after flooding was recognized as a considerable financial burden on the colonial government. For example, "the high [road] expenditure in 1875 was due to the floods in the months of October and November of 1874 ...which caused damage to some of the main roads, the restoration of which entailed an excess of expenditure" (Handbook of Jamaica, 1881, p.232), while "the Bog Walk Road in St. Catherine was repeatedly damaged by floods...[and] the number of the smaller bridges requiring repair was and still is considerable, and...the Department is faced with a heavy task for their reconstruction" (Departmental Reports, 1916, 452). Similarly, for railways in 1916 it was noted that "ordinary expenditure exceeds last years by 11,334 pounds or 10.8%...to making good the damage caused by the flood rains" (Departmental Reports, 1916, 86). Moreover, the government was fearful of the effect that interruptions to inland traffic due to flooding was likely to have on local production. For example, the delay in transport could prove detrimental for producers of such rapidly decomposing

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[17] Also examples include "the Potosi Bridge in St. James [that] got badly damaged during the Flood rains, and...it was found necessary to re-design the bridge and completely rebuild"(Departmental Reports, 1916, 499) and "as a result of heavy rains, the northern abutement of the road bridge to the Water Valley Sliding failed and had to be rebuilt" (Departmental Reports, 1918, p.71).

fruits likely bananas and oranges and the deep ruts caused by floods and landslides injured transported fruits (House of Commons, 1900). Finally, government officials were aware of the likely fall in tax revenues due to flooding in "...that the characteristics common to all of them [Collectors of Taxes] was the threat of drought and flood, the hard times following their wake" (Departmental Reports, 1912, 65).

4.3 Data

4.3.1 Railways

We digitized and geo-referenced Railway lines and station locations by year of completion using the maps and information in Horsford (2011). These are depicted for the start (1895) and end (1925) of our period of analysis in Figure 4.1. In line with the outline of its evolution in Section 4.2.4, most of the network was already completed by 1895. More precisely, only 12.2% of the 185 miles had not been present. One may also want to note that the railway lines, except for the line between Kingston and Montego Bay, tended to connect the east to the west rather than the south to the north.

4.3.2 Roads

In order to geocode and time the location of main Roads over our period of analysis we digitised the available maps for the years 1895 (Thomas Harrison, 1895), 1905 (Public Works Department, 1905), and 1920 (Chamber of Commerce of the United States of America. Transportation and Communication Department Creator, 1920) and identified the date of placement of the post-1895 segments using information from the *Legislative Council Minutes*[18], the *Annual General Reports of Jamaica (Departmental reports)*[19], as well as The Laws of Jamaica (1895, 1896, 1898, 1911, 1924, 1925). The starting and ending period of the road network is depicted in Figure 4.1. While the majority of major roads already existed in 1895, there were considerable extensions over the next 30

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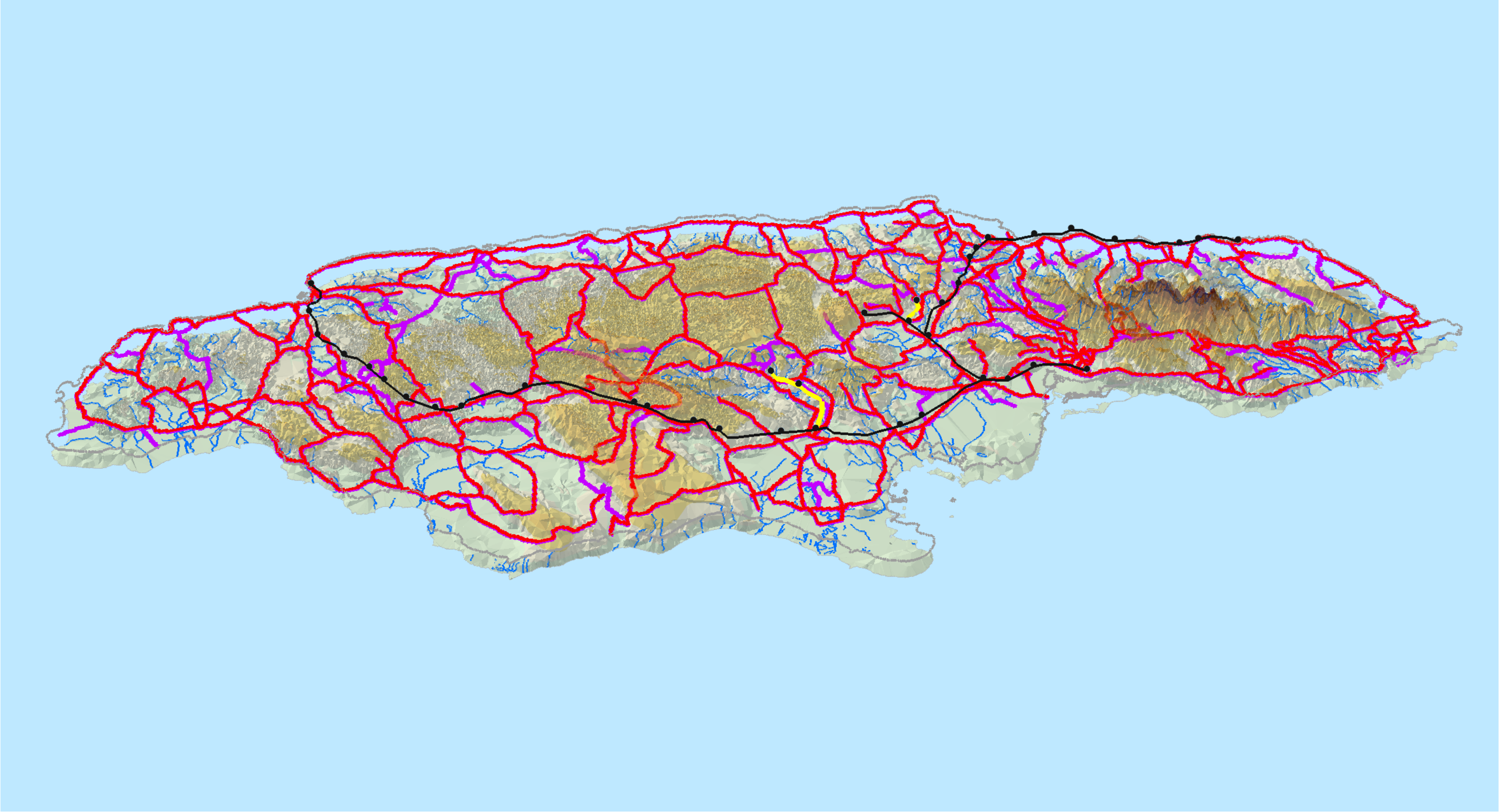
[18] Legislative Council of Jamaica (1893, 1895, 1896, 1897, 1898, 1899, 1906, 1914, 1924)

[19] Departmental Reports (1896, 1898, 1900, 1902, 1904, 1906, 1908, 1910, 1912, 1914, 1916, 1918, 1920, 1921, 1924, 1926)

years, where the road density increased from 2702 to 3259 km over this period, with additions across all parishes.

FIGURE 4.1: Evolution of Jamaican Railway and Road System (1895-1925)



Notes: (a) Black line is railway system in 1895, whereas yellow lines are additional lines by 1925; (b) Black dots are railways stations. Red lines are major roads in 1895; (c) Purple lines are additional major roads by 1925; (d) Railway lines and stations are elevated to 5000 meters and major roads to 4000 meters above sea level for visual purposes.

4.3.3 Floods

The annual *Report on the Transactions of the Public Works Department* lists the main roads that were affected by flood events as well as the location of the event, where the location was either given in terms of the specific town(s) or the towns between which the main road affected lied. This allowed us to identify the exact segment for any year that was affected by a flood event within the main road transportation network. As an example, we depict the transport network and the affected road segments for 1917 in Figure D.2. Accordingly, while large parts of Jamaica were affected in that year, some were spared. Moreover, these flood events tended to be very location, and hence road, specific.

Unfortunately, unlike for major roads, reports on the state of the railways over our sample period were only published intermittently and thus could not be used to consistently determine when and where the railway lines might have been impeded by flooding. In order to nevertheless identify the segments likely affected, we instead assumed that any railway line within 3km of major road segmented damaged by floods was also affected. We cross-checked this with the few reports that were available and this appeared to identify which railway segments were affected reasonably well.

The *Report on the Transactions of the Public Works Department* also contains information on the total annual parish level expenditure on main roads and maintenance costs, including spending due to flood damage and landslides. We use these to determine how long a flood event was likely to be impeding the transportation network.

4.3.4 Tax Revenues

Total Taxes

Unfortunately there are no annual parish level direct measures of economic outcomes, such as output, prices, wages, etc., available for Jamaica during our time period. We thus instead use total internal tax revenue as proxy for local economic activity, as gathered from the annual reports on *Customs and Internal Revenue*. In this regard internal tax collections generally constituted around 40% of total government revenue during our sample period, where the remainder was attributable to customs revenue from import (45%) and export (15%) duties. One should also note that by the end of our sample period income tax had not yet been introduced, and thus all revenue was extracted by the targeting of individual or enterprises economic activity or their ownership of tangible assets.

Tax Sub-Components

Tax revenue during the period of interest was collected from a number of sources, and these sources can arguably provide some insight into the sectoral composition of the parish economies. However, some of these taxes had only been introduced after or dropped before the end of our sample period, and thus do not cover our full sample period. We thus restrict our analysis to the components that existed and are consistently reported for our entire sample period (1895 to 1925).[20]

Firstly, any person in Jamaica owning or living on land as a tenant was obliged to pay a tax on the property, as set forth under Law 30 of 1867. Moreover, Law 10 of 1886 gave parishes the right to collect annual taxes on all houses based on their estimated value. As the revenue from the latter tax was to be used to finance regional provision of poor relief, it was implemented in all parishes.

Taxes were also due on the production of any distilled alcohol, liqueurs, or any other alcoholic compound, as set forth by the Rum Duty Law 10 of 1878. Noteworthy is that the tax only needed to be paid once the alcohol once was sold or consumed, and not while it was being stored.[21] Additionally, the non-producing establishments selling spirits were required to pay for an annual license, as set forth in the Law 18 of 1867 and further refined in Law 28 of 1896.

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[20] The excluded internal revenue sources include taxes on holdings, schools, transportation animals and vehicles, quit rents, hawkers' licenses, and gas, fire, and water rates.

[21] To take account of what was being stored, individuals producing alcohol had to complete an annual return quantifying the production, sale, consumption, and storage of their product(s).

A number of occupations in the services sector were required to purchase annual licenses from the colonial government to operate their profession. More specifically, Law 18 of 1867 required a licence for merchants, general factor dealers, wholesale dealers, storekeepers, commissioners, auctioneers, pawnbrokers[22], retailers (except spirits), wharfingers, and newspaper proprietors, for each premise where the business (including vessels) was conducted.

The agricultural sector was also taxed for certain purposes. In accordance with Law 26 of 1868 all land used for growing sugarcane, coffee, ginger, arrowroot, corn, ground nuts, cotton, tobacco, cacoa, provisions, pimiento, guinea grass, land in wood or ruinate, or land used for pasture were taxed at the same rate by acre. Additionally, persons buying or selling coffee, pimento, ginger, arrowroot, cocoa, dyewoods, or bananas had to pay to obtain a license, annually renewable, to do so for each premise of transaction. During the sample period, this law was extended to include the right to sell anywhere within the parish for which it was acquired, as well as to cover any trade in nutmeg, orange oil, oranges, shaddocks, grape fruit, other citrus fruit, and coconuts.

We digitalized the annual values by parish for the total tax revenue ($TOTAL$), as well as each of the its sub-components just outlined, i.e., revenue obtained from the property tax ($PROPT$), the house tax ($HOUSET$), rum duties ($RUMD$), spirit licenses ($SPIRITL$), trade licenses ($TRADEL$), and agricultural licenses ($AGRIL$), where these were all deflated to 1895 values. Since these sub-components only constitute a part of total tax revenue, we also summed them ($STOTAL$). Finally, as the *Customs and Internal Revenue* reports only provided the acres of agricultural land taxed rather than revenue collected, we used the total acres as a measure of taxes on cropland production ($CROP$).

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[22] Pawnbroker licenses were later covered by Law 24 of 1902.

4.3.5 Other Data

We generated two other parish level measures for our analysis. Firstly, we use the gridded GAEZ v4 Crop Suitability Index in Classes from Fischer et al. (2021) to capture each parish's suitability for the arguably four most important crops cultivated during out time period, namely sugar, banana, coffee and cassava. More precisely, the data classifies land areas in terms of their suitability for each of these crops according to a normalised suitability index (SI) ranging from 0 to 10,000, where higher values indicate greater suitability. We use the average value of SI of all cells whose centroid falls within a parish to proxy each administrative area's time invariant suitability for the four aforementioned crops. Secondly, we digitized the station level average monthly rainfall measurements from the monthly *Jamaica Weather Report* for each parish's capital and used these to proxy parish level average mean monthly rainfall for the years 1895 to 1925.

4.4 Methodology

4.4.1 Definition of Market Access

In terms of measuring the market access ($MA^{\mathbf{NF}}$) of each parish to other potential (parish) markets via the transportation network we follow Donaldson and Hornbeck (2016) and define it as:

$$MA_{it}^{\mathbf{NF}} = \sum_{d \neq i} \tau_{idt}^{-\theta} N_{dt} \tag{4.1}$$

where i, d, and t denote origin parish, destination parish, and year, respectively. τ is the cost of transporting goods from origin parish i to destination parish d and θ is the trade elasticity, while N is the population size of destination parish d. As in Donaldson (2018) we proxy τ as:

$$\tau_{idt} = LCP_{idt}\Big(\mathbf{R}_t, \mathbf{ff}\Big) \tag{4.2}$$

where LCP is the least cost path (LCP), i.e., the lowest cost effective distance, between some central point in origin parish i and some central point in destination parish o. In this regard, LCP is assumed to depend on the transportation network $\mathbf{R}$, as well on the relative cost $\mathbf{ff}$ of travelling along possible routes to transport goods between the central points according to the mode of transport. Since, as we argued above, coastal transport was not really a feasible option in Jamaica, we only consider the railway and roads so that $\mathbf{ff} = \Big(\alpha_{rail}, \alpha_{road}\Big)$, where we normalize $\mathbf{ff}$ by the relative cost of using the railways so that $\alpha_{rail} = 1$.

In terms of incorporating the impact of flooding within the transportation network on the market access of a parish it is helpful to think of this network as a collection of nodes and arcs, where a (or several) flood incidence(s) within a year may temporarily *shut off* one or more of the arcs connecting the nodes. We distinguish the transportation network during such a flood year as $\mathbf{R}_t^{\mathbf{F_t}=1}$, whereas when there is no flooding impeding the network it is $\mathbf{R}_t^{\mathbf{F_t}=0}$. Importantly, different segments of the network over time and space may be shut off when $\mathbf{F_t} = \mathbf{1}$ and thus $\mathbf{R}_t^{\mathbf{F_t}=1}$ can vary across years even if $\mathbf{R}_t$ remains the same. Thus one can think of the market access measure in Equation (4.1) as one ignoring any network disruption during flooding and re-write it as $MA_{it}^{\mathbf{NF}}$ based on rail network $\mathbf{R}_t^{\mathbf{NF}}$, while defining it when taking account of flooding as $MA_{it}^{\mathbf{F}_t=0,1}$ with rail network $\mathbf{R}_t^{\mathbf{F}_t=0,1}$. The loss in market access due to flooding (FMA_{it}) can then be denoted as:

$$FMA_{it} = MA_{it}^{\mathbf{NF}} - MA_{it}^{\mathbf{F}_t=0,1} \tag{4.3}$$

where $FMA_{it} \geq 0$.

4.4.2 Calculation of Market Access

There are four necessary inputs for calculating the market access measures in Equation 4.3, namely the time varying transportation networks $\mathbf{R}_t^{\mathbf{NF}}$ and $\mathbf{R}_t^{\mathbf{F}_t=0,1}$, the relative cost of road travel α_{road}, the trade elasticity δ, and the time varying parish level populations N_t. To calculate structural changes in the extent of the network over time ($\mathbf{R}_t^{\mathbf{NF}}$) we created a set of connecting arcs and nodes using the geo-referenced maps of railways and the major roads described in Section 4.3. Since, as argued earlier, the railway and roads were compliments rather than substitutes in our context, we considered these as part of a general network. To determine the network under potential flood events ($\mathbf{R}_t^{\mathbf{F}_t=0,1}$) we *shut off* those road segments in the network that were affected by a flood as well as those on the railway lines that were within 1km of these road segments.

As is apparent from the discussion in Section 4.2.5, the complexity of the Jamaican agrarian economy and its transport needs, as well as the lack of sufficient data, makes it difficult to determine the actual relative costs of railroad versus road transportation of goods. We thus, instead, assume the relative cost to be 4.5 times higher for roads than railways, i.e., in line with Donaldson (2018) for India for the period 1870 to 1930.[23] To put this value into context, using the railway price structure for passengers and the cost of travelling by livery buggy, as well as the opportunity cost of the time difference implied by the average wage, then for a trip from Kingston to Port Antonio for such a cost difference would make a traveller indifferent between in relative cost of travelling by train rather than by road if he/she had 45 lbs of goods to carry in 1895 and 59 lbs in 1925. While, as noted earlier, we do not have sufficient information to do similar calculations in terms of freight transport for most of our sample period, for the 1920s if one considers the freight costs on the Kingston to Richmond route noted in Section 4.2.4, then $\alpha_{road} = 4.5$ would mean the same amount spent sending 2.7, 1.4, and 1.1 tons of ground provision, sugar, and coffee, respectively, by train or road. If

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[23] One may want to note in this regard that the first Jamaican railway line was built only nine years after that of India (1835) and thus is likely to have been of similar technology.

we assume a two ton goods limit for livery buggies, one would suspect that particularly for the large sugar and coffee, and likely also banana, estates, that sending much larger quantities by railroad would have been the much less costly option if α_{road} was at least 4.5. For example, using data on average sugar estate production from Huesler and Strobl (2024a) suggests that these over our sample period produced on average 170 tons of sugar per year.[24] Nevertheless, given the importance of small scale farming where the farmers or higglers brought their much smaller quantities of goods to markets themselves rather than sending them by freight transport, we also experimented with setting $\alpha_{road} = 1$.

We assume the trade elasticity δ to be 2.788 as Hornbeck and Rotemberg (2021), but also explored using values of 1.815 and 8.22 as the authors did. To approximate N_{it} we use the HYDE 3.2.1 gridded population database, which provides decennial gridded population counts at the 0.1 degree level (Klein Goldewijk et al., 2017). These data are used to determine the most populous point within a parish in the relevant decade from which to calculate market access.[25]

With all inputs at hand we next assumed that the baseline cost of moving along this network is contingent on the elevation of each segment, following Lewis (2021). The consequent LCP calculations between the parish central points were then carried out using the *leastcostpath* package in *R*. This provided us with annual market measures for FMA_{it}, $MA_{it}^{\mathbf{NF}}$, and $MA_{it}^{\mathbf{F}_t=0,1}$.

4.4.3 Empirical Specification

We first estimate the effect of market access on parish-level local economic activity ignoring the possibly impeding effect of floods on the transport network:

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[24] The data are given in hogsheads, where one hogshead weighs roughly 812kg.

[25] One should note that these always were the main towns in each parish and did not change over our sample period.

$$log(Y_{it}) = \alpha + \sum_{j=0}^{\rho} \beta_{MA^{\mathbf{NF}}_{t-j}} MA^{\mathbf{NF}}_{it-j} + \sum_{j=0}^{\rho} \beta_{\mathbf{X}_{t-j}} \mathbf{X_{it-j}} + \mu_i + \lambda_t + \gamma TREND_{it} + \epsilon_{it} \tag{4.4}$$

where Y is our local economic activity proxy as derived from tax data, $MA^{\mathbf{NF}}$ is the market access measure ignoring flooding, μ_i and λ_t are parish and year fixed effects, respectively, and $TREND$ are parish level time trends, while $\mathbf{X}$ are a vector of additional time varying parish level controls. One should note that we allow for up to ρ lagged effects of $MA^{\mathbf{NF}}$ and the additional controls in $\mathbf{X}$. Standard errors are modelled as robust to hetereoskedasticity.

