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Abstract

We investigate how the frequent flooding that damaged the internal transport infrastructure in late 19th and early 20th colonial Jamaica affected local economies. To this end the evolution of the road and railways transport system was geo-referenced and combined with geo-localized damaging flood events, as well as with information on local economic activity proxied by internal tax revenue. Econometric analysis on our 30 year parish level time varying data set shows that lower market access from the flood disruptions to transport reduced tax revenue on average by 3.5%, and during some incidences up to 9.1%, over its two year impact. Decomposing the tax data by source suggests that both the property and the non-agricultural service sectors suffered after damaging floods. In contrast, flood disruptions benefited the agricultural sector, although only agricultural traders and not producers appear to have gained from investments in the transport network in general.

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Keywords: Transportation Network, Flooding, Market Access, Regional Economics, Jamaica

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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, 1954; 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, 1954; 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 et al. (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 et al., 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

[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.

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 et al., 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; Campbell et al., 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 et al., 2020). As noted by Lay et al. (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.

2 Historical Background

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 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]

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

[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.

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 et al., 2023), the latter resulting in flashfloods and landslides (Miller et al., 2009).

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 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]

[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).

[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.

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 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.

2.4.1 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

[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).

instigated an extensive repair and modernisation program, as well as extending it 24.5 miles to Porus (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.

2.4.2 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, 1954). 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 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

[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.

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, 1954; 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 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, 1954),[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).

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

[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 (1954) 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).

2.4.3 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).

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).

2.4.4 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

[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.

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, 1896b). 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, 1896b). Thus, given that the average daily wage rate was between 1 and 1.5 shillings 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] 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

[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, 1896b).

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).

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" (Departmen-

tal 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

[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).

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 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).

3 Data

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 2. In line with the outline of its evolution in Section 2.4.1, 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.

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 2. While the majority of major roads already existed in 1895, there were considerable extensions

[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)

over the next 30 years, where the road density increased from 2702 to 3259 km over this period, with additions across all parishes.

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 3. 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.

3.4 Tax Revenues

3.4.1 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.

3.4.2 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.

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

[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).

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

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 ($CROP$).

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 Methodology

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:

$$MA_{it}^{\mathbf{NF}} = \sum_{d \neq i} \tau_{idt}^{-\theta} N_{dt} \tag{1}$$

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:

$$\tau_{idt} = LCP_{idt}\Big(\mathbf{R}_t, \alpha\Big) \tag{2}$$

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 α 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 $\alpha = \Big(\alpha_{rail}, \alpha_{road}\Big)$, where we normalize α 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 (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:

$$FMA_{it} = MA_{it}^{\mathbf{NF}} - MA_{it}^{\mathbf{F}_t=0,1} \tag{3}$$

where $FMA_{it} \geq 0$.

4.2 Calculation of Market Access

There are four necessary inputs for calculating the market access measures in Equation 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 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 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 2.4.4, 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 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 (2024) 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

[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.

[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.

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 $MA_{it}^{\mathbf{F}_t=0,1}$.

4.3 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:

$$log(Y_{it}) = \alpha + \sum_{j=0}^{\rho} \beta_{MA_{t-j}^{\mathbf{NF}}} MA_{it-j}^{\mathbf{NF}} + \sum_{j=0}^{\rho} \beta_{\mathbf{X}_{t-j}} \mathbf{X_{it-j}} + \mu_i + \lambda_t + \gamma TREND_{it} + \epsilon_{it} \tag{4}$$

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) 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 3:

$$\begin{aligned} log(Y_{it}) = \alpha + \sum_{j=0}^{3} \beta_{MA_{t-j}^{\mathbf{F}=0,1}} MA_{it-j}^{\mathbf{F}=0,1} + \sum_{j=0}^{3} \beta_{FMA_{t-j}} FMA_{it-j} + \sum_{j=0}^{\rho} \beta_{\mathbf{X}_{t-j}} \mathbf{X_{it-j}} \\ + \mu_i + \lambda_t + \gamma TREND_{it} + \epsilon_{it} \end{aligned} \tag{5}$$

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) and (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 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) and (5).

5 Results

5.1 Descriptive Statistics

Table 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 4 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.

Examining the annual number of flood events in a parish ($FLOOD$) in Table 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 5 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 3 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 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 3 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 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.

5.2 Econometric Results

5.2.1 Total Tax Revenue

Table 4 Panel A shows the results of estimating equation (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%.

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) and (5) for various combinations of these parameters; see Table 5. 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 $\theta = 2.788$.

5.2.2 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 6. 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.

The remainder of the columns in Table 6 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 6, 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

[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 19^{th} century over 80 per cent of rum produced was exported; see Smith (2008).

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 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 6. 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 6. The increases similarly occurred in the first two years, but were considerably smaller than for the other service 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

[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.

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 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.

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

[30] For instance, Huesler and Strobl (2024) 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.

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

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 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 et al., 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 et al., 2022; Andreasen et al., 2023).

Table 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.

Table 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 $\theta = 2.788$ & α =4.5.

Table 3: 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 4: 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

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.

Table 5: 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.

Table 6: Impact of Market Access on Total Tax Revenue Components

Panel A: MA