We further decompose market access in the regression specification (4.4) into its flood accounting equivalent ($MA^{\mathbf{F=0,1}}$) as well as the loss in market access due to flooding (FMA) as determined by the identity in Equation 4.3:

$$\begin{aligned} log(Y_{it}) = \alpha + \sum_{j=0}^{3} \beta_{MA^{\mathbf{F=0,1}}_{t-j}} MA^{\mathbf{F=0,1}}_{it-j} + \sum_{j=0}^{3} \beta_{FMA_{t-j}} FMA_{it-j} + \sum_{j=0}^{\rho} \beta_{\mathbf{X}_{t-j}} \mathbf{X_{it-j}} \\ + \mu_i + \lambda_t + \gamma TREND_{it} + \epsilon_{it} \end{aligned} \tag{4.5}$$

A main worry in terms of the causal interpretation of $\beta_{MA^{\mathbf{NF}}}$ or $\beta_{MA^{\mathbf{F=0,1}}}$ is that, even after controlling for parish level and year specific fixed effects, as well as parish level trends, the placement of railway lines and the declaration of roads as 'major' to be funded by the colonial government could be correlated with shocks that affect local economic activity. While such transportation infrastructure decisions are not likely to be a problem in terms of FMA since flood events are arguably temporally and spatially largely unpredictable particularly after controlling for parish level fixed effects which would capture their local distribution, extreme precipitation incidences might be correlated with general climatic variations relevant to local agricultural production, the primary driver of local economic production. To capture such economic shocks we include parish mean rainfall as well as its interaction with sugar, coffee, bananas, and cassava suitability in $\mathbf{X}$ to capture crop level differences in water needs.

Finally, we need to determine the number of lags ρ of $MA^{\mathbf{NF}}$, $MA^{\mathbf{F=0,1}}$, and FMA to include in specifications (4.4) and (4.5). Since our main coefficients of interest is $\beta_{FMA_{t-j}}$, i.e, the impact of flooding events on market access, we would want to know how long a damaging flooding event is likely to impede the affected segment of the transportation network. To roughly ascertain this with the available data we investigate how long such events induce greater road expenditure for flood repairs. More specifically, we regress the inverse hyperbolic sine of parish level annual expenditure on flood damage of roads ($COSTFLOOD$) on the number of flood events within a parish, controlling for parish and yearly fixed effects, as well as parish level trends. The results of doing so, systematically including up to four lags, is shown in Table 4.1. As can be seen, road maintenance expenditure increases in the two years after flood events, with quantitative effects of increases expenditure by 28.9 and 23.6 per cent in $t-1$ and $t-2$, respectively. It thus seems reasonable to set $\rho = 3$ to ensure that the lag structure captures all delayed transportation network effects of floods in specifications (4.4) and (4.5).

TABLE 4.1: Impact of Flood Events on Road Expenditure for Flood Repair

Model:	(1)	(2)	(3)	(4)	(5)
$FLOOD_t$	0.0161	0.0150	0.0541	0.0538	0.0673
	(0.1336)	(0.1306)	(0.1301)	(0.1306)	(0.1308)
$FLOOD_{t-1}$		0.3953^{***}	0.3928^{**}	0.3977^{***}	0.3955^{***}
		(0.1519)	(0.1523)	(0.1501)	(0.1492)
$FLOOD_{t-2}$			0.3241^{**}	0.3228^{**}	0.3341^{**}
			(0.1397)	(0.1396)	(0.1374)
$FLOOD_{t-3}$				0.0486	0.0401
				(0.1334)	(0.1324)
$FLOOD_{t-4}$					0.1655
					(0.1271)
Observations	371	371	371	371	371
Within R^2	0.14365	0.16359	0.17717	0.17748	0.18096

Notes: (a) Dependent Variable as is the inverse hyperbolic sine transformation of $COSTFLOOD$; (b) Parish and time specific fixed effects, as well as are included in all regressions; (c) ***, **, and * indicate 1, 5, and 10 percent significance levels, respectively; (d) Standard errors are clustered at the parish level.

4.5 Results

4.5.1 Descriptive Statistics

Table 4.2 provides summary statistics for the parish level main variables used in our analysis. Accordingly, the mean parish level total tax revenue is about £24,000, i.e., about 8 Shilling per capita given the parish level population size over our sample period. In terms of our tax revenue sources measured in monetary values, they constitute about 57% of the actual total. Of these, rum duties are the largest source (47%), while agricultural licenses bring in the least amount of revenue (1.9%). In general, taxes on property and houses are a much more important source of government income than licenses fees required for persons conducting certain trades. Figure D.3 shows the temporal evolution of total tax revenue as well as the sub-components. As an be seen, while volatile, total revenue from taxes does not seem to be on any noticeable trend over our sample period. Moreover, the sum of sub-components appears to follow a very similar pattern to the island's total tax collected. Looking at the temporal trends of the individual sub-components, their respective shares seem not to have changed much over the 30 years of our data.

TABLE 4.2: Summary Statistics

Statistic	N	Mean	St. Dev.	Min	Max
$TOTAL$	371	23,781.11	30,200.11	5,473.75	173,730.75
$STOTAL$	371	13,586.88	19,351.03	58.89	103,533.25
$HOUSET$	371	3,654.19	3,700.40	0.00	21,478.73
$PROPT$	371	2,118.27	942.83	0.00	5,819.96
$RUMD$	371	6,441.32	14,945.07	0.00	75,578.36
$SPIRITL$	371	905.10	642.33	0.00	3,130.22
$TRADEL$	371	311.13	384.81	0.00	2,200.90
$AGRIL$	371	263.29	211.88	22.43	1,243.34
$CROPS$	371	139,700.01	63,274.46	0.00	293,450.00
$FLOOD$	371	0.73	1.57	0.00	10.00
$COSTFLOOD$	371	485.68	895.65	0.00	7,499.80
$MA^{\mathbf{NF}}$	371	26.25	1.44	23.84	31.73
$MA^{\mathbf{F}=0,1}$	371	26.19	1.44	23.84	31.69
FMA	371	0.05	0.18	0.00	1.84
$FMA \neq 0$	255	0.08	0.21	0.00	1.84

Notes: (a) *TOTAL* is total revenue, *AGRIL* are revenues from Agricultural Buyer's Licences, *TRADEL* are Trade Licences, *RUMD* are Rum Duties, *SPIRITL* are Spirit Licences, *HOUSET* are Parish Rates, *PROPT* are Property Taxes, *CROPS* are Acres of land taxed for agricultural purposes. *STOTAL* is the sum of the revenue from *HOUSET, PROPT, RUMD, SPIRITL, TRADEL, and AGRIL*: (b) *COSTFLOOD* is expenditure on repairs of roads damaged by flooding, and *FLOOD* is the number of flood events in a parish; (c) $MA^{\mathbf{NF}}$ is total market access ignoring flood disruptions, $MA^{\mathbf{F}=0,1}$ is market access taking account of disruptions due to flooding, and FMA are flood induced reductions to market access, where all market access variables are calculated using θ = 2.788 & α =4.5.

Examining the annual number of flood events in a parish ($FLOOD$) in Table 4.2 indicates that on average a parish experiences close to one event (0.72) annually, but that this can vary substantially, with some zero-event years and two parishes, Saint Ann and Saint Catherine, having experienced as much as 10 floods in a single year. Figure D.4 further depicts the temporal share share of the fourteen Jamaican parishes that were affected by at least one flood per year. Accordingly, the number of regions affected varies substantially from year to year, with two years with no incidence (1896 and 1925) and all regions affected in 1915. In general, there appears to be a slight downward trend in the share affected. Examining the average number of floods island wide and by parish in Table D.1 shows that flood events impeding the transport system were common in Jamaica, with about 10 per year across the island. Moreover, some parishes were much more affected than others, where Trelawny was the least stricken (0.15 per year) and Portland the most (2.88). Noteworthy is that the three most affected parishes (Portland, Saint Mary, and Saint Thomas) lie in the eastern part of the island.

Table 4.2 also provides the total spending to repair road damages due to flooding. Accordingly, flood related road expenditure averaged about £486 in a parish annually. The island wide and parish specific figures, normalized by cost per mile of road, in Table D.1 indicate that on average just over £6,000 were spent annually per mile to repair roads after flood damage. The highest expenditure over our sample period was in Saint Mary (£1,131), while the least amount was spent in Kingston (£2.29). Other high spenders include Portland (£912), Saint Andrew (£871), and Saint Catherine (£804). In terms of total maintenance costs, on average island wide 8.4% was for flood repairs. Across parishes most of maintenance cost was dedicated to flood damages in Saint Catherine (14.6%), with Manchester being the lowest spender (1.8%).

Finally, the last four rows of Table 4.2 provide descriptive statistics for our market access proxies. As can be seen, MA has considerable variability in our data, ranging from 23.84 to 31.73. Taking account of disruptions due to flood events (MFA) reduces its mean only marginally (0.22%), which is not surprising given that $FMA \neq 0$ is only

0.08. One may also want to note that of our total data set 31.6% parish-years have no market access disrupting event.

4.5.2 Econometric Results

Total Tax Revenue

Table 4.3 Panel A shows the results of estimating equation (4.4) using various trade elasticity values θ. As can be seen, changes in market access through the transportation network ($MA^{\mathbf{NF}}$) has a significant and positive impact on total tax revenue the following year ($t-1$). The coefficient size varies with the assumed elasticity, where it is slightly less precisely estimated when we assume this to be low (1.815). One may also want to note that the R^2 is highest when one lets $\theta = 2.788$. Using the coefficient estimates of this latter specification implies that a standard deviation in market access (10.35) increases local economic activity, as captured by total tax revenue generated, by 4.2%.

TABLE 4.3: Impact of Market Access on Total Tax Revenue

Panel A

	(1)	(2)	(3)
θ	1.815	2.788	8.22
Variables			
$MA_t^{\mathbf{NF}}$	0.0016	0.0012	2.78×10^{-5}
	(0.0026)	(0.0011)	(0.0003)
$MA_{t-1}^{\mathbf{NF}}$	0.0064**	0.0040**	0.0007**
	(0.0032)	(0.0015)	(0.0004)
$MA_{t-2}^{\mathbf{NF}}$	0.0023	0.0016	0.0003
	(0.0029)	(0.0011)	(0.0002)
$MA_{t-3}^{\mathbf{NF}}$	-0.0003	0.0009	-2.88×10^{-5}
	(0.0025)	(0.0010)	(0.0003)
Observations	371	371	371
Within R^2	0.09346	0.11020	0.09369

Panel B

	(1)	(2)	(3)
θ	1.815	2.788	8.22
FMA_t	-0.1741**	-0.0883***	-0.0177**
	(0.0715)	(0.0312)	(0.0072)
FMA_{t-1}	-0.2086**	-0.0781*	-0.0162*
	(0.0957)	(0.0419)	(0.0091)
FMA_{t-2}	-0.0085	-0.0297	-0.0151**
	(0.0929)	(0.0384)	(0.0076)
FMA_{t-3}	-0.1329	-0.0623	-0.0217**
	(0.1172)	(0.0414)	(0.0090)
$MA_t^{\mathbf{F=0,1}}$	0.0010	0.0010	2.68×10^{-5}
	(0.0026)	(0.0011)	(0.0003)
$MA_{t-1}^{\mathbf{F=0,1}}$	0.0059*	0.0040**	0.0008**
	(0.0032)	(0.0016)	(0.0004)
$MA_{t-2}^{\mathbf{F=0,1}}$	0.0023	0.0015	0.0003
	(0.0028)	(0.0011)	(0.0002)
$MA_{t-3}^{\mathbf{F=0,1}}$	-0.0010	0.0008	-4.25×10^{-5}
	(0.0027)	(0.0010)	(0.0003)
Observations	371	371	371
Within R^2	0.11016	0.11026	0.11026

Heteroskedasticity-robust standard-errors in parentheses
*Signif. Codes: ***: 0.01, **: 0.05, *: 0.1*

Notes: (a) Dependent variable is the inverse hyperbolic sine transformation of total tax revenue; (b) Parish and time specific fixed effects, parish specific time trends, and mean annual rainfall as well as its interaction with sugar, cassava, banana, and coffee suitability measures are included in all regressions; (c) ***, **, and * indicate 1, 5, and 10 percent significance levels, respectively; (d) Standard errors are clustered at the parish level; $\alpha = 4.5$ for all specifications.

The results of decomposing $MA^{\mathbf{NF}}$ into its non-flooded measure as well as the extent of market access that is impeded by flooding are displayed in Panel B. As in Panel A, the level of precision on the significant coefficient of $MA^{\mathbf{F}=0,1}$ and the R^2 are slightly higher for $\theta = 2.788$. In terms of the estimated coefficients one should note the 'effective' market access measure impacts are very similar to those ignoring the impact of flooding regardless of trade elasticity. Thus, not taking account of changes in market access due to these extreme climate shocks does not necessarily lead to any noticeable measurement error in its impact on local economic activity. Importantly, however, the reduction in market access due to flooding has a direct negative impact on total taxes collected. More specifically, the coefficients on FMA are negative and significant in the year of the flooding and this lasts until the subsequent year for all values of θ. Taking the estimated coefficients at face value for $\theta = 2.788$, the average reduction in market access when a flood event occurs within the transport network system decreases parish tax revenue by 1.4%, while the largest observed shock over our sample period implies a 3.7% fall in the first year, with analogous effects of 2.1 and 5.4% respectively for $t - 1$.

In order to also see how sensitive the results are to the choice of the relative transport cost parameter α and trade elasticity θ, we re-ran specifications (4.4) and (4.5) for various combinations of these parameters; see Table D.2. Accordingly, results are fairly similar if we assume the same transport cost of travelling on roads and railways, regardless of the chosen trade elasticity. However, once we assume that travelling on roads is more than ten times larger than on railways, the positive impact of market access disappears, regardless of whether we take account of changes to it during flood events or not. The negative impact of the reduction in market access through floods is also somewhat sensitive to the assumed value of relative costs, although one always finds an immediate and sometimes a lagged effect on total tax revenue. Overall these supplementary regressions suggest that assuming a too high value of α may not accurately reflect the actual cost of roads relative to railways as a mode of transport. For the remainder of the analysis we will thus continue to assume $\alpha = 4.5$ and $\theta = 2.788$.

Tax Revenue Components

We next try to gain insight into how changes in market access due to flooding may have affected different sectors of the local parish economies by decomposing tax revenue into some of its sources. In this regard, we first aggregated the available monetary components into their total, since as noted earlier, the ones used do not capture the entire tax revenue pie. The results of this are given in the first column for our two regression specifications in Table 4.4. As can be seen from Panel A, this sub-total ($STOTAL$) also suggests that market access $MA^{\mathbf{NF}}$ measured ignoring flood events increased local economic activity at $t-1$, although the estimated effect is on average somewhat lower (4.1%). In terms of decomposing market access into its effective measure after taking account of the impeding effect of flood on the transport network system (see Panel B), as with total tax revenue there is no noticeable change in the coefficient on market access. Examining FMA for the sub-total one again finds that reductions in the network reduced the total of tax revenue of the captured components in t and $t-1$, although the estimated impact is also smaller, namely 0.7 and 0.6%, respectively, for the average reduction. Thus it appears that the tax components for which we have sufficient data may in net aggregate have been less affected than the omitted tax sources by flooding disruptions.

TABLE 4.4: Impact of Market Access on Total Tax Revenue Components

Panel A: MA

Dependent Variables:	STOTAL	HOUSET	PROPT	RUMD	SPIRITL	TRADEL	AGRIL	CROPS
Variables								
MA_t	0.0012	0.0184**	0.0185**	0.0184***	0.0141**	0.0114**	0.0034*	-0.0059
	(0.0011)	(0.0089)	(0.0082)	(0.0064)	(0.0068)	(0.0055)	(0.0017)	(0.0071)
MA_{t-1}	0.0040**	0.0215**	0.0219***	0.0182***	0.0164**	0.0130**	0.0045**	-0.0039
	(0.0015)	(0.0089)	(0.0082)	(0.0054)	(0.0068)	(0.0054)	(0.0018)	(0.0071)
MA_{t-2}	0.0016	0.0140	0.0138*	0.0159***	0.0100	0.0088	0.0017	0.0017
	(0.0011)	(0.0089)	(0.0082)	(0.0051)	(0.0068)	(0.0054)	(0.0019)	(0.0075)
MA_{t-3}	0.0009	0.0110	0.0100	0.0139***	0.0099	0.0079	0.0034*	0.0029
	(0.0010)	(0.0086)	(0.0079)	(0.0049)	(0.0066)	(0.0054)	(0.0018)	(0.0068)
Within R^2	0.11020	0.05641	0.06728	0.11049	0.05543	0.05345	0.11017	0.05040

Panel B: FMA

Dependent Variables:	STOTAL	HOUSET	PROPT	RUMD	SPIRITL	TRADEL	AGRIL	CROPS
Variables								
FMA_t	-0.0883***	-0.4016	-0.3746	-0.1875	-0.2105	-0.2449	0.0044	0.3071
	(0.0312)	(0.2691)	(0.2524)	(0.2670)	(0.2251)	(0.1835)	(0.0773)	(0.2140)
FMA_{t-1}	-0.0781*	-0.5548*	-0.5505**	-0.3618	-0.3436	-0.3619*	-0.0003	0.5558*
	(0.0419)	(0.2843)	(0.2775)	(0.2667)	(0.2344)	(0.1953)	(0.0882)	(0.3215)
FMA_{t-2}	-0.0297	-0.8131**	-0.8395**	-0.3460	-0.6294**	-0.5884***	0.2015**	0.5192*
	(0.0384)	(0.3432)	(0.3379)	(0.2391)	(0.2748)	(0.2226)	(0.0866)	(0.2902)
FMA_{t-3}	-0.0623	-0.6660*	-0.7136*	-0.1301	-0.5089	-0.4287*	0.1680	0.6687*
	(0.0414)	(0.3964)	(0.3879)	(0.2782)	(0.3113)	(0.2488)	(0.1151)	(0.3922)
MAF_t	0.0010	0.0171**	0.0178**	0.0173**	0.0133**	0.0106**	0.0036**	-0.0051
	(0.0011)	(0.0087)	(0.0079)	(0.0065)	(0.0066)	(0.0053)	(0.0017)	(0.0069)
MAF_{t-1}	0.0040**	0.0205**	0.0209**	0.0176***	0.0156**	0.0123**	0.0047**	-0.0028
	(0.0016)	(0.0088)	(0.0081)	(0.0057)	(0.0068)	(0.0054)	(0.0019)	(0.0068)
MAF_{t-2}	0.0015	0.0115	0.0112	0.0154***	0.0080	0.0071	0.0025	0.0032
	(0.0011)	(0.0088)	(0.0081)	(0.0055)	(0.0066)	(0.0053)	(0.0019)	(0.0069)
MAF_{t-3}	0.0008	0.0112	0.0100	0.0143***	0.0097	0.0082	0.0033*	0.0036
	(0.0010)	(0.0086)	(0.0080)	(0.0054)	(0.0066)	(0.0054)	(0.0019)	(0.0063)
Observations	371	371	371	371	371	371	371	371
Within R^2	0.12496	0.08407	0.09921	0.11920	0.07525	0.08635	0.12657	0.08215

Notes: (a) Dependent variables are the inverse hyperbolic sine transformations of each tax revenue component; (b) Parish and time specific fixed effects, parish specific time trends, and mean annual rainfall as well as its interaction with sugar, cassava, banana, and coffee suitability measures are included in all regressions; (c) ***, **, and * indicate 1, 5, and 10 percent significance levels, respectively; (d) Standard errors are clustered at the parish level; (e) $\alpha = 4.5$ and $\theta = 2.788$ for all specifications.

The remainder of the columns in Table 4.4 contains the results on the components of taxes analysed. As with the sub-total of the monetary sources, the general net impact of market access is very similar regardless of whether one takes account of flooding or not, for all sub-components. Examining taxes from housing shows that market access increased the derived revenue at both t and $t-1$, with mean quantitative effects of 17.6 and 21.2%, respectively. The impact of property taxes is similar to that of housing, i.e., with analogous rises of 18.4 and 21.8%. More importantly, the loss in access to market due flooding resulted in drops of housing and property tax revenue, with similar mean quantitative impacts of around 4.4% at t and 6.4% at $t-1$. Thus, the findings on these two types of taxes suggest that while property ownership benefited from greater market access, the land property sector was susceptible to flooding affecting the transportation network within Jamaica. Whether this was a result of less property ownership expansion, a failure to pay taxes on existing ownership, or property abandonment unfortunately cannot be discerned from the available data.

Looking at the the fourth column of Table 4.4, market access was particular beneficial for alcohol production, as suggested by the duties collected for this derivative of sugarcane processing. More specifically, an increase in market access through a more connected network increased rum duties for the contemporary and the complete set of lags of $MA^{\mathbf{NF}}$, continuously contributing a yearly around 0.1%.[26] Since in Jamaica rum was the primary alcohol produced, but much of it was exported (Smith, 2008)[27], it is likely that the island wide investments in transportation reduced the cost of transporting rum to the main exporting ports, such as Kingston or Port Antonio, or facilitated the location of rum distilleries further away from these, where property prices are likely to have been lower. Importantly, however, any disruptions in the transportation network through flooding did not reduce the amount of rum duties collected in a parish. One may want to note in this regard, that, as outlined earlier, rum duties

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[26] Including a further three lags, albeit at the cost of reducing the sample size, suggested that at most there was still a marginally significant impact at $t-4$, but with an estimated impact about half that at t.

[27] For example, in the late 19th century over 80 per cent of rum produced was exported; see Smith (2008).

were only collected on alcohol consumption or sale rather than on any amount stored after production. Thus the lack of impact does not necessarily mean that a reduction in local rum production was not a consequence of the disruption, since internal sales or exports could be satisfied by repleting existing stocks.

Examining taxes from licences to sell spirits in the fifth column, one discovers that increasing market access induced a rise in their purchase for the first two years, with average impacts of 14.2 and 16.6%. When a flood affected the transportation network, however, the number of spirit licences fell two years after the event by 3.7 per cent for both. Data on all spirits imported for consumption, as well as on rum production, export, and consumption figures from the *Departmental Reports* and Smith (2008) suggest that over our sample period it was mostly rum that was being consumed in the premises selling spirits.[28] Since the result above for rum duties did not indicate any impeding impact after flooding, the drop in spirit licenses suggests a possible consolidation of the number of selling premises rather than a drop in local demand for rum.

As with spirits, trade licenses experienced an increase in the first two years of an expansion of the transport network, where the impacts are somewhat smaller, i.e., 10.9 and 12.7%; see Column 6 of Table 4.4. The impeding effect of flooding disruptions were, however, more immediate, showing up already a year after the shocks, and more persistent, with significant coefficients on all three lags.[29] The implied quantitative average reductions are 2.9, 4.7, and 3.4%, respectively.

Those selling and buying agricultural produce also benefited from investment in the internal transport system through market access, as indicated by the estimates for agricultural licenses in the penultimate column of Table 4.4. The increases similarly occurred in the first two years, but were considerably smaller than for the other service

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[28] For example, for the 1890s rum constituted about 97% of all spirits consumed within Jamaica.

[29] Including lags up to $t-6$ of FMA with a reduced sample size suggested that any impact did not last beyond these first three years.

sectors, namely 3.7% for t and 4.9% for $t-1$. However, flood disruptions to the network actually increased the number of licences two years later, suggesting that more costly transportation to other parishes was beneficial to local trading activity in the agricultural products covered by the licenses. The quantitative impact is a 1.6% rise in revenue after a typical disruption.

The last column, displaying the estimates on the total acres of cropland for which taxes had to be paid, allows us to also gauge the effects of market access and flooding on the local production of crops. In particular, we firstly find that greater internal market access did not increase the acreage of cropland for which taxes were collected. This result stands in contrast to Chan (2022), who finds for the US that railroad expansion in the late 19^{th} century led to an expansion of local output and acreage. However, Chan (2022) also demonstrated that the increase in output and acreage was not due to regional comparative advantage in specific crops, but rather because of an improved use of farming inputs, namely increases in rural labor, improved farmland, and more valuable capital employed. One may want to note that such improvements in agricultural input use would have been less likely in Jamaica during our sample period given that agricultural employment consisted mostly of small scale farmers tied to their farms, and any substantial improvements in farmland use and capital stock would have likely been hampered by access to finance.[30] These aspects of the Jamaican agricultural sector at the time could possibly provide an explanation for the lack of beneficial effects of market access if similarly this meant no spillovers on the local production of crops for which there was a local natural advantage. It could also be that since the agricultural sector consisted mainly of small scale farms, many of these were likely not directly connected to major roads or the railways network and thus could not gain any substantial reduction in transportation costs from it.

As with licences to purchase and sell agricultural products, the estimates on FMA in the last column suggest that reduced market access through flooding of transport

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[30] For instance, Huesler and Strobl (2024a) show that technological adoption in the sugar industry over the period was severely laggard compared to the state of the art, in large part due to a lack of access to finance.

infrastructure increased total local cropland. Here the effect is more immediate, starting a year after the flood, and is significant for all included lags, with average rises of 4.4, 4.2, and 5.3%, respectively.[31] Thus while permanent increases in market access did not manifest themselves in discernible benefits, at least within the first few years, any temporary disruptions in the existing inter-regional transport costs due to flood damages to the network increased local agricultural product and the number of local agricultural traders. One possibility is that these disruptions in the network caused temporary price differences, as suggested by the findings of Burgess and Donaldson (2012) for India's railway expansion, which resulted in planting crops on marginal land and subsequent greater trading activity in local agricultural markets.

4.6 Conclusion

Investments in the road and railway infrastructure was seen as important means to stem the slow decline of the sugar industry and encourage the growth of other agricultural sectors in late 19^{th} and early 20^{th} century colonial Jamaica. However, the geography and climatology of the island also made the Jamaican internal transport system susceptible to damages arising from flooding due to heavy, and frequent, rainfall. To explore empirically how such disruptions might have impacted any benefits local regional economies derived from greater regional integration through reduced transport costs, we assembled a parish level, time varying data set of the road and railway network, transport disrupting flood events, and local economic activity proxied by tax revenue data.

The results from our econometric analysis show that while local economies benefited from the increased market access enabled by the investments in the internal transport system, flooding induced damages to it partially impeded such gains. In particular, flooding caused regional economic losses of around 5.4% and in some incidences up to 9.1% over two years. Dis-aggregating the tax revenue data by source indicated

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[31] Further lags with a reduced sample size were not significant.

that this flooding eroded the economic benefits particularly in the property and the non-agricultural service sectors. In contrast, the disruptions had a positive impact on local agricultural traders and crop cultivators, although it must be noted that only the former seemed to enjoy any general gains from greater market access from the transport network. One possible reason could be that regional crop price variations as a result of the disruption might have encouraged temporary cultivation of marginal lands.

While the general consensus appears to be that early investments in transport infrastructure have been beneficial for regional economies in the past, our paper provides first evidence that such gains were likely partially impeded in settings where the transport infrastructure was susceptible to extreme climate. One could also argue that our findings have broader implications for today's developing world, where investment in transport infrastructure is still seen as a crucial means to greater national and regional growth (De Soyres, Mulabdic, and Ruta, 2020; Saidi et al., 2020). More specifically, although modern transport systems are of course much more equipped to deal with any extreme climate shocks compared to the days of colonial Jamaica, the reliability of the transport system is still pertinent for its success (Rozenberg et al., 2019), and this remains a problem in many developing countries (Brooks and Donovan, 2020; Schweikert et al., 2020; Dube, Nhamo, and Chikodzi, 2022; Andreasen et al., 2023).

Appendix A

Tropical Storms Colonial Bank

TABLE A.1: Economic Structure

Country	Year	Sugar	Rum	Cacao	Bananas	Oils	Gold	Total Exports
Antigua	1922	0.97	0.00	0.00	0.00	0.00	0.00	813,512.00
Barbados	1922	0.55	0.00	0.00	0.00	0.00	0.00	4,041,108.00
Dominica	1922	0.00	0.00	0.14	0.00	0.00	0.00	329,698.00
Grenada	1922	0.00	0.00	0.68	0.00	0.00	0.00	1,081,278.00
Guyana	1922	0.55	0.01	0.00	0.00	0.00	0.01	11,695,033.00
Jamaica	1922	0.24	0.02	0.04	0.48	0.00	0.00	16,599,194.00
St.Kitts	1922	0.89	0.00	0.00	0.00	0.00	0.00	691,085.00
St.Lucia	1922	0.62	0.00	0.25	0.01	0.00	0.00	484,226.00
St.Vincent	1922	0.10	0.00	0.15	0.00	0.00	0.00	58,326.00
Trinidad & Tobago	1922	0.33	0.00	0.34	0.00	0.22	0.00	15,482,508.00
Antigua	1927	0.98	0.00	0.00	0.00	0.00	0.00	1,798,807.00
Barbados	1927	0.66	0.00	0.00	0.00	0.00	0.00	6,052,231.00
Dominica	1927	0.00	0.00	0.30	0.00	0.00	0.00	300,114.00
Grenada	1927	0.00	0.00	0.65	0.00	0.00	0.00	2,277,285.00
Guyana	1927	0.57	0.03	0.00	0.00	0.00	0.01	15,506,812.00
Jamaica	1927	0.18	0.02	0.04	0.54	0.00	0.00	21,165,300.00
St.Kitts	1927	0.98	0.00	0.00	0.00	0.00	0.00	1,223,493.00
St.Lucia	1927	0.56	0.00	0.23	0.02	0.00	0.00	659,580.00
St.Vincent	1927	0.35	0.00	0.12	0.00	0.00	0.00	95,611.00
Trinidad & Tobago	1927	0.15	0.00	0.33	0.00	0.40	0.00	24,281,007.00

Notes: This Table illustrates the share of the major export products relative to the value of total exports. The underlying data is from (Bulmer-Thomas, 2012).

TABLE A.2: Summary Statistics

Statistic	N	Mean	St. Dev.	Min	Max
HURR	14	104.27	99.457	65.9	142
CAC	1,915	371,511.90	585,419.60	19,689.87	2,660,850.00
CAO	1,916	277,263.50	489,836.10	35.77	3,130,709.00
DEP	1,651	322,148.90	664,790.20	208.65	3,019,872.00
SAV	1,916	594,757.50	796,771.20	41,760.91	4,625,106.00
POPD	324	23.71	77.61	0.03	1,010.55

Notes: Summary statistics of the underlying variables. *HURR* are Hurricanes, *CAC* are Current Account Balances (credit), *DEP* Deposits, *CAO* are overdrawn Current Accounts and *SAV* are Savings Account Balances. *POPD* is the population density per km^2.

TABLE A.3: Robustness: Effect of tropical storms on Banking Variables

Banking Variable: Model:	CAC (1)	CAO (2)	SAV (3)	DEP (4)
Variables				
$DESTRUCTION_t$	0.0198^{***}	0.0162^{***}	0.0031	0.0211^{***}
	(0.0030)	(0.0034)	(0.0033)	(0.0047)
$DESTRUCTION_{t-0.5m}$	0.0123^{***}	0.0177^{***}	0.0036	0.0201^{***}
	(0.0022)	(0.0040)	(0.0030)	(0.0047)
$DESTRUCTION_{t-1m}$	0.0136^{***}	0.0140^{***}	0.0019	0.0207^{***}
	(0.0043)	(0.0046)	(0.0032)	(0.0066)
$DESTRUCTION_{t-1.5m}$	0.0115^{**}	0.0131^{***}	0.0008	0.0181^{***}
	(0.0051)	(0.0049)	(0.0024)	(0.0050)
$DESTRUCTION_{t-2m}$	0.0110^{**}	0.0068	0.0018	0.0179^{***}
	(0.0053)	(0.0075)	(0.0022)	(0.0051)
$DESTRUCTION_{t-2.5m}$	0.0084	0.0114^{*}	0.0019	0.0172^{***}
	(0.0061)	(0.0067)	(0.0017)	(0.0041)
$DESTRUCTION_{t-3m}$	0.0055	0.0164^{***}	0.0008	0.0167^{***}
	(0.0070)	(0.0047)	(0.0019)	(0.0043)
$DESTRUCTION_{t-3.5m}$	0.0012	0.0273^{***}	0.0002	0.0142^{***}
	(0.0069)	(0.0069)	(0.0020)	(0.0038)
$DESTRUCTION_{t-4m}$	0.0031	0.0342^{***}	0.0012	0.0161^{***}
	(0.0051)	(0.0056)	(0.0022)	(0.0036)
$DESTRUCTION_{t-4.5m}$	0.0034	0.0333^{***}	-0.0005	0.0169^{***}
	(0.0070)	(0.0053)	(0.0014)	(0.0035)
$DESTRUCTION_{t-5m}$	0.0070	0.0290^{***}	-0.0009	0.0201^{***}
	(0.0053)	(0.0062)	(0.0016)	(0.0033)
$DESTRUCTION_{t-5.5m}$	0.0039	0.0316^{***}	0.0005	0.0178^{***}
	(0.0046)	(0.0049)	(0.0012)	(0.0045)
$DESTRUCTION_{t-6m}$	0.0070	0.0320^{***}	8.73×10^{-6}	0.0160^{***}
	(0.0055)	(0.0040)	(0.0017)	(0.0041)
$DESTRUCTION_{t-6.5m}$	0.0068	0.0376^{***}	0.0011	0.0148^{***}
	(0.0064)	(0.0096)	(0.0017)	(0.0040)
$DESTRUCTION_{t-7m}$	0.0087	0.0246^{***}	0.0021	0.0152^{***}
	(0.0088)	(0.0033)	(0.0013)	(0.0041)
$DESTRUCTION_{t-7.5m}$	0.0165^{***}	0.0219^{***}	0.0034^{***}	0.0150^{***}
	(0.0062)	(0.0041)	(0.0011)	(0.0042)
$DESTRUCTION_{t-8m}$	0.0015	0.0167^{***}	0.0023^{*}	0.0183^{*}
	(0.0078)	(0.0045)	(0.0012)	(0.0099)

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TABLE A.3: (Continued) Robustness: Effect of tropical storms on Banking Variables

Banking Variable:	CAC	CAO	SAV	DEP
Model:	(1)	(2)	(3)	(4)
$DESTRUCTION_{t-8.5m}$	0.0149**	0.0161***	0.0045***	0.0173***
	(0.0065)	(0.0035)	(0.0012)	(0.0050)
$DESTRUCTION_{t-9m}$	0.0169**	0.0113***	0.0045***	0.0171***
	(0.0081)	(0.0035)	(0.0009)	(0.0052)
$DESTRUCTION_{t-9.5m}$	0.0183***	0.0110**	0.0054***	0.0158***
	(0.0070)	(0.0046)	(0.0011)	(0.0053)
$DESTRUCTION_{t-10m}$	0.0170***	0.0117**	0.0050***	0.0083*
	(0.0061)	(0.0051)	(0.0010)	(0.0046)
$DESTRUCTION_{t-10.5m}$	0.0153***	0.0086**	0.0050***	0.0080*
	(0.0034)	(0.0043)	(0.0010)	(0.0044)
$DESTRUCTION_{t-11m}$	0.0164***	0.0106**	0.0054***	0.0090**
	(0.0031)	(0.0042)	(0.0009)	(0.0038)
$DESTRUCTION_{t-11.5m}$	0.0120***	0.0107**	0.0050***	0.0151*
	(0.0039)	(0.0046)	(0.0009)	(0.0079)
$DESTRUCTION_{t-12m}$	0.0150***	0.0128***	0.0053***	0.0146*
	(0.0027)	(0.0041)	(0.0012)	(0.0087)
Fixed-effects				
factor(month)	Yes	Yes	Yes	Yes
factor(year)	Yes	Yes	Yes	Yes
factor(Location)	Yes	Yes	Yes	Yes
Fit statistics				
Observations	1,650	1,650	1,650	1,650
R^2	0.97119	0.92888	0.98568	0.96942
Within R^2	0.04509	0.01855	0.01205	0.03089

Heteroskedasticity-robust standard-errors in parentheses
*Signif. Codes: ***: 0.01, **: 0.05, *: 0.1*

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TABLE A.4: Fisher Randomization Test: obtained t-Values

	CAC_f	CAC	CAO_f	CAO	SAV_f	SAV	DEP_f	DEP
$DESTRUCTION_t$	0.99	5.43	-1.14	4.31			0.50	4.02
$DESTRUCTION_{t-0.5m}$	0.93	3.87	-0.89	4.05			0.41	3.83
$DESTRUCTION_{t-1m}$	0.99	2.44	-0.83	2.62			0.36	2.82
$DESTRUCTION_{t-1.5m}$	-0.20	1.68	-0.26	2.31			0.40	3.18
$DESTRUCTION_{t-2m}$							0.37	3.00
$DESTRUCTION_{t-2.5m}$							0.31	3.63
$DESTRUCTION_{t-3m}$			0.07	3.09			0.49	3.50
$DESTRUCTION_{t-3.5m}$			-0.66	3.71			0.64	3.22
$DESTRUCTION_{t-4m}$			0.62	5.94			0.31	4.06
$DESTRUCTION_{t-4.5m}$			2.36	6.02			0.57	4.45
$DESTRUCTION_{t-5m}$			1.13	4.47			0.50	5.71
$DESTRUCTION_{t-5.5m}$			1.09	6.10			0.47	3.50
$DESTRUCTION_{t-6m}$			0.29	7.84			1.52	3.49
$DESTRUCTION_{t-6.5m}$			0.03	3.72			1.39	3.24
$DESTRUCTION_{t-7m}$			0.07	7.43			0.96	3.26
$DESTRUCTION_{t-7.5m}$	-0.64	2.14	-1.02	4.88	1.93	2.09	0.95	3.21
$DESTRUCTION_{t-8m}$			-1.22	3.20			0.67	1.66
$DESTRUCTION_{t-8.5m}$	0.15	1.80	-0.83	4.15	0.47	2.83	0.52	3.06
$DESTRUCTION_{t-9m}$	-1.68	1.66	-0.27	2.76	1.39	3.89	0.60	2.96

Notes: This table shows the t-Values for the Banking Variables (CAC, CAO, SAVINGS and DEP) as well as the ones obtained from the Fisher Randomization Test (CAC_f, CAO_f, SAV_f and DEP_f).

TABLE A.5: Robustness: Effect of tropical storms on Banking Variables

Model:	CAC (1)	CAC (2)	CAO (3)	CAO (4)	SAV (5)	SAV (6)	DEP (7)	DEP (8)
Variables								
$HURR_t$	0.0557	0.0821**	0.0772*	0.1002**	0.0050	0.0152	0.1225***	0.1345***
	(0.0378)	(0.0372)	(0.0426)	(0.0435)	(0.0252)	(0.0254)	(0.0449)	(0.0453)
$HURR_{t-0.5m}$	0.0577*	0.0830***	0.0824**	0.1044***	0.0192	0.0291	0.1122**	0.1237**
	(0.0317)	(0.0319)	(0.0390)	(0.0391)	(0.0221)	(0.0222)	(0.0483)	(0.0485)
$HURR_{t-1m}$	0.0578	0.0823*	0.0635	0.0852**	-0.0055	0.0041	0.1245**	0.1359**
	(0.0438)	(0.0435)	(0.0423)	(0.0424)	(0.0195)	(0.0197)	(0.0593)	(0.0597)
$HURR_{t-1.5m}$	0.0557	0.0787*	-0.0030	0.0179	-0.0020	0.0070	0.0995**	0.1107**
	(0.0453)	(0.0448)	(0.0651)	(0.0656)	(0.0205)	(0.0208)	(0.0505)	(0.0504)
$HURR_{t-2m}$	0.0394	0.0621	0.0182	0.0386	-0.0008	0.0080	0.1065**	0.1174**
	(0.0514)	(0.0510)	(0.0599)	(0.0606)	(0.0155)	(0.0158)	(0.0495)	(0.0495)
$HURR_{t-2.5m}$	0.0222	0.0434	0.0843*	0.1033**	-0.0047	0.0035	0.0883*	0.0983**
	(0.0581)	(0.0581)	(0.0448)	(0.0445)	(0.0150)	(0.0152)	(0.0457)	(0.0458)
$HURR_{t-3m}$	-0.0079	0.0145	0.1459**	0.1658**	-0.0088	-6.32×10^{-5}	0.0778	0.0883*
	(0.0567)	(0.0571)	(0.0659)	(0.0665)	(0.0157)	(0.0159)	(0.0483)	(0.0483)
$HURR_{t-3.5m}$	3.52×10^{-5}	0.0229	0.2326***	0.2526***	-0.0022	0.0067	0.0845**	0.0950**
	(0.0452)	(0.0458)	(0.0505)	(0.0509)	(0.0173)	(0.0176)	(0.0408)	(0.0412)
$HURR_{t-4m}$	0.0218	0.0437	0.2422***	0.2614***	-0.0123	-0.0038	0.1091***	0.1191***
	(0.0578)	(0.0586)	(0.0467)	(0.0475)	(0.0119)	(0.0121)	(0.0336)	(0.0346)
$HURR_{t-4.5m}$	0.0267	0.0510	0.2232***	0.2445***	-0.0109	-0.0015	0.1397***	0.1508***
	(0.0495)	(0.0499)	(0.0507)	(0.0513)	(0.0130)	(0.0134)	(0.0321)	(0.0331)
$HURR_{t-5m}$	0.0090	0.0333	0.2232***	0.2445***	-0.0019	0.0075	0.1208***	0.1319***
	(0.0370)	(0.0372)	(0.0410)	(0.0421)	(0.0112)	(0.0115)	(0.0395)	(0.0404)
$HURR_{t-5.5m}$	0.0055	0.0294	0.2646***	0.2856***	-0.0032	0.0061	0.1392***	0.1501***
	(0.0501)	(0.0506)	(0.0289)	(0.0306)	(0.0103)	(0.0107)	(0.0377)	(0.0388)
$HURR_{t-6m}$	0.0218	0.0458	0.2884***	0.3094***	-0.0034	0.0059	0.1239***	0.1348***
	(0.0496)	(0.0498)	(0.0786)	(0.0795)	(0.0158)	(0.0162)	(0.0352)	(0.0365)
$HURR_{t-6.5m}$	0.0182	0.0420	0.1870***	0.2078***	0.0039	0.0132	0.0898***	0.1007***
	(0.0635)	(0.0635)	(0.0271)	(0.0289)	(0.0147)	(0.0150)	(0.0346)	(0.0360)
$HURR_{t-7m}$	0.1076**	0.1329***	0.1627***	0.1844***	0.0157	0.0254**	0.0815**	0.0926**
	(0.0493)	(0.0497)	(0.0320)	(0.0333)	(0.0115)	(0.0120)	(0.0387)	(0.0401)
$HURR_{t-7.5m}$	0.0547	0.0803	0.1579***	0.1798***	0.0172**	0.0270***	0.0847	0.0959
	(0.0690)	(0.0695)	(0.0424)	(0.0436)	(0.0088)	(0.0090)	(0.0582)	(0.0594)
$HURR_{t-8m}$	0.0630	0.0892	0.1329***	0.1556***	0.0234**	0.0336***	0.0888	0.1006
	(0.0711)	(0.0718)	(0.0347)	(0.0365)	(0.0115)	(0.0119)	(0.0636)	(0.0646)
$HURR_{t-8.5m}$	0.0859	0.1117**	0.0800***	0.1024***	0.0303***	0.0404***	0.0936**	0.1052**
	(0.0561)	(0.0566)	(0.0274)	(0.0296)	(0.0079)	(0.0084)	(0.0472)	(0.0485)
$HURR_{t-9m}$	0.1235**	0.1500**	0.0595	0.0827**	0.0338***	0.0441***	0.0865*	0.0986**
	(0.0614)	(0.0621)	(0.0381)	(0.0403)	(0.0064)	(0.0069)	(0.0484)	(0.0496)
$HURR_{t-9.5m}$		0.1371**		0.0917**		0.0466***		0.0324
		(0.0566)		(0.0434)		(0.0102)		(0.0450)
$HURR_{t-10m}$		0.1323***		0.0870**		0.0447***		0.0317
		(0.0422)		(0.0389)		(0.0086)		(0.0446)
$HURR_{t-10.5m}$		0.1218***		0.0728**		0.0461***		0.0418
		(0.0299)		(0.0370)		(0.0081)		(0.0398)
$HURR_{t-11m}$		0.0869**		0.0991**		0.0431***		0.0402

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TABLE A.5: (Continued) Robustness: Effect of tropical storms on Banking Variables

	CAC	CAC	CAO	CAO	SAV	SAV	DEP	DEP
Model:	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
		(0.0434)		(0.0409)		(0.0108)		(0.0396)
$HURR_{t-11.5m}$		0.0890***		0.1118***		0.0399***		0.0797
		(0.0334)		(0.0366)		(0.0104)		(0.0766)
$HURR_{t-12m}$		0.1008***		0.1212***		0.0384***		0.0784
		(0.0341)		(0.0328)		(0.0113)		(0.0769)
Fixed-effects								
factor(month)	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
factor(year)	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
factor(Location)	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Fit statistics								
Observations	1,650	1,650	1,650	1,650	1,650	1,650	1,650	1,650
R^2	0.97021	0.97074	0.92854	0.92867	0.98556	0.98567	0.96895	0.96901
Within R^2	0.01261	0.02995	0.01390	0.01565	0.00335	0.01134	0.01595	0.01775

Heteroskedasticity-robust standard-errors in parentheses
*Signif. Codes: ***: 0.01, **: 0.05, *: 0.1*

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TABLE A.6: Estimated Wind Speeds in km/h for Four Storms Across Branches

Gray Branch	Storm 1	Storm 2	Storm 3	Storm 4
	1922-09-15	1924-08-28	1926-07-28	1926-09-15
Antigua	143	133	65.9	81.4
Barbados	0	0	0	0
Berbice	0	0	0	0
Demerara	0	0	0	0
Dominica	87.7	108	83.4	0
Falmouth	0	0	0	0
Grenada	0	0	0	0
Kingston	0	0	0	0
Montego Bay	0	0	0	0
Morant Bay	0	0	0	0
Port Antonio	0	0	0	0
Port Maria	0	0	0	0
San Fernando	0	0	0	0
Savanna la Mar	0	0	0	0
St. Anns Bay	0	0	0	0
St. Kitts	134	133	68.8	73.4
St. Lucia	0	67.5	73.3	0
St. Vincent	0	0	0	0
Trinidad	0	0	0	0

Notes: This table reports the estimated wind speeds at different branches affected by the four noted storms. The values represent wind speeds measured in kilometers per hour.

TABLE A.7: Effect of tropical storms on Banking Variables

Banking Variable: Model:	CAC (1)	CAO (2)	SAV (3)	DEP (4)
Variables				
STORM1_TREATED	-0.2240***	0.0068	-0.0267	-0.1465
	(0.0600)	(0.1001)	(0.1067)	(0.1036)
STORM2_TREATED	-0.2609***	-0.1744***	-0.1176***	-0.1690***
	(0.0384)	(0.0634)	(0.0108)	(0.0639)
STORM3_TREATED	0.2049***	-0.2397***	0.0315***	0.0485*
	(0.0461)	(0.0604)	(0.0120)	(0.0260)
$DESTRUCTION_t$	0.0021	0.0078**	0.0006	0.0040
	(0.0028)	(0.0034)	(0.0042)	(0.0039)
$DESTRUCTION_{t-0.5m}$	0.0082**	0.0135***	0.0027	0.0162***
	(0.0033)	(0.0049)	(0.0028)	(0.0042)
$DESTRUCTION_{t-1m}$	0.0096***	0.0099*	0.0010	0.0167***
	(0.0026)	(0.0055)	(0.0032)	(0.0053)
$DESTRUCTION_{t-1.5m}$	0.0077***	0.0092	-5.04×10^{-5}	0.0143***
	(0.0024)	(0.0060)	(0.0024)	(0.0046)
$DESTRUCTION_{t-2m}$	0.0072***	0.0028	0.0010	0.0140***
	(0.0027)	(0.0091)	(0.0022)	(0.0045)
$DESTRUCTION_{t-2.5m}$	0.0045	0.0074	0.0011	0.0133***
	(0.0046)	(0.0082)	(0.0017)	(0.0039)
$DESTRUCTION_{t-3m}$	0.0018	0.0126***	9.16×10^{-6}	0.0131***
	(0.0053)	(0.0047)	(0.0018)	(0.0038)
$DESTRUCTION_{t-3.5m}$	-0.0026	0.0239***	-0.0007	0.0107**
	(0.0051)	(0.0053)	(0.0021)	(0.0045)
$DESTRUCTION_{t-4m}$	-0.0007	0.0307***	0.0003	0.0126***
	(0.0037)	(0.0041)	(0.0021)	(0.0048)
$DESTRUCTION_{t-4.5m}$	-0.0004	0.0294***	-0.0013	0.0132***
	(0.0059)	(0.0040)	(0.0016)	(0.0048)
$DESTRUCTION_{t-5m}$	0.0022	0.0250***	-0.0020	0.0155***
	(0.0048)	(0.0048)	(0.0016)	(0.0052)
$DESTRUCTION_{t-5.5m}$	-0.0009	0.0275***	-0.0005	0.0132***
	(0.0047)	(0.0043)	(0.0015)	(0.0050)
$DESTRUCTION_{t-6m}$	0.0022	0.0279***	-0.0010	0.0114**
	(0.0040)	(0.0037)	(0.0019)	(0.0057)
$DESTRUCTION_{t-6.5m}$	0.0019	0.0334***	3.33×10^{-6}	0.0100*
	(0.0032)	(0.0106)	(0.0019)	(0.0061)
$DESTRUCTION_{t-7m}$	0.0038	0.0202***	0.0011	0.0104*
	(0.0054)	(0.0038)	(0.0014)	(0.0063)
$DESTRUCTION_{t-7.5m}$	0.0112***	0.0174***	0.0023**	0.0100
	(0.0034)	(0.0031)	(0.0010)	(0.0063)

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TABLE A.7: (Continued) Effect of tropical storms on Banking Variables

Banking Variable: Model:	CAC (1)	CAO (2)	SAV (3)	DEP (4)
$DESTRUCTION_{t-8m}$	0.0040	0.0166^{***}	0.0019	0.0226^{**}
	(0.0081)	(0.0038)	(0.0013)	(0.0097)
$DESTRUCTION_{t-8.5m}$	0.0101^{***}	0.0116^{***}	0.0035^{***}	0.0127^{*}
	(0.0038)	(0.0032)	(0.0010)	(0.0066)
$DESTRUCTION_{t-9m}$	0.0120^{**}	0.0067^{**}	0.0035^{***}	0.0123^{*}
	(0.0051)	(0.0032)	(0.0007)	(0.0064)
STORM1_TREATED x STORM2_TREATED	-0.1284^{***}	-0.0458	0.0743^{***}	-0.2934^{***}
	(0.0452)	(0.0595)	(0.0131)	(0.0704)
STORM1_TREATED x STORM3_TREATED	-0.0620	-0.3673^{***}	0.0390^{*}	-0.0426
	(0.1001)	(0.0630)	(0.0202)	(0.0508)
Fixed-effects				
factor(month)	Yes	Yes	Yes	Yes
factor(year)	Yes	Yes	Yes	Yes
factor(Location)	Yes	Yes	Yes	Yes
Fit statistics				
Observations	1,650	1,650	1,650	1,650
R^2	0.97372	0.93009	0.98578	0.97118
Within R^2	0.12883	0.03523	0.01857	0.08681

Heteroskedasticity-robust standard-errors in parentheses
*Signif. Codes: ***: 0.01, **: 0.05, *: 0.1*

TABLE A.8: Effect of tropical storms on Banking Variables (subsample)

Banking Variable:	CAC	CAO	SAV	DEP
Model:	(1)	(2)	(3)	(4)
Variables				
$DESTRUCTION_{t-0.5m}$	0.0123***	0.0090***	0.0013	0.0116***
	(0.0031)	(0.0030)	(0.0032)	(0.0032)
$DESTRUCTION_{t-1m}$	0.0055**	0.0100***	0.0018	0.0107***
	(0.0024)	(0.0033)	(0.0029)	(0.0036)
$DESTRUCTION_{t-1.5m}$	0.0069*	0.0064*	-7.56×10^{-5}	0.0121**
	(0.0042)	(0.0034)	(0.0032)	(0.0052)
$DESTRUCTION_{t-2m}$	0.0055	0.0056	-0.0010	0.0098***
	(0.0051)	(0.0038)	(0.0023)	(0.0037)
$DESTRUCTION_{t-2.5m}$	0.0049	-0.0005	-0.0001	0.0098**
	(0.0054)	(0.0074)	(0.0022)	(0.0039)
$DESTRUCTION_{t-3m}$	0.0022	0.0030	2.49×10^{-5}	0.0089***
	(0.0060)	(0.0070)	(0.0017)	(0.0029)
$DESTRUCTION_{t-3.5m}$	-3.95×10^{-5}	0.0080**	-0.0010	0.0089***
	(0.0067)	(0.0036)	(0.0018)	(0.0030)
$DESTRUCTION_{t-4m}$	-0.0047	0.0193***	-0.0015	0.0067***
	(0.0066)	(0.0062)	(0.0018)	(0.0023)
$DESTRUCTION_{t-4.5m}$	-0.0031	0.0253***	-0.0004	0.0083***
	(0.0049)	(0.0049)	(0.0021)	(0.0020)
$DESTRUCTION_{t-5m}$	-0.0036	0.0242***	-0.0023*	0.0083***
	(0.0067)	(0.0049)	(0.0013)	(0.0020)
$DESTRUCTION_{t-5.5m}$	-0.0004	0.0207***	-0.0027*	0.0116***
	(0.0052)	(0.0054)	(0.0014)	(0.0019)
$DESTRUCTION_{t-6m}$	-0.0034	0.0232***	-0.0012	0.0093***
	(0.0045)	(0.0050)	(0.0014)	(0.0026)
$DESTRUCTION_{t-6.5m}$	-0.0007	0.0243***	-0.0020	0.0079***
	(0.0054)	(0.0040)	(0.0019)	(0.0024)
$DESTRUCTION_{t-7m}$	-0.0010	0.0301***	-0.0007	0.0065**
	(0.0063)	(0.0084)	(0.0019)	(0.0025)
$DESTRUCTION_{t-7.5m}$	0.0009	0.0171***	0.0003	0.0067***
	(0.0087)	(0.0039)	(0.0015)	(0.0026)
$DESTRUCTION_{t-8m}$	0.0089	0.0137***	0.0016	0.0061**
	(0.0062)	(0.0046)	(0.0013)	(0.0028)
$DESTRUCTION_{t-8.5m}$	-0.0066	0.0095**	-1.41×10^{-5}	0.0105*
	(0.0082)	(0.0039)	(0.0016)	(0.0063)
$DESTRUCTION_{t-9m}$	0.0071	0.0084***	0.0024*	0.0084**
	(0.0066)	(0.0025)	(0.0014)	(0.0035)
Fixed-effects				
factor(month)	Yes	Yes	Yes	Yes

Continued on next page

TABLE A.8: (Continued) Effect of tropical storms on Banking Variables (subsample)

Banking Variable: Model:	CAC (1)	CAO (2)	SAV (3)	DEP (4)
factor(year)	Yes	Yes	Yes	Yes
factor(Location)	Yes	Yes	Yes	Yes
Fit statistics				
Observations	1,349	1,349	1,349	1,349
R^2	0.97057	0.93821	0.98749	0.97151
Within R^2	0.01358	0.01355	0.00418	0.01076

Heteroskedasticity-robust standard-errors in parentheses

*Signif. Codes: ***: 0.01, **: 0.05, *: 0.1*

Effect of the first and second tropical storm on the Banking Variables

TABLE A.9: Effect of tropical storms on Banking Variables (including pre-trends)

Banking Variable: Model:	CAC (1)	CAO (2)	SAV (3)	DEP (4)
Variables				
$DESTRUCTION_{t+3m}$	0.0004	-0.0011	-0.0017	-0.0020
	(0.0033)	(0.0039)	(0.0041)	(0.0029)
$DESTRUCTION_{t+2.5m}$	0.0006	-0.0076**	-0.0001	-0.0029
	(0.0033)	(0.0036)	(0.0049)	(0.0031)
$DESTRUCTION_{t+2m}$	-0.0025	-0.0082	0.0009	-0.0029
	(0.0023)	(0.0051)	(0.0048)	(0.0031)
$DESTRUCTION_{t+1.5m}$	0.0023	0.0043	-0.0002	-0.0032
	(0.0034)	(0.0042)	(0.0041)	(0.0033)
$DESTRUCTION_{t+1m}$	0.0008	0.0021	4.24×10^{-6}	-0.0029
	(0.0020)	(0.0063)	(0.0049)	(0.0034)
$DESTRUCTION_{t+0.5m}$	-0.0009	0.0059	-0.0011	0.0004
	(0.0025)	(0.0050)	(0.0054)	(0.0029)
STORM1_TREATED	-0.2493***	-0.0137	-0.0382	-0.1627*
	(0.0656)	(0.1009)	(0.1043)	(0.0877)
STORM2_TREATED	-0.2580***	-0.1846***	-0.1228***	-0.1739***
	(0.0385)	(0.0646)	(0.0110)	(0.0641)
STORM3_TREATED	0.2096**	-0.1463*	0.0247*	0.0638*
	(0.0930)	(0.0753)	(0.0138)	(0.0361)
WIND	-0.0004	0.0073**	0.0001	0.0021
	(0.0029)	(0.0036)	(0.0041)	(0.0032)
$DESTRUCTION_{t-0.5m}$	0.0065**	0.0139***	0.0025	0.0140***
	(0.0031)	(0.0051)	(0.0028)	(0.0034)
$DESTRUCTION_{t-1m}$	0.0077***	0.0100*	0.0005	0.0144***
	(0.0027)	(0.0053)	(0.0032)	(0.0044)
$DESTRUCTION_{t-1.5m}$	0.0063**	0.0092	-0.0005	0.0122***
	(0.0026)	(0.0059)	(0.0024)	(0.0036)
$DESTRUCTION_{t-2m}$	0.0057**	0.0032	0.0004	0.0122***
	(0.0029)	(0.0091)	(0.0022)	(0.0036)
$DESTRUCTION_{t-2.5m}$	0.0031	0.0067	0.0006	0.0113***
	(0.0046)	(0.0086)	(0.0017)	(0.0030)
$DESTRUCTION_{t-3m}$	0.0008	0.0117**	-0.0004	0.0113***
	(0.0054)	(0.0049)	(0.0017)	(0.0029)
$DESTRUCTION_{t-3.5m}$	-0.0036	0.0236***	-0.0010	0.0092***
	(0.0052)	(0.0054)	(0.0020)	(0.0036)
$DESTRUCTION_{t-4m}$	-0.0020	0.0296***	0.0002	0.0108***
	(0.0037)	(0.0042)	(0.0021)	(0.0038)
$DESTRUCTION_{t-4.5m}$	-0.0025	0.0284***	-0.0017	0.0108***
	(0.0058)	(0.0041)	(0.0015)	(0.0038)

Continued on next page

TABLE A.9: (Continued) Effect of tropical storms on Banking Variables (including pre-trends)

Banking Variable: Model:	CAC (1)	CAO (2)	SAV (3)	DEP (4)
$DESTRUCTION_{t-5m}$	0.0002	0.0249***	-0.0022	0.0136***
	(0.0047)	(0.0047)	(0.0016)	(0.0047)
$DESTRUCTION_{t-5.5m}$	-0.0028	0.0274***	-0.0007	0.0113***
	(0.0045)	(0.0042)	(0.0015)	(0.0042)
$DESTRUCTION_{t-6m}$	0.0002	0.0278***	-0.0013	0.0096*
	(0.0039)	(0.0038)	(0.0019)	(0.0050)
$DESTRUCTION_{t-6.5m}$	-0.0001	0.0332***	-0.0002	0.0082
	(0.0034)	(0.0107)	(0.0019)	(0.0055)
$DESTRUCTION_{t-7m}$	0.0018	0.0200***	0.0008	0.0084
	(0.0056)	(0.0039)	(0.0014)	(0.0056)
$DESTRUCTION_{t-7.5m}$	0.0093***	0.0174***	0.0021*	0.0082
	(0.0036)	(0.0032)	(0.0011)	(0.0057)
$DESTRUCTION_{t-8m}$	0.0014	0.0166***	0.0017	0.0202**
	(0.0081)	(0.0039)	(0.0014)	(0.0081)
$DESTRUCTION_{t-8.5m}$	0.0080**	0.0117***	0.0032***	0.0108*
	(0.0039)	(0.0033)	(0.0010)	(0.0060)
$DESTRUCTION_{t-9m}$	0.0099*	0.0067**	0.0032***	0.0103*
	(0.0053)	(0.0033)	(0.0007)	(0.0057)
STORM1_TREATED x STORM2_TREATED	-0.1105**	-0.0432	0.0790***	-0.2488***
	(0.0455)	(0.0598)	(0.0128)	(0.0694)
STORM1_TREATED x STORM3_TREATED	-0.1395	-0.3682***	0.0166	-0.0557
	(0.1160)	(0.1200)	(0.0198)	(0.0932)
Fixed-effects				
factor(month)	Yes	Yes	Yes	Yes
factor(year)	Yes	Yes	Yes	Yes
factor(Location)	Yes	Yes	Yes	Yes
Fit statistics				
Observations	1,514	1,514	1,514	1,514
R^2	0.97497	0.93425	0.98652	0.97271
Within R^2	0.12410	0.02696	0.02000	0.07536

*Heteroskedasticity-robust standard-errors in parentheses. Signif. Codes: ***: 0.01, **: 0.05, *: 0.1.*

TABLE A.10: Effect of tropical storms on Banking Variables: Homogenous Population Weights

Banking Variable:	CAC	CAO	SAV	DEP
Model:	(1)	(2)	(3)	(4)
Variables				
$DESTRUCTION_t$	0.5620**	0.5519***	0.0354	0.9456***
	(0.2739)	(0.1696)	(0.1282)	(0.1871)
$DESTRUCTION_{t-0.5m}$	0.2836	0.5722***	0.0487	0.8649***
	(0.1920)	(0.1868)	(0.1199)	(0.1836)
$DESTRUCTION_{t-1m}$	0.3845*	0.3880*	-0.0408	0.8678***
	(0.1974)	(0.2041)	(0.1310)	(0.2538)
$DESTRUCTION_{t-1.5m}$	0.4394**	0.3692*	-0.0129	0.7399***
	(0.1971)	(0.2147)	(0.1223)	(0.2059)
$DESTRUCTION_{t-2m}$	0.3613*	0.2927	-0.0321	0.7288***
	(0.2053)	(0.2184)	(0.0881)	(0.2110)
$DESTRUCTION_{t-2.5m}$	0.2920	0.1884	0.0173	0.6569***
	(0.1921)	(0.2821)	(0.0840)	(0.1851)
$DESTRUCTION_{t-3m}$	0.1482	0.2659	-0.0057	0.6910***
	(0.2257)	(0.2695)	(0.0755)	(0.1832)
$DESTRUCTION_{t-3.5m}$	0.1456	0.7539***	-0.0411	0.5878***
	(0.2646)	(0.2171)	(0.0729)	(0.1574)
$DESTRUCTION_{t-4m}$	0.0226	1.022***	-0.0496	0.5891***
	(0.2698)	(0.3125)	(0.0846)	(0.1730)
$DESTRUCTION_{t-4.5m}$	0.0397	1.161***	0.0058	0.6542***
	(0.2277)	(0.2890)	(0.0843)	(0.1580)
$DESTRUCTION_{t-5m}$	0.2000	1.087***	-0.0513	0.7749***
	(0.2741)	(0.2532)	(0.0683)	(0.1486)
$DESTRUCTION_{t-5.5m}$	0.1584	1.115***	-0.0401	0.8638***
	(0.2263)	(0.2678)	(0.0737)	(0.1372)
$DESTRUCTION_{t-6m}$	0.0447	1.186***	-0.0387	0.7050***
	(0.1695)	(0.2168)	(0.0656)	(0.1647)
$DESTRUCTION_{t-6.5m}$	0.3361	0.9440***	-0.0354	0.7090***
	(0.2384)	(0.3239)	(0.0541)	(0.1831)
$DESTRUCTION_{t-7m}$	0.1910	1.411***	0.0431	0.4680**
	(0.3194)	(0.3764)	(0.0494)	(0.2095)
$DESTRUCTION_{t-7.5m}$	0.2508	0.9849***	0.0936*	0.4372*
	(0.3695)	(0.1351)	(0.0499)	(0.2605)
$DESTRUCTION_{t-8m}$	0.2991	0.6182***	0.1180*	0.2759
	(0.3359)	(0.1639)	(0.0676)	(0.3965)
$DESTRUCTION_{t-8.5m}$	0.1591	0.5470***	0.1149**	0.4830
	(0.3167)	(0.1533)	(0.0581)	(0.3554)
$DESTRUCTION_{t-9m}$	0.5752*	0.5317***	0.1415***	0.5451*

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TABLE A.10: (Continued) Effect of tropical storms on Banking Variables: Homogenous Population Weights

Banking Variable: Model:	CAC (1)	CAO (2)	SAV (3)	DEP (4)
	(0.3477)	(0.1769)	(0.0520)	(0.3149)
Fixed-effects				
factor(month)	Yes	Yes	Yes	Yes
factor(year)	Yes	Yes	Yes	Yes
factor(Location)	Yes	Yes	Yes	Yes
Fit statistics				
Observations	1,659	1,659	1,659	1,659
R^2	0.97018	0.92845	0.98549	0.96927
Within R^2	0.01354	0.01378	0.00250	0.02787

Heteroskedasticity-robust standard-errors in parentheses

*Signif. Codes: ***: 0.01, **: 0.05, *: 0.1*

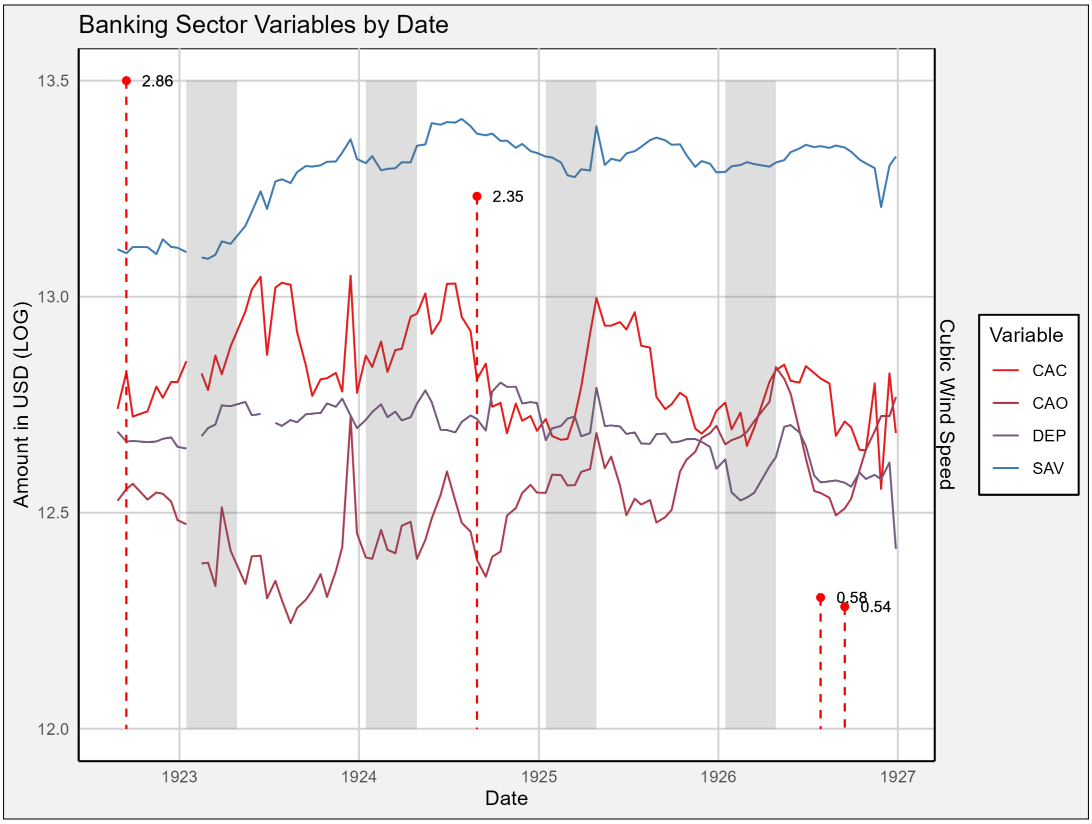


FIGURE A.1: This figure illustrate the evolution of the average value of the Banking Variables over time (in LOG and deflated in US$). *CAC* are Current Account Balances (credit), *CAO* are overdrawn Current Accounts, *DEP* are Deposits and *SAV* are Savings Account Balances. The red points are the cubic wind speeds (divided by 1 million) of the tropical storms occurring during the period. The grey shaded area represents the harvest season (January to May).

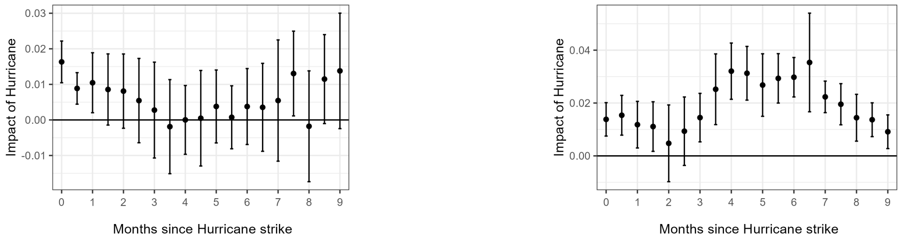


FIGURE A.2: Current Account Balances (in logs)

FIGURE A.3: Overdrawn Current Accounts (in logs)

FIGURE A.4: This figure reports the estimated impact of tropical storms on Current Account Balances and overdrawn Current Accounts (both in logs) and the corresponding 95% confidence intervals between 1922 and 1927.

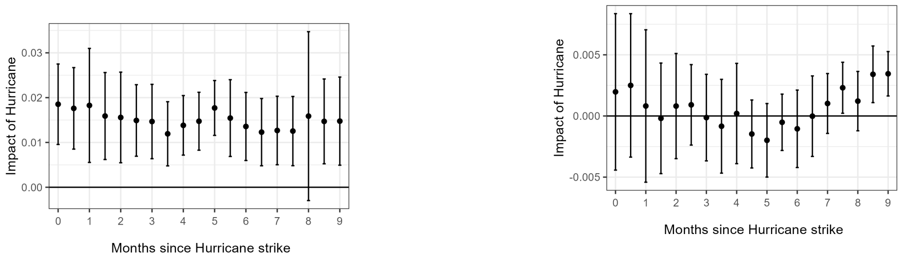


FIGURE A.5: Deposits (in logs)

FIGURE A.6: Savings Account Balances (in logs)

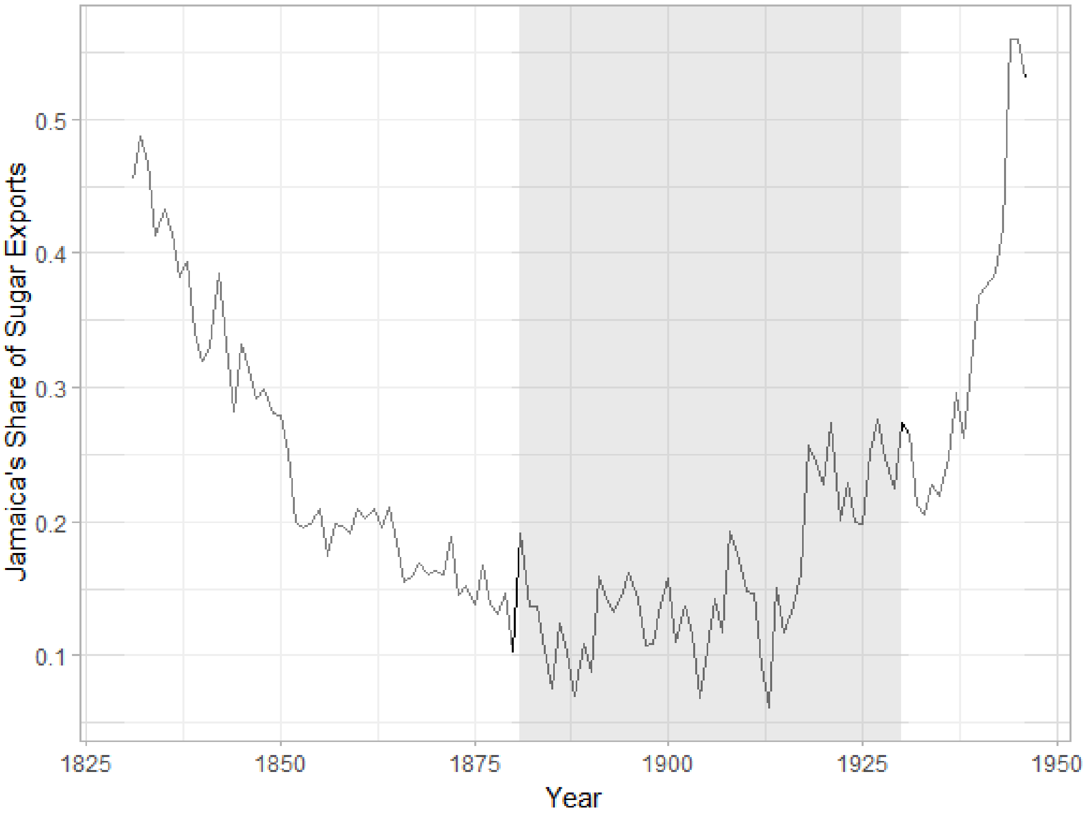
FIGURE A.7: This figure reports the estimated impact of tropical storms on Deposits and Savings Account Balances (both in logs) and the corresponding 95% confidence intervals between 1922 and 1927.

Appendix B

Creative Destruction

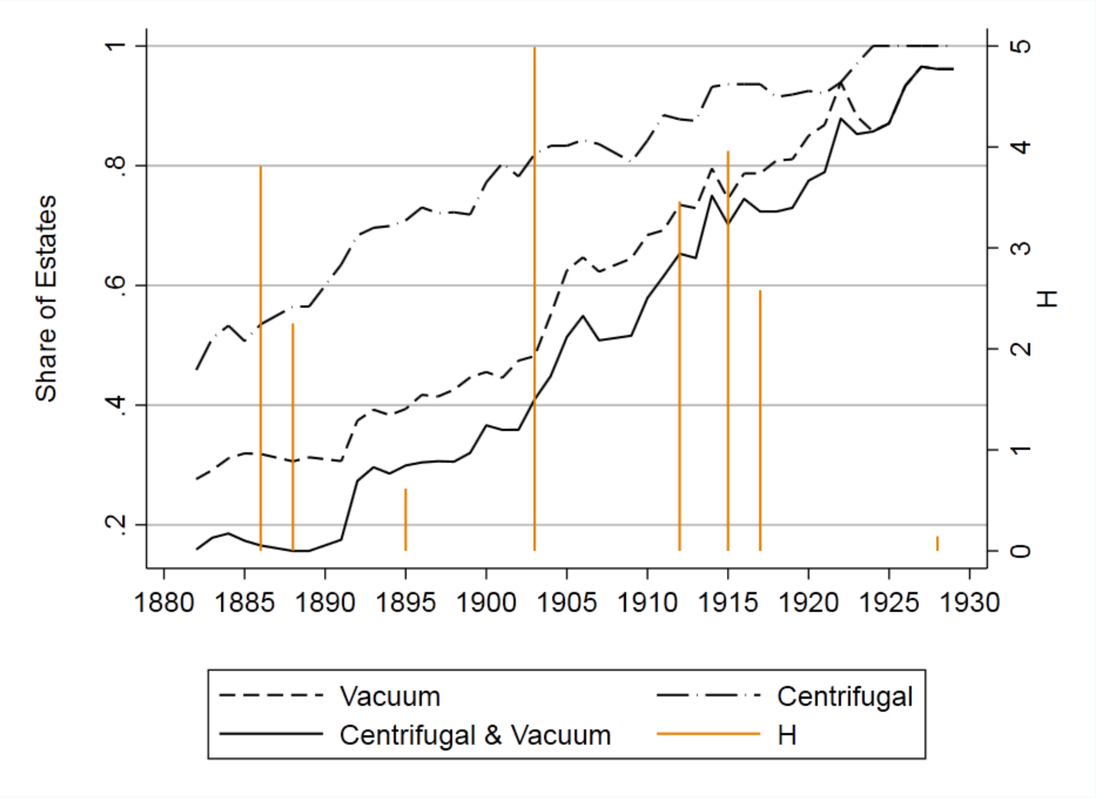
pdflscape

FIGURE B.1: Jamaica's Share of English Caribbean Sugar Exports



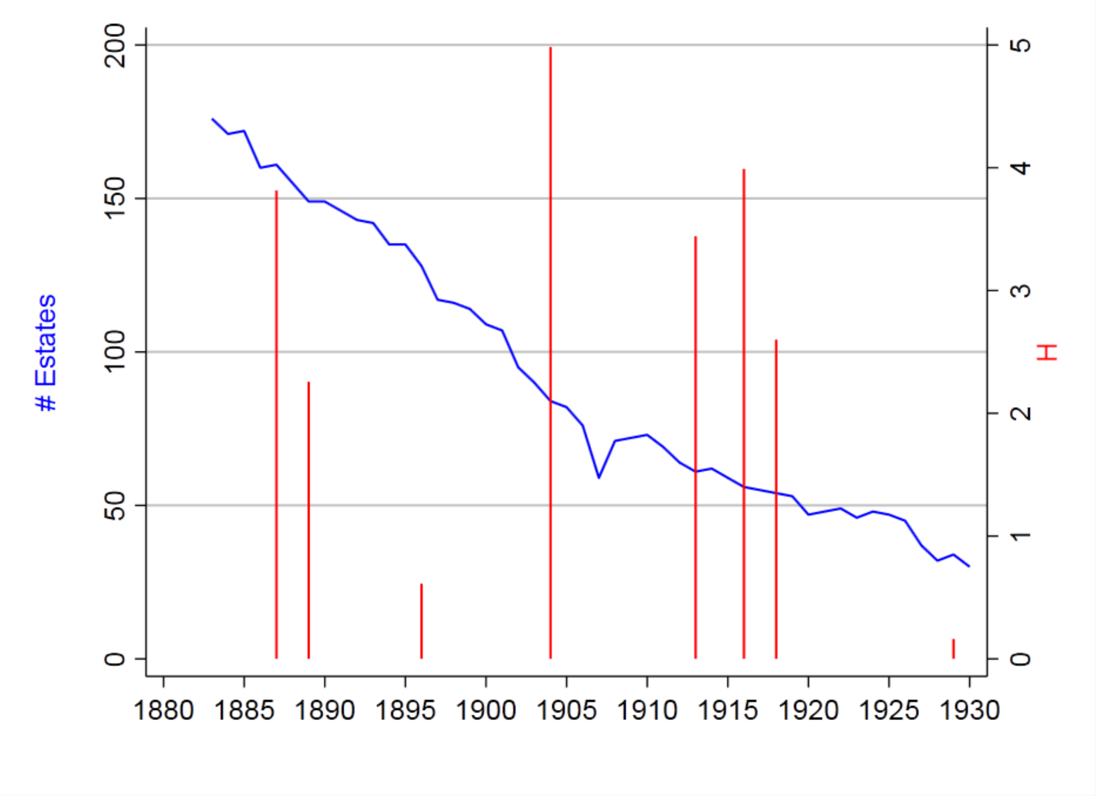
Notes: This graph illustrates Jamaica's share of sugar exports compared to the other sugar exporting Caribbean colonies in the British Empire, such as Barbados, Antigua, Montserrat, the Virgins, Grenada and the Grenadines, St. Vincent, St. Lucia, Dominica, Trinidad, Tobago, Nevis and St. Kitts. The underlying data comes from Deerr (1950). The gray shaded area is the study period.

FIGURE B.2: Share of Estates Using Modernized Sugar Processing Technology



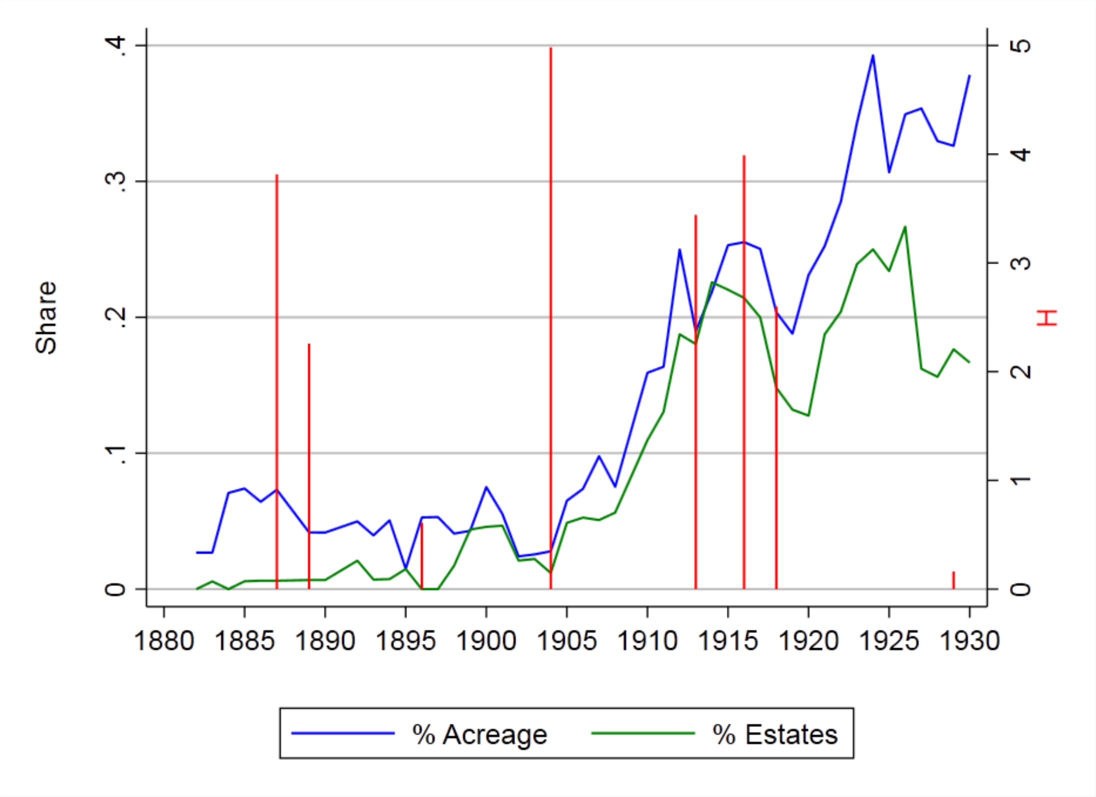
Notes: This graph illustrates the share of existing estates utilizing centrifugals, vacuum pans, or both. *H* is the hurricane damage index described in Section 2.3.

FIGURE B.3: Number of Sugar Producing Estates



Notes: This graph depicts the number of estates which are planting and processing sugar. *H* is the hurricane damage index described in Section 2.3.

FIGURE B.4: Estates Outsourcing to Central Factories



Notes: This graph depicts the share of outsourcing estates and their share in acreage sugar planted. *H* is the hurricane damage index described in Section 2.3. The underlying data comes from the Handbook of Jamaica (1880-1938).

TABLE B.1: Impact of Hurricane on Process Upgrading & Prices

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)
Process:	ftC	ftC	ftC	ftC	ftV	ftV	ftV	ftV	$ftC \times ftV$	$ftC \times ftV$	$ftC \times ftV$	$ftC \times ftV$
$H_{i,t-1}$	0.310**	0.155	0.217*	0.234**	0.180*	0.066	0.046	0.110*	0.147**	0.008	0.036	0.078*
	(0.097)	(0.082)	(0.091)	(0.087)	(0.084)	(0.054)	(0.088)	(0.050)	(0.058)	(0.050)	(0.045)	(0.037)
$H_{i,t-1} \times \sum_{j=0}^{J} \frac{PS_{t-1-j}}{J+1}$	-9.630	35.437	13.553	1.074	27.926	10.523	93.054	45.998	28.446	30.654	74.552**	38.901
	(25.902)	(29.777)	(38.940)	(32.079)	(32.279)	(18.587)	(57.346)	(45.640)	(20.553)	(22.060)	(29.802)	(26.790)
$H_{i,t-1} \times \sum_{j=0}^{J} \frac{PB_{t-1-j}}{J+1}$	-3.054	-4.404*	-3.418	-2.784	-3.490	-1.319	-6.006*	-3.843	-3.222*	-2.027	-4.872**	-3.144
	(1.593)	(1.758)	(2.152)	(1.771)	(2.609)	(0.960)	(2.610)	(3.016)	(1.631)	(1.069)	(1.747)	(1.717)
$\overline{H_i}$	0.173	0.164	0.168	0.171	-0.064	-0.063	-0.060	-0.066	-0.174	-0.164	-0.166	-0.176
	(0.265)	(0.251)	(0.270)	(0.272)	(0.138)	(0.140)	(0.135)	(0.139)	(0.129)	(0.128)	(0.125)	(0.130)
H_i^{σ}	0.063	0.057	0.067	0.068	0.086	0.086	0.083	0.087	0.151*	0.147*	0.145*	0.153*
	(0.121)	(0.114)	(0.123)	(0.124)	(0.058)	(0.058)	(0.057)	(0.058)	(0.055)	(0.054)	(0.053)	(0.055)
$AGE_{i,t}$	-0.002	-0.002	-0.002	-0.002	-0.003*	-0.003*	-0.003*	-0.003*	-0.003*	-0.003*	-0.003	-0.003*
	(0.003)	(0.003)	(0.003)	(0.003)	(0.002)	(0.002)	(0.002)	(0.002)	(0.001)	(0.001)	(0.001)	(0.001)
$AGE_{i,t}^2$	0.000	0.000	0.000	0.000	0.000*	0.000*	0.000*	0.000*	0.000*	0.000*	0.000*	0.000*
	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)
$ATTD_{i,t}$	0.006	0.006	0.006	0.006	0.004	0.004	0.004	0.004	0.015	0.015	0.014	0.015
	(0.014)	(0.014)	(0.015)	(0.015)	(0.008)	(0.008)	(0.008)	(0.008)	(0.008)	(0.008)	(0.007)	(0.008)
$OWNS_{i,t}$	-0.008	-0.008	-0.008	-0.008	0.003	0.003	0.002	0.003	0.000	-0.000	0.000	0.000
	(0.007)	(0.007)	(0.008)	(0.008)	(0.003)	(0.003)	(0.003)	(0.003)	(0.003)	(0.003)	(0.003)	(0.003)
LAT_i	0.119*	0.107*	0.118*	0.121*	0.012	0.010	0.010	0.013	0.009	0.006	0.006	0.009
	(0.058)	(0.055)	(0.059)	(0.059)	(0.028)	(0.029)	(0.027)	(0.029)	(0.031)	(0.032)	(0.030)	(0.031)
$LONG_i$	0.016	0.015	0.017	0.017	-0.005	-0.005	-0.005	-0.005	-0.002	-0.003	-0.003	-0.002
	(0.034)	(0.032)	(0.034)	(0.034)	(0.012)	(0.013)	(0.012)	(0.013)	(0.013)	(0.013)	(0.012)	(0.013)
$MILL_{i,t}$	-0.001	-0.002	-0.002	-0.001	0.007	0.007	0.007	0.007	0.011	0.011	0.011	0.011
	(0.017)	(0.017)	(0.018)	(0.018)	(0.010)	(0.010)	(0.010)	(0.010)	(0.009)	(0.009)	(0.009)	(0.009)
J:	0	1	2	3	0	1	2	3	0	1	2	3
Obs.	713	713	713	713	1360	1360	1360	1360	1462	1462	1462	1462
$Pseudo-R^2$	0.213	0.214	0.212	0.212	0.175	0.174	0.175	0.174	0.166	0.165	0.167	0.165

Notes: (a) Probit model; (b) Coefficients reported as marginal effects; (c) ** and * are 1 and 5 per cent significance levels; (d) Standard errors (clustered by estate) in parentheses; (e) Time and parish dummies included but not reported. (f) The number of years covered are 18, 2, and 28 for the regression involving ftC, ftV, and $ftC \times ftV$, respectively.

TABLE B.2: Impact of Hurricane on Process Upgrading & Financing

	(1)	(2)	(3)	(4)	(5)	(6)
Process:	ftV	$ftC \times ftV$	ftV	$ftC \times ftV$	ftV	$ftC \times ftV$
$H_{i,t-1}$	0.015*	0.010	0.015*	0.010	0.037	0.031
	(0.008)	(0.007)	(0.008)	(0.007)	(0.096)	(0.048)
$LOAN_{i,1912}$	-0.210**	-0.327**	0.261	0.721*	0.277	0.643*
	(0.078)	(0.120)	(0.273)	(0.325)	(0.291)	(0.316)
$LOAN_{i,1912} \times H_{i,t-1}$			-0.128	-0.287**	-0.131	-0.257*
			(0.081)	(0.112)	(0.088)	(0.108)
$\sum_{j=0}^{2} \frac{PS_{i,t-1-j}}{3} \times H_{i,t}$					98.353	74.941**
					(63.622)	(30.354)
$\sum_{j=0}^{2} \frac{PB_{i,t-1-j}}{3} \times H_{i,t}$					-6.222*	-4.835**
					(2.863)	(1.743)
$\overline{H_i}$	-0.067	-0.168	-0.067	-0.169	-0.060	-0.161
	(0.141)	(0.133)	(0.141)	(0.134)	(0.134)	(0.124)
H_i^{σ}	0.087	0.150*	0.087	0.151*	0.082	0.142*
	(0.059)	(0.057)	(0.059)	(0.057)	(0.056)	(0.053)
$AGE_{i,t}$	-0.003*	-0.003*	-0.003*	-0.003*	-0.003*	-0.003*
	(0.002)	(0.001)	(0.002)	(0.001)	(0.002)	(0.001)
$AGE_{i,t}^2$	0.000*	0.000*	0.000*	0.000*	0.000*	0.000*
	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)
$ATTD_{i,t}$	0.004	0.016	0.004	0.016	0.004	0.014
	(0.008)	(0.008)	(0.008)	(0.008)	(0.008)	(0.007)
$OWNS_{i,t}$	0.003	0.000	0.003	0.000	0.002	-0.000
	(0.003)	(0.003)	(0.003)	(0.003)	(0.003)	(0.003)
LAT_i	0.010	0.008	0.010	0.008	0.011	0.007
	(0.028)	(0.032)	(0.029)	(0.032)	(0.027)	(0.030)
$LONG_i$	-0.005	-0.003	-0.005	-0.003	-0.005	-0.003
	(0.013)	(0.013)	(0.013)	(0.013)	(0.012)	(0.012)
$MILL_{i,t}$	0.007	0.011	0.007	0.011	0.007	0.010
	(0.010)	(0.010)	(0.010)	(0.010)	(0.010)	(0.009)
Obs.	1360	1462	1360	1462	1360	1462
$Pseudo-R^2$	0.174	0.164	0.174	0.164	0.177	0.169

Notes: (a) Probit model; (b) Coefficients reported as marginal effects; (c) ** and * are 1 and 5 per cent significance levels; (d) Standard errors (clustered by estate) in parentheses; (e) Time and parish dummies included but not reported. (f) The number of years covered in the data used for the estimation is 28.

TABLE B.3: Impact of Hurricane on Process Upgrading ($ftC \times ftV$) & Financing - Robustness Checks

	(1)	(2)	(3)	(4)	(5)	(6)	(7)
$H_{i,t}$	0.032	0.023	0.031	0.598	0.598	0.598	0.598*
	(0.051)	(0.121)	(0.018)	(0.437)	(0.405)	(0.325)	(0.259)
$LOAN_{i,1912}$	0.647*	0.745	0.643**	12.607**	12.607**	12.607**	12.607**
	(0.319)	(0.433)	(0.111)	(2.744)	(2.639)	(2.696)	(2.581)
$LOAN_{i,1912} \times H_{i,t}$	-0.258*	-0.291*	-0.257**	-4.994**	-4.994**	-4.994**	-4.994**
	(0.109)	(0.149)	(0.038)	(0.943)	(0.931)	(0.887)	(0.854)
$\sum_{j=0}^{2} \frac{PS_{i,t-1-j}}{3} \times H_{i,t}$	85.567**	69.799**	74.941**	1451.6**	1451.6**	1451.6**	1451.6**
	(26.091)	(28.214)	(10.576)	(331.6)	(253.7)	(176.98)	(127.5)
$\sum_{j=0}^{2} \frac{PB_{i,t-1-j}}{3} \times H_{i,t}$	-5.483**	-4.434*	-4.835**	-93.48**	-93.48**	-93.48**	-93.48**
	(1.399)	(1.893)	(0.588)	(19.97)	(18.46)	(13.06)	(9.419)
$WAR_t \times \sum_{j=0}^{2} \frac{PS_{i,t-1-j}}{3} \times H_{i,t}$	0.455						
	(0.540)						
$WAR_t \times H_{i,t}$	-0.046						
	(0.120)						
$DUTY_t \times \sum_{j=0}^{2} \frac{PS_{i,t-1-j}}{3} \times H_{i,t}$		2.835					
		(11.134)					
$DUTY_t \times H_{i,t}$		-0.013					
		(0.054)					
Std.Err.	Plant.	Plant.	Storm-Year	Conley-0km	Conley-20km	Conley-50km	Conley-100km
Obs.	1462	1462	1462	1462	1462	1462	1462
$Pseudo - R^2$	0.169	0.169	0.169	0.169	0.169	0.169	0.169

Notes: (a) Probit model; (b) Coefficients reported as marginal effects in Columns 1 thru 3 and as standard coefficients in Columns 4 thru 6; (c) ** and * are 1 and 5 per cent significance levels; (d) Standard errors are clustered by plantation in Columns 1 and 2 (Plant.), clustered by storm and year in Column 3 (Storm-Year), and Conley (1999) spatial standard errors with 20, 50, and 100km thresholds in Columns 4, 5, and 6 (Conley-0km, -20km, -50km, -100km), respectively; (e) Controls for mean and standard deviation of hurricane damage, age and age squared, attorney dummy, number of plantations owned, presence of steam mill, latitude and longitude (except in the Conley standard error regressions in Columns 4 thru 6), and time and parish dummies included but not reported.

Appendix C

Natural Disasters & School Attendance

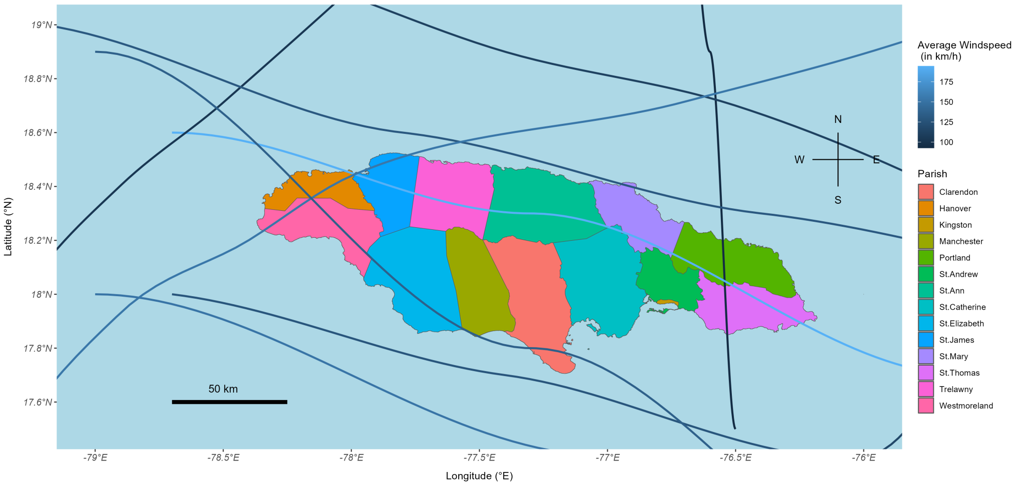
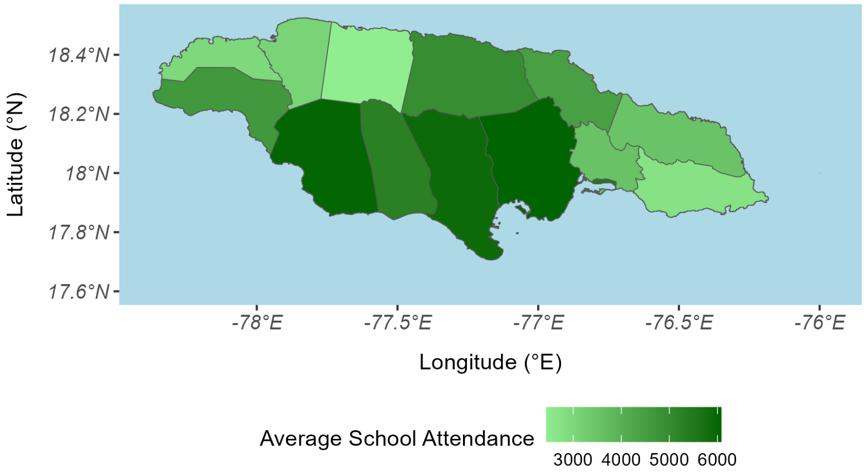
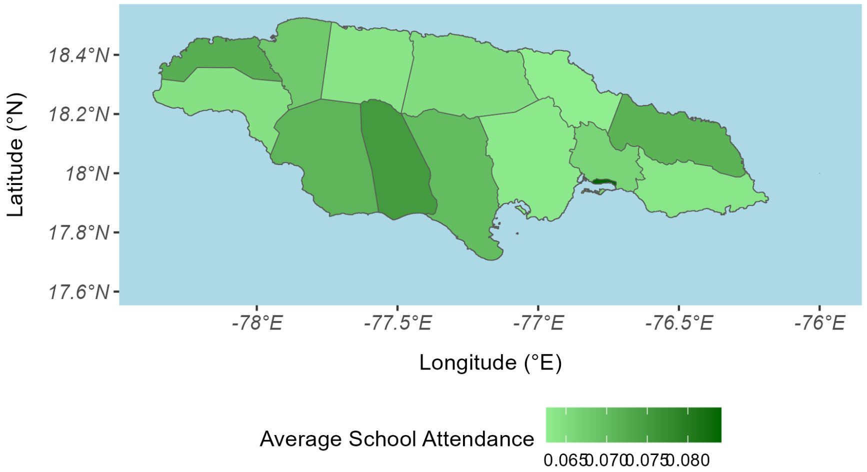


FIGURE C.1: Spatial Distribution (and intensity) of Hurricanes between 1895 and 1942.



(A) School Attendance



(B) School Attendance (LOG) as share of Population

FIGURE C.2: Spatial Distribution of: (a) School Attendance, (b) School Attendance (LOG) as share of Population.

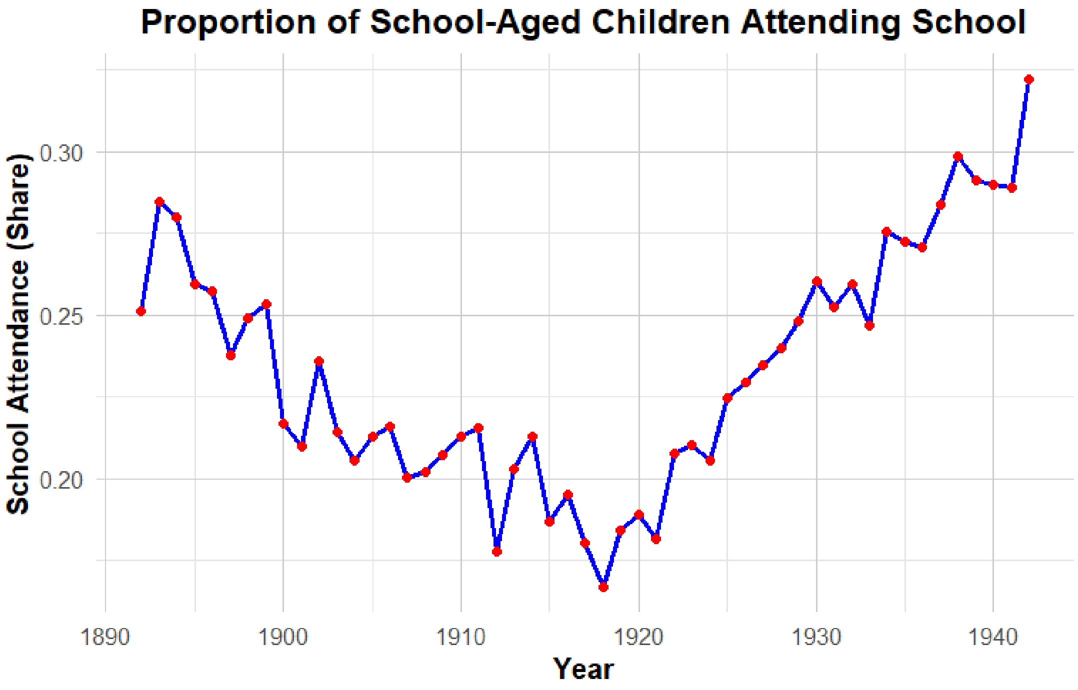


FIGURE C.3: Proportion of School-Aged Children (6-14 years old) Attending School

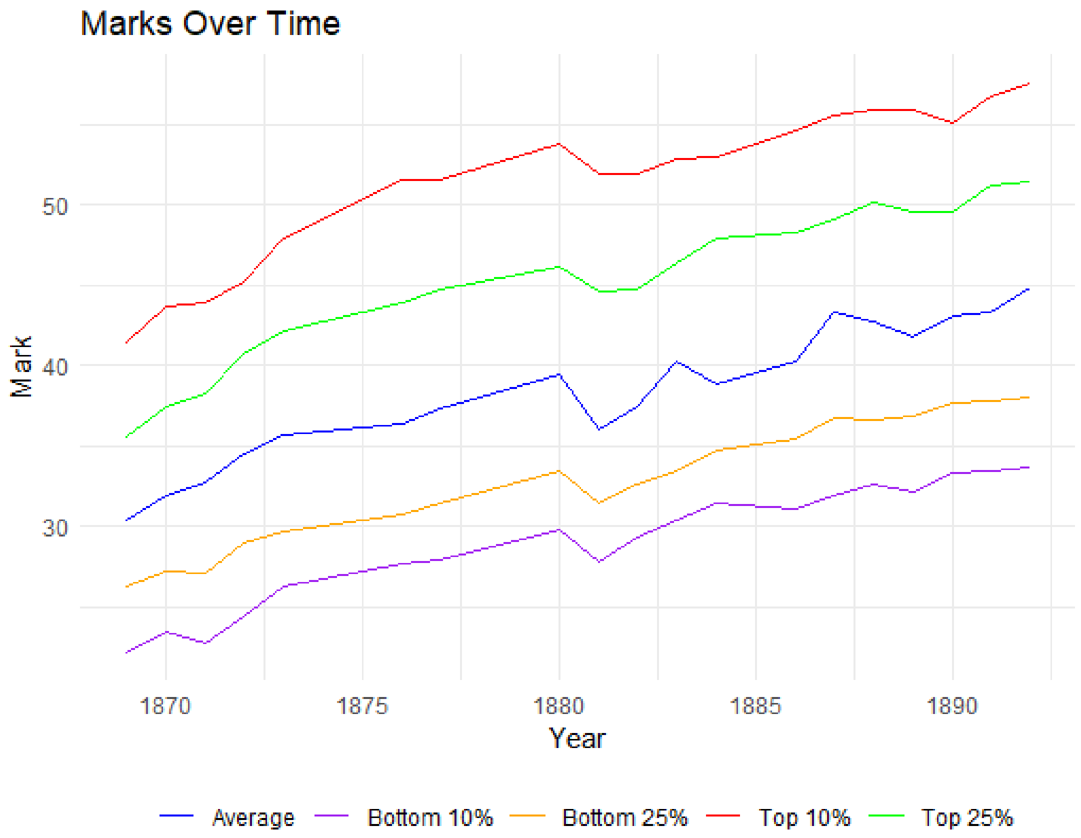


FIGURE C.4: Marks over time

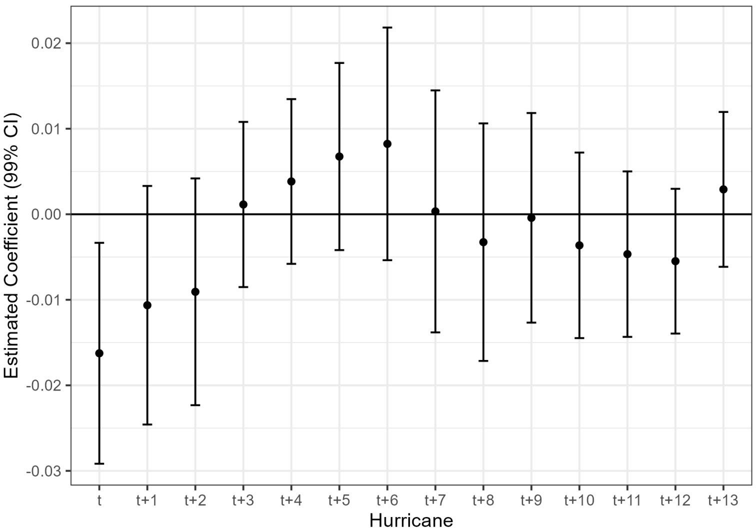


FIGURE C.5: Impact of hurricanes (95% CI) on school attendance (119km/h)

TABLE C.1: Effect of Hurricanes on School Attendance

Model:	(1) 119km/h	(2) 119km/h	(3) 154km/h	(4) 154km/h
Variables				
$HURR_t$	-0.0155***	-0.0146***	-0.0201***	-0.0212***
	(0.0050)	(0.0048)	(0.0063)	(0.0074)
$HURR_{t-1m}$	-0.0096*	0.0020	-0.0186***	-0.0037
	(0.0053)	(0.0035)	(0.0063)	(0.0040)
$HURR_{t-2m}$	-0.0077	7.75×10^{-5}	-0.0148**	-0.0007
	(0.0051)	(0.0027)	(0.0063)	(0.0035)
$HURR_{t-3m}$	0.0026	0.0084***	-0.0006	0.0097**
	(0.0037)	(0.0030)	(0.0043)	(0.0039)
$HURR_{t-4m}$	0.0055	0.0059*	0.0057	0.0085*
	(0.0038)	(0.0032)	(0.0048)	(0.0044)
$HURR_{t-5m}$	0.0086**	0.0051	0.0099**	0.0066*
	(0.0043)	(0.0036)	(0.0048)	(0.0040)
$HURR_{t-6m}$	0.0106**	0.0058	0.0118	0.0074
	(0.0050)	(0.0041)	(0.0073)	(0.0056)
$INFLUENZA_t$	-0.5435***	-0.2385***	-0.5443***	-0.2386***
	(0.0893)	(0.0857)	(0.0893)	(0.0858)
$LINTREND$	-17.05***	-6.262***	-16.49***	-5.597***
	(0.8894)	(1.028)	(0.8391)	(0.9918)
$EARTHK_t$		-0.0295		-0.0295
		(0.0182)		(0.0182)
$EARTHK_{t-1m}$		0.0054*		0.0054*
		(0.0028)		(0.0028)
$EARTHK_{t-2m}$		0.0026		0.0026
		(0.0023)		(0.0023)

Continued on next page

TABLE C.1: (Continued) Effect of Hurricanes on School Attendance

Model:	(1) 119km/h	(2) 119km/h	(3) 154km/h	(4) 154km/h
$EARTHK_{t-3m}$		-0.0018		-0.0017
		(0.0025)		(0.0025)
$EARTHK_{t-4m}$		0.0014		0.0014
		(0.0026)		(0.0026)
$EARTHK_{t-5m}$		-0.0040*		-0.0040*
		(0.0024)		(0.0024)
$EARTHK_{t-6m}$		0.0011		0.0012
		(0.0024)		(0.0024)
$Attendance_{t+1m}$		0.5384***		0.5389***
		(0.0391)		(0.0390)
Fit statistics				
Observations	8,541	8,541	8,541	8,541
R^2	0.87010	0.90963	0.86977	0.90950
Within R^2	0.10980	0.38067	0.10753	0.37980

Heteroskedasticity-robust standard-errors in parentheses.

*Signif. Codes: ***: 0.01, **: 0.05, *: 0.1.*

Parish level, yearly and monthly fixed effects are included in all models. $HURR$ represents the cubic wind speed divided by 1 million, $EARTHK$ represents the Rossi Forel scale of the Kingston earthquake, $INFLUENZA$ is an Influenza dummy for October, November, and December in 1918, as well as for January and February in 1919 and $LINTREND$ are parish-level linear trends.

TABLE C.2: Effect of Hurricanes on School Attendance

Model:	(1)	(2)	(3)	(4)	(5)	(6)
	119km/h	119km/h	154km/h	154km/h	119km/h	119km/h
Variables						
$HURR_{t+1m}$	0.0031	0.0031	0.0044	0.0053	0.0054	0.0053
	(0.0044)	(0.0045)	(0.0044)	(0.0059)	(0.0059)	(0.0061)
$HURR_{t}$	-0.0193***	-0.0193***	-0.0177***	-0.0214***	-0.0214***	-0.0207***
	(0.0056)	(0.0056)	(0.0053)	(0.0069)	(0.0069)	(0.0065)
$HURR_{t-1m}$	-0.0151***	-0.0151***	-0.0106**	-0.0236***	-0.0237***	-0.0198***
	(0.0058)	(0.0058)	(0.0054)	(0.0068)	(0.0068)	(0.0064)
$HURR_{t-2m}$	-0.0162***	-0.0162***	-0.0088*	-0.0236***	-0.0237***	-0.0163**
	(0.0056)	(0.0056)	(0.0052)	(0.0068)	(0.0068)	(0.0064)
$HURR_{t-3m}$	-0.0076*	-0.0077*	0.0014	-0.0115***	-0.0115***	-0.0023
	(0.0040)	(0.0041)	(0.0038)	(0.0043)	(0.0043)	(0.0043)
$HURR_{t-4m}$	-0.0051	-0.0051	0.0040	-0.0045	-0.0046	0.0041
	(0.0040)	(0.0040)	(0.0037)	(0.0048)	(0.0049)	(0.0047)
$HURR_{t-5m}$	-0.0031	-0.0029	0.0070	-0.0001	-4.93×10^{-5}	0.0082*
	(0.0046)	(0.0046)	(0.0043)	(0.0050)	(0.0050)	(0.0047)
$HURR_{t-6m}$	-0.0033	-0.0034	0.0085	0.0009	0.0010	0.0100
	(0.0057)	(0.0057)	(0.0053)	(0.0074)	(0.0074)	(0.0072)
$HURR_{t-7m}$	0.0003	-0.0016	0.0004	0.0007	0.0007	0.0027
	(0.0060)	(0.0064)	(0.0055)	(0.0075)	(0.0076)	(0.0062)
$EARTHK_{t}$	-0.0244	-0.0502**	-0.0467**	-0.0247	-0.0506**	-0.0469**
	(0.0184)	(0.0224)	(0.0223)	(0.0184)	(0.0224)	(0.0223)
$EARTHK_{t-1m}$	-0.0076	-0.0330***	-0.0297**	-0.0079	-0.0334***	-0.0298**
	(0.0083)	(0.0126)	(0.0123)	(0.0083)	(0.0126)	(0.0123)
$EARTHK_{t-2m}$	-0.0024	-0.0278**	-0.0232**	-0.0028	-0.0282**	-0.0233**
	(0.0064)	(0.0112)	(0.0109)	(0.0064)	(0.0112)	(0.0109)
$EARTHK_{t-3m}$	-0.0038	-0.0294***	-0.0247**	-0.0042	-0.0297***	-0.0248**
	(0.0056)	(0.0107)	(0.0104)	(0.0056)	(0.0108)	(0.0104)
$EARTHK_{t-4m}$	-0.0012	-0.0267**	-0.0221**	-0.0016	-0.0271**	-0.0222**
	(0.0051)	(0.0105)	(0.0101)	(0.0051)	(0.0105)	(0.0102)
$EARTHK_{t-5m}$	-0.0058	-0.0312***	-0.0266***	-0.0061	-0.0317***	-0.0268***
	(0.0043)	(0.0101)	(0.0098)	(0.0043)	(0.0102)	(0.0098)
$EARTHK_{t-6m}$	-0.0024	-0.0279***	-0.0233**	-0.0028	-0.0283***	-0.0236**
	(0.0038)	(0.0100)	(0.0096)	(0.0038)	(0.0100)	(0.0096)
$INFLUENZA$			-0.5483***			-0.5454***
			(0.0886)			(0.0893)
$LINTREND$			-14.84***			-14.60***
			(0.7820)			(0.7499)
$HURR_{t-7m,\dots,t-12m}$	No	Yes	No	Yes	No	Yes
$EARTHK_{t-7m,\dots,t-12m}$	No	Yes	No	Yes	No	Yes

Continued on next page

TABLE C.2: Effect of Hurricanes on School Attendance (continued)

Model:	(1) 119km/h	(2) 119km/h	(3) 154km/h	(4) 154km/h	(5) 119km/h	(6) 119km/h
Fit statistics						
Observations	8,793	8,793	8,793	8,793	8,793	8,793
Within R^2	0.00801	0.01268	0.11373	0.00470	0.00906	0.11147

Heteroskedasticity-robust standard-errors in parentheses.
*Signif. Codes: ***: 0.01, **: 0.05, *: 0.1.*
Parish level, yearly and monthly fixed effects are included in all models. $HURR$ represents the cubic wind speed divided by 1 million, $EARTHK$ represents the Rossi Forel scale of the Kingston earthquake, $INFLUENZA$ is an Influenza dummy for October, November, and December in 1918, as well as for January and February in 1919 and $LINTREND$ are parish-level linear trends.

Table C.3: Effect of Hurricanes on School Attendance

Model:	(1) 119km/h	(2) 119km/h	(3) 119km/h	(4) 119km/h
Variables				
$DESTR_m$	-10.20^{***}	-7.81^{***}	-5.90^{***}	-5.87^{***}
	(1.53)	(2.02)	(1.88)	(1.88)
$DESTR_{t-1m}$		-5.46^{**}	-2.91	-2.91
		(2.28)	(2.10)	(2.1)
$DESTR_{t-2m}$		-1.24	1.19	1.19
		(1.92)	(1.77)	(1.77)
$DESTR_{t-3m}$		-1.89	0.93	0.948
		(1.96)	(1.75)	(1.75)
$DESTR_{t-4m}$		-2.54	1.48	1.50
		(2.02)	(1.84)	(1.84)
$DESTR_{t-5m}$		-4.82^{**}	0.49	0.43
		(1.99)	(1.87)	(1.88)
$INFLUENZA$		-0.54***	-0.54***	-0.55***
		(0.09)	(0.09)	(0.09)
$LINTREND$			-16.40***	-16.35***
			(0.88)	(0.88)
$EARTHK_t$				-0.0235
				(0.0181)
$EARTHK_{t-1m}$				-0.0071
				(0.0081)
$EARTHK_{t-2m}$				-0.0004
				(0.0062)
$EARTHK_{t-3m}$				-0.0018
				(0.0054)
$EARTHK_{t-4m}$				0.0006
				(0.0049)
$EARTHK_{t-5m}$				-0.0036
				(0.0042)
$EARTHK_{t-6m}$				-0.0005
				(0.0037)
Fit statistics				
Observations	8,541	8,541	8,541	8,541
R^2	0.85446	0.86492	0.86974	0.87005
Within R^2	0.00262	0.07429	0.10733	0.10947

*Heteroskedasticity-robust standard-errors in parentheses. Signif. Codes: ***: 0.01, **:*

*0.05, *: 0.1.* Parish level, yearly and monthly fixed effects are included in all models. $DESTR$ represents the population weighted destruction index, $EARTHK$ represents the Rossi Forel scale of the Kingston earthquake, $INFLUENZA$ is an Influenza dummy for October, November, and December in 1918, as well as for January and February in 1919 and $LINTREND$ are parish-level linear trends.

TABLE C.4: Effect of Hurricanes on School Attendance

Model:	(1) 154km/h	(2) 154km/h	(3) 154km/h	(4) 154km/h
Variables				
$DESTR_t$	-10.60^{**}	-11.10^{**}	-8.68^{**}	-8.65^{**}
	(4.58)	(4.54)	(4.33)	(4.33)
$DESTR_{t-1m}$		-11.10^{**}	-6.82	-6.80
		(4.54)	(4.22)	(4.22)
$DESTR_{t-2m}$		-5.87^{*}	-0.29	-0.27
		(3.00)	(2.95)	(2.96)
$DESTR_{t-3m}$		-4.22	1.91	1.93
		(3.20)	(3.23)	(3.23)
$DESTR_{t-4m}$		-3.01	3.63	3.65
		(3.09)	(3.03)	(3.03)
$DESTR_{t-5m}$		-2.75	4.71	4.73
		(3.93)	(3.87)	(3.87)
$DESTR_{t-6m}$		-2.37	3.55	3.41
		(3.04)	(2.66)	(2.69)
$INFLUENZA$		-0.5385***	-0.5444***	-0.5450***
		(0.0885)	(0.0893)	(0.0893)
$LINTREND$			-16.49***	-16.43***
			(0.8389)	(0.8391)
$EARTHK_t$				-0.0236
				(0.0181)
$EARTHK_{t-1m}$				-0.0072
				(0.0081)
$EARTHK_{t-2m}$				-0.0005
				(0.0062)
$EARTHK_{t-3m}$				-0.0019
				(0.0054)
$EARTHK_{t-4m}$				0.0005
				(0.0049)
$EARTHK_{t-5m}$				-0.0037
				(0.0042)
$EARTHK_{t-6m}$				-0.0005
				(0.0037)
Fit statistics				
Observations	8,541	8,541	8,541	8,541
R^2	0.85415	0.86436	0.86962	0.86993
Within R^2	0.00049	0.07049	0.10648	0.10862

*Heteroskedasticity-robust standard-errors in parentheses. Signif. Codes: ***: 0.01, **:*

*0.05, *: 0.1.* Parish level, yearly and monthly fixed effects are included in all models. $DESTR$ represents the population weighted destruction index, $EARTHK$ represents the Rossi Forel scale of the Kingston earthquake, $INFLUENZA$ is an Influenza dummy for October, November, and December in 1918, as well as for January and February in 1919 and $LINTREND$ are parish-level linear trends.

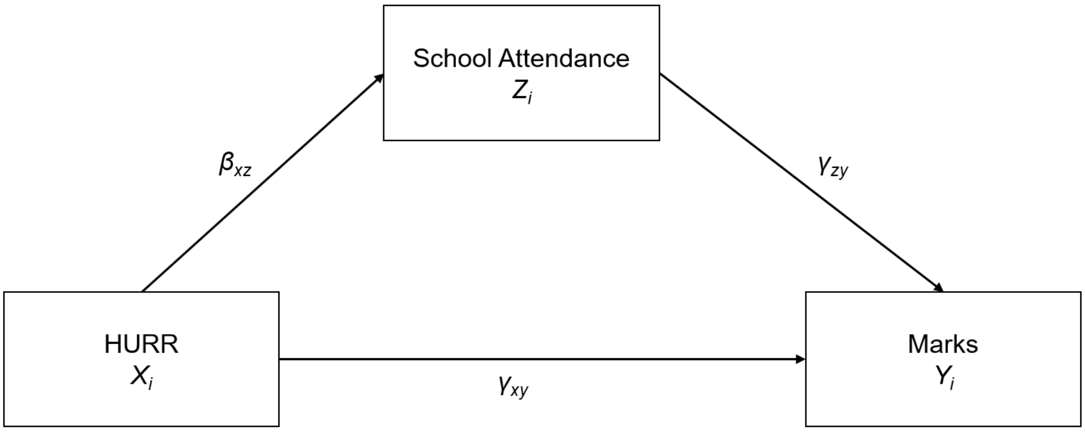


FIGURE C.6: Graphical Illustration of the Mediation Analysis

TABLE C.5: Mediation Analysis: First and Second Stage

	Panel A: First Stage					
	(1)	(2)	(3)	(4)	(5)	(6)
Variables						
$HURR_t$	-0.009**	-0.056***	-0.052***	-0.009**	-0.056***	-0.052***
	(0.004)	(0.017)	(0.016)	(0.004)	(0.017)	(0.016)
Adj. R^2	0.098	0.130	0.204	0.098	0.130	0.001
	Panel B: Second Stage					
	(1)	(2)	(3)	(4)	(5)	(6)
$Attendance_t$	12.335***	11.986***	10.435***	12.335***	11.986***	10.435***
	(0.027)	(0.276)	(0.276)	(0.274)	(0.276)	(0.276)
$HURR_t$	0.087	0.017	0.003	0.087	0.017	0.003
	(0.062)	(0.318)	(0.308)	(0.004)	(0.318)	(0.308)
Adj. R^2	0.339	0.350	0.392	0.339	0.350	0.392
Location FE	Yes	Yes	Yes	Yes	Yes	Yes
Yearly FE	No	Yes	Yes	No	Yes	Yes
Teacher Trained	No	No	Yes	No	No	Yes
Observations	9,321	9,321	9,321	9,321	9,321	9,321

Robust standard-errors in parentheses. Dependent Variable in Panel A is *Average Attendance (log)* and the dependent Variable in Panel B is *MARKS*. The independent variable is *HURR*, whereas the threshold is set at 119km/h (columns 1 to 3) or 154km/h (columns 4 to 6). Town-fixed effects are included in all regressions. Yearly-fixed Effects are included in columns (2), (3), (5) and (6) and a variable indicating whether the teacher is trained or not is included in columns (3) and (6). Signif. Codes:***: 0.01,**: 0.05,*: 0.1

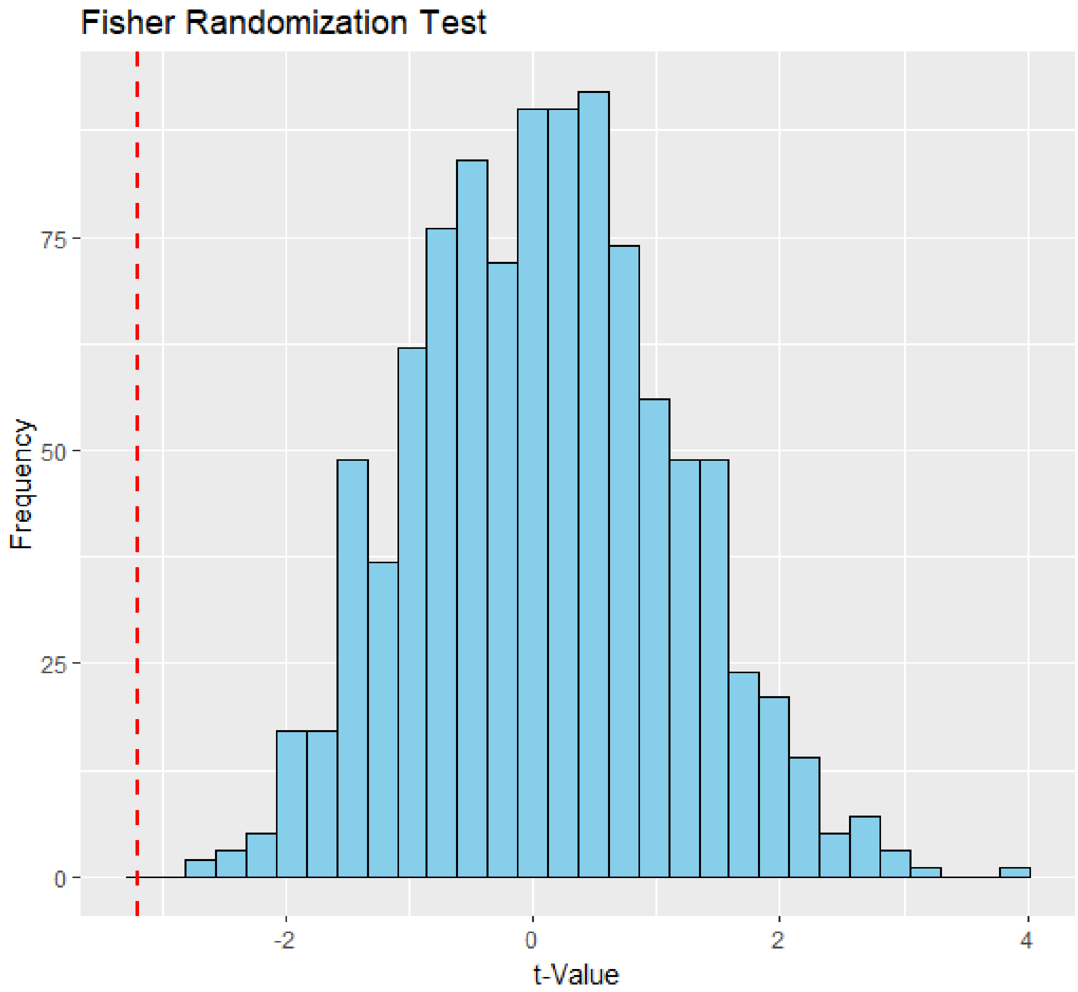


FIGURE C.7: Fisher Randomization Test: $HURR_t$

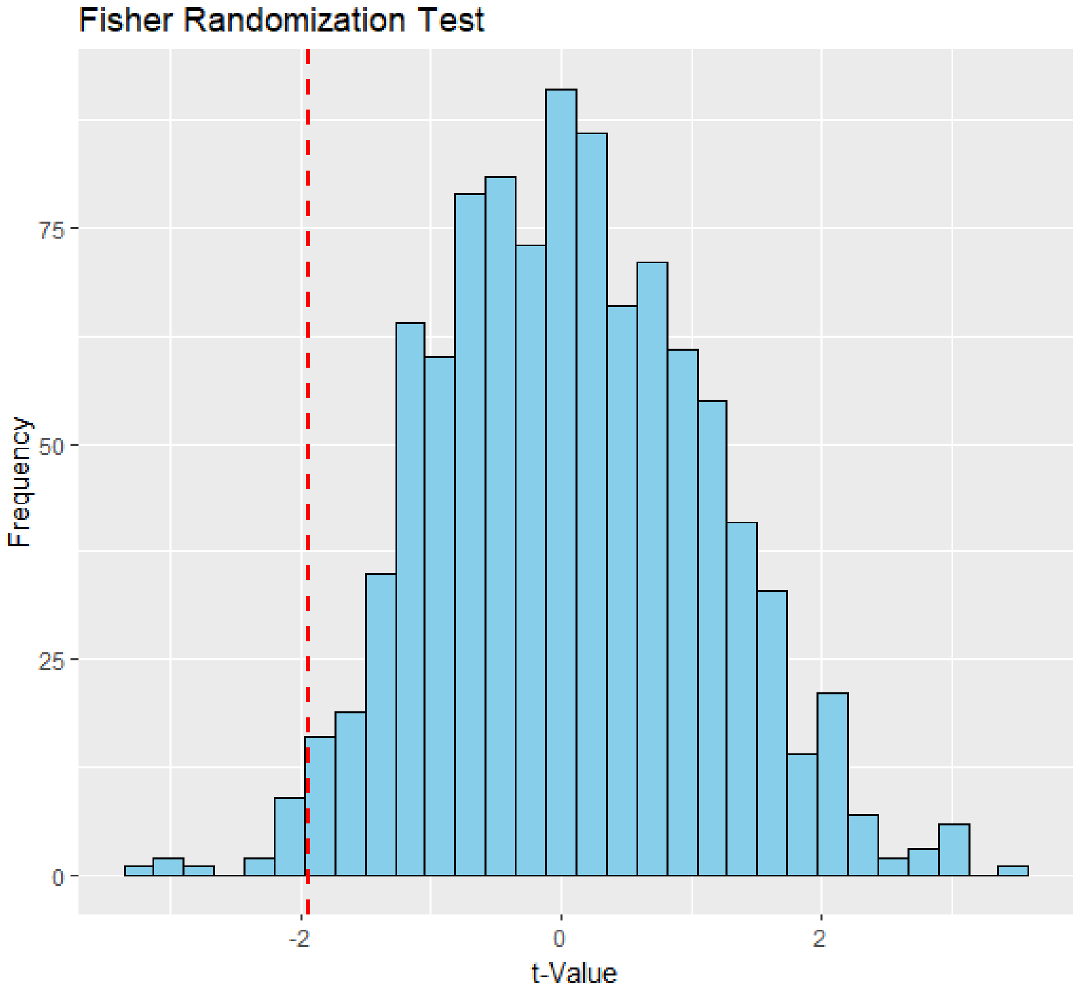


FIGURE C.8: Fisher Randomization Test: $HURR_{t-1m}$

Appendix D

Floods & Market Access

TABLE D.1: Parish Level Summary Statistics

Parish	$\frac{Floods}{Year}$	$\frac{COSTFLOOD}{Mile}$	$\frac{COSTFLOOD}{Expenditure}$
Clarendon	0.36	505.23	0.096
Hanover	0.24	157.12	0.060
Kingston	0.17	2.29	0.042
Manchester	0.55	41.48	0.018
Portland	2.88	911.93	0.144
Saint Andrew	0.67	871.40	0.155
Saint Ann	0.36	229.85	0.051
Saint Catherine	0.91	803.84	0.146
Saint Elizabeth	0.73	75.10	0.020
Saint James	1.09	296.27	0.093
Saint Mary	1.27	1,130.81	0.120
Saint Thomas	1.09	736.71	0.141
Trelawny	0.15	130.61	0.054
Westmoreland	0.18	113.50	0.031
Jamaica	10.65	6,006.14	0.084

Notes: $\frac{Floods}{Year}$ is the number of flood events per year, $\frac{COSTFLOOD}{Mile}$ is the expenditure on roads due to flood repair per mile of road, and $\frac{COSTFLOOD}{Expenditure}$ is the share of total expenditure on roads for flood repair.

TABLE D.2: Impact of Market Access on Total Tax Revenue for various α and θ

Panel A: MA no Damage

Model:	(1)	(2)	(3)	(4)	(5)	(6)
α	1	10.8	1	10.8	1	10.8
θ	1.815	1.815	2.788	2.788	8.22	8.22
$MA_t^{\mathbf{NF}}$	-0.0018	0.0007	-0.0006	-0.0007	-0.0002	-2.87×10^{-5}
	(0.0028)	(0.0019)	(0.0012)	(0.0013)	(0.0004)	(0.0003)
$MA_{t-1}^{\mathbf{NF}}$	0.0084*	0.0016	0.0040*	0.0019	0.0011*	0.0005
	(0.0050)	(0.0018)	(0.0023)	(0.0017)	(0.0006)	(0.0003)
$MA_{t-2}^{\mathbf{NF}}$	0.0038	2.13×10^{-5}	0.0024	-0.0005	0.0003	0.0005
	(0.0038)	(0.0022)	(0.0018)	(0.0013)	(0.0003)	(0.0003)
$MA_{t-3}^{\mathbf{NF}}$	0.0068**	0.0031	0.0024	0.0019	0.0007	0.0004
	(0.0034)	(0.0024)	(0.0018)	(0.0012)	(0.0005)	(0.0004)
Observations	371	371	371	371	371	371
Within R^2	0.12377	0.07888	0.12020	0.09140	0.12098	0.10432

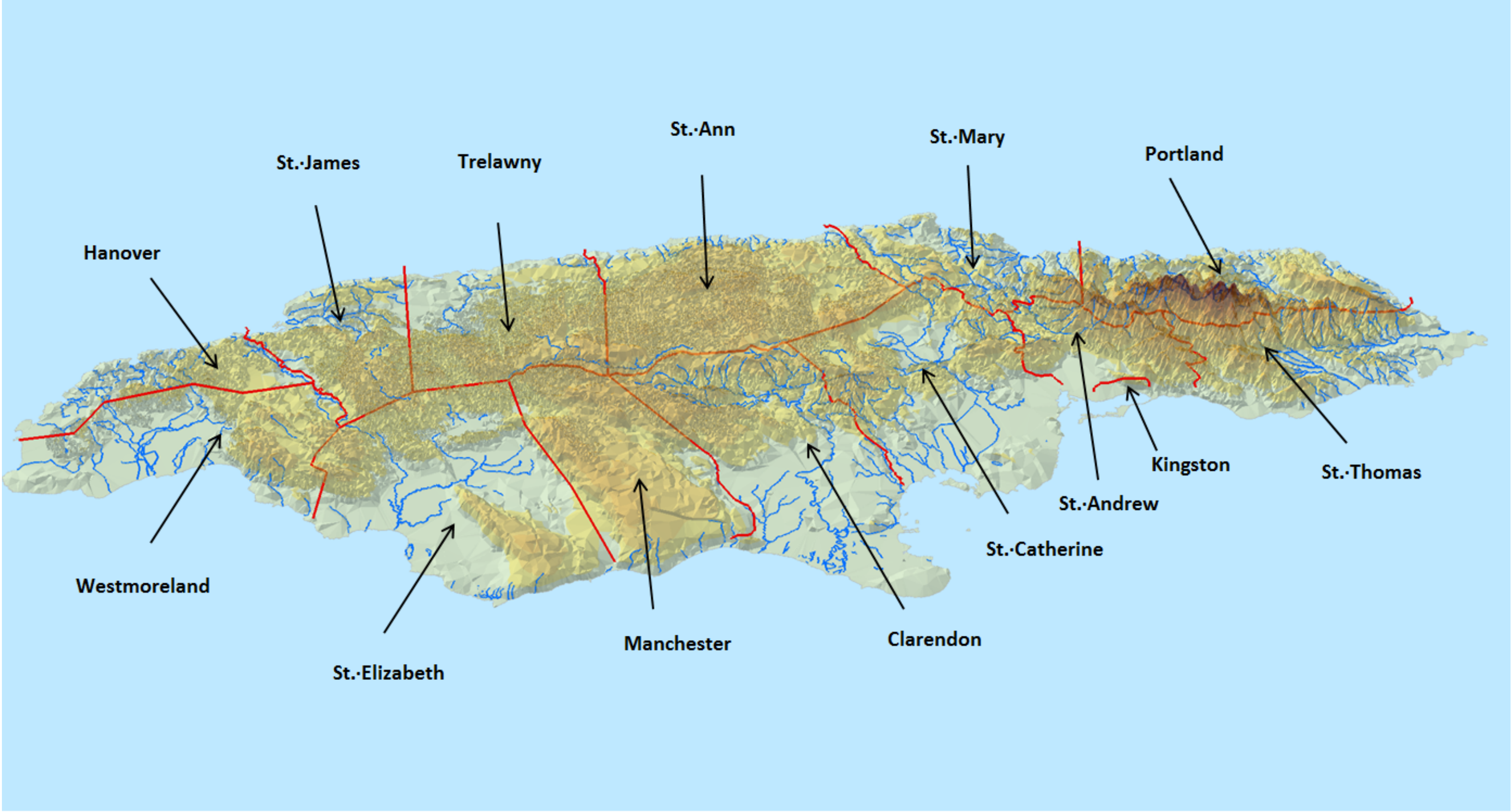
Panel B: FMA & MA Damage

Model:	(1)	(2)	(3)	(4)	(5)	(6)
α	1	10.8	1	10.8	1	10.8
θ	1.815	1.815	2.788	2.788	8.22	8.22
FMA_t	-0.1911***	-0.1440**	-0.1045***	-0.0853**	-0.0230***	-0.0148*
	(0.0667)	(0.0698)	(0.0348)	(0.0370)	(0.0086)	(0.0076)
FMA_{t-1}	-0.1693*	-0.2051*	-0.0838*	-0.0633	-0.0155*	-0.0172*
	(0.0925)	(0.1076)	(0.0431)	(0.0442)	(0.0091)	(0.0101)
FMA_{t-2}	-0.1071	-0.1059	-0.0615*	-0.0749**	-0.0203**	-0.0158*
	(0.0773)	(0.0667)	(0.0321)	(0.0330)	(0.0099)	(0.0087)
FMA_{t-3}	-0.0886	-0.1864	-0.0524	-0.0944*	-0.0159*	-0.0168
	(0.1289)	(0.1196)	(0.0579)	(0.0569)	(0.0088)	(0.0126)
$MA_t^{\mathbf{F=0,1}}$	-0.0027	0.0003	-0.0011	-0.0009	-0.0003	-7.09×10^{-5}
	(0.0028)	(0.0019)	(0.0012)	(0.0013)	(0.0004)	(0.0003)
$MA_{t-1}^{\mathbf{F=0,1}}$	0.0079	0.0012	0.0039*	0.0018	0.0011*	0.0004
	(0.0050)	(0.0018)	(0.0023)	(0.0017)	(0.0006)	(0.0003)
$MA_{t-2}^{\mathbf{F=0,1}}$	0.0035	-0.0005	0.0024	-0.0008	0.0003	0.0005
	(0.0041)	(0.0022)	(0.0019)	(0.0013)	(0.0004)	(0.0003)
$MA_{t-3}^{\mathbf{F=0,1}}$	0.0065*	0.0024	0.0024	0.0018	0.0008	0.0004
	(0.0036)	(0.0023)	(0.0019)	(0.0012)	(0.0005)	(0.0004)
Observations	371	371	371	371	371	371
Within R^2	0.13928	0.09828	0.13911	0.11022	0.14048	0.11805

Notes: (a) Dependent Variable is the inverse hyperbolic sine transformation of total tax revenue; (b) Parish and time specific fixed effects, parish specific time trends, and mean annual rainfall as well as its interaction with sugar, cassava, banana, and coffee suitability measures are included in all regressions;

(c) ***, **, and * indicate 1, 5, and 10 percent significance levels, respectively; (d) Standard errors are clustered at the parish level.

FIGURE D.1: Parishes of Jamaica



Notes: (a) Red lines delineate parish boundaries. Light blue lines identify river system; (b) Increased background shading of brown indicates higher elevation.

FIGURE D.2: Flood Disruptions to Jamaican Railway and Road System in 1917

Notes: (a) Black line is railway system in 1917 and black dots corresponding railway stations; (b) Red lines are major roads unaffected by flooding in 1917; (c) Dark blue lines are major roads affected by flooding in 1917; (d) Railway lines and stations are elevated to 5000 meters and major roads to 4000m above sea level for visual purposes.

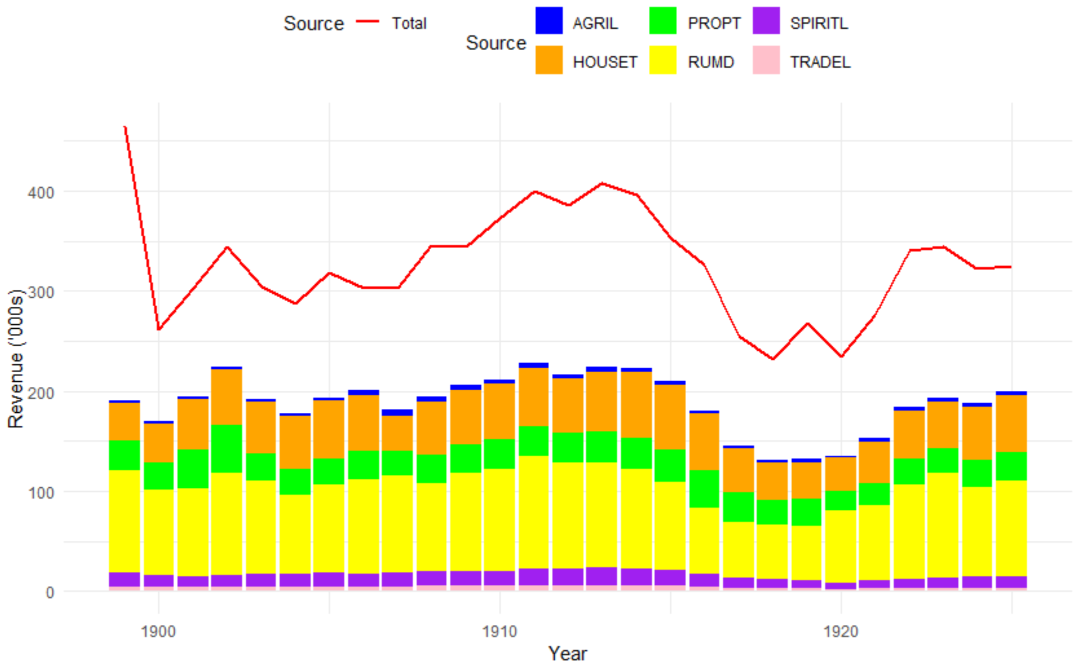


FIGURE D.3: Total Internal Tax Revenue & Components

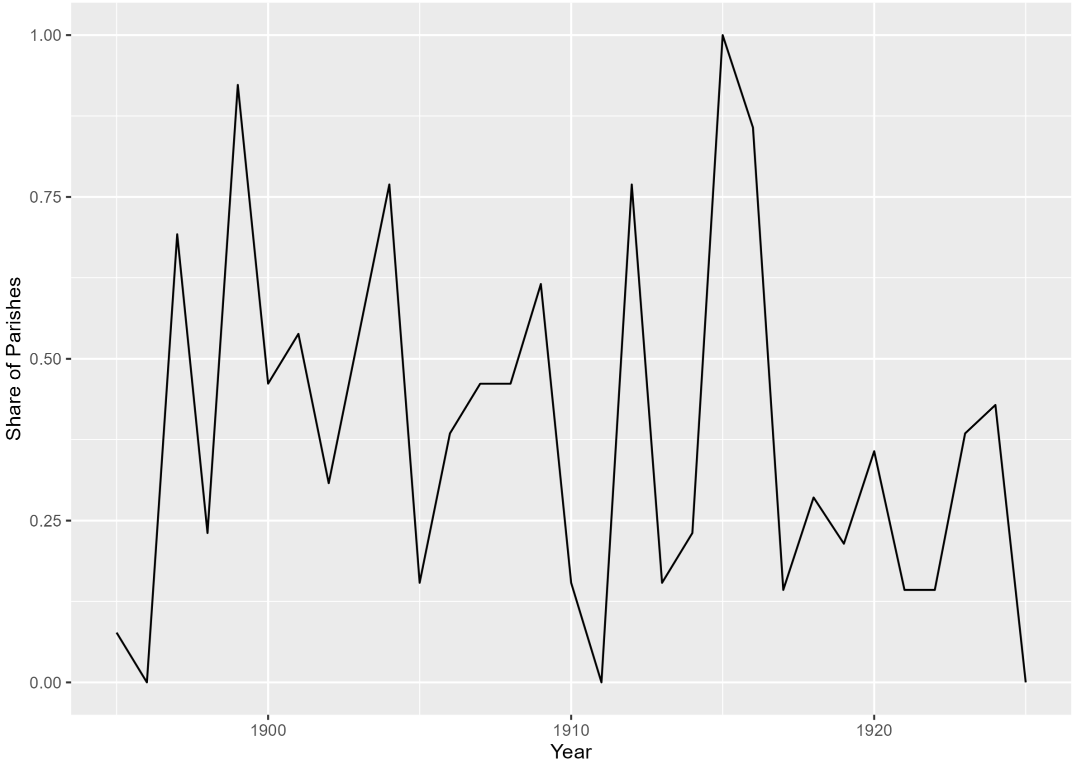


FIGURE D.4: Share of Parishes affected by a Flood over time.

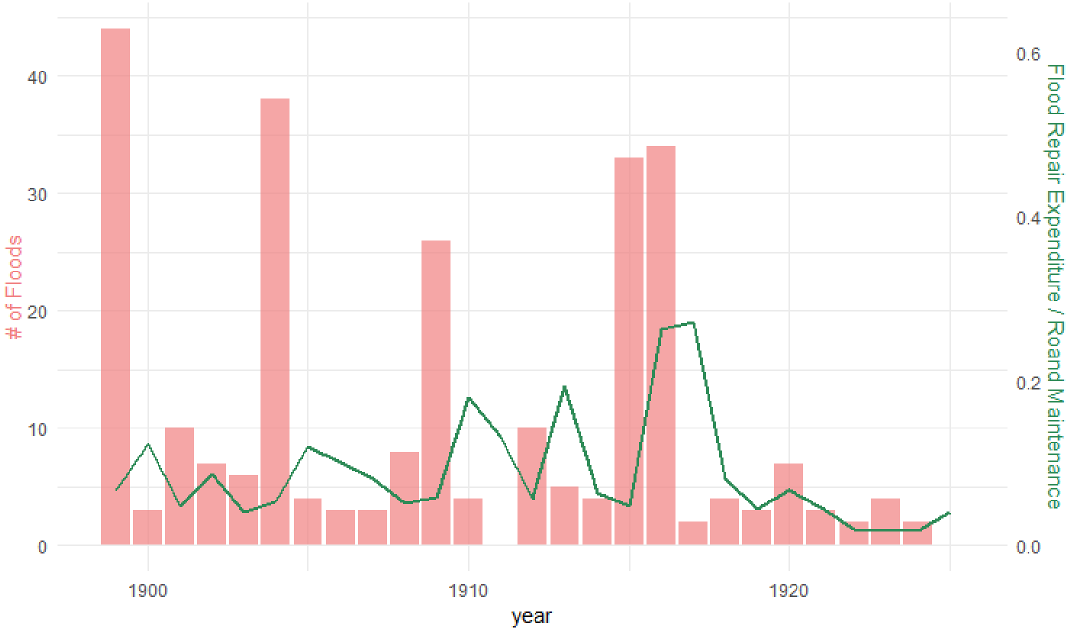


FIGURE D.5: Evolution of Number of Floods per Year (total) and Share of Road Maintenance for Flood Repairs

Appendix E

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I declare herewith that I wrote this thesis on my own, without the help of others. Wherever I have used permitted sources of information, I have made this explicitly clear within my text and I have listed the referenced sources. I understand that if I do not follow these rules that the Senate of the University of Bern is authorized to revoke the title awarded on the basis of this thesis according to Article 36, paragraph 1, litera r of the University Act of September 5th, 1996.

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Joël Yves Hüsler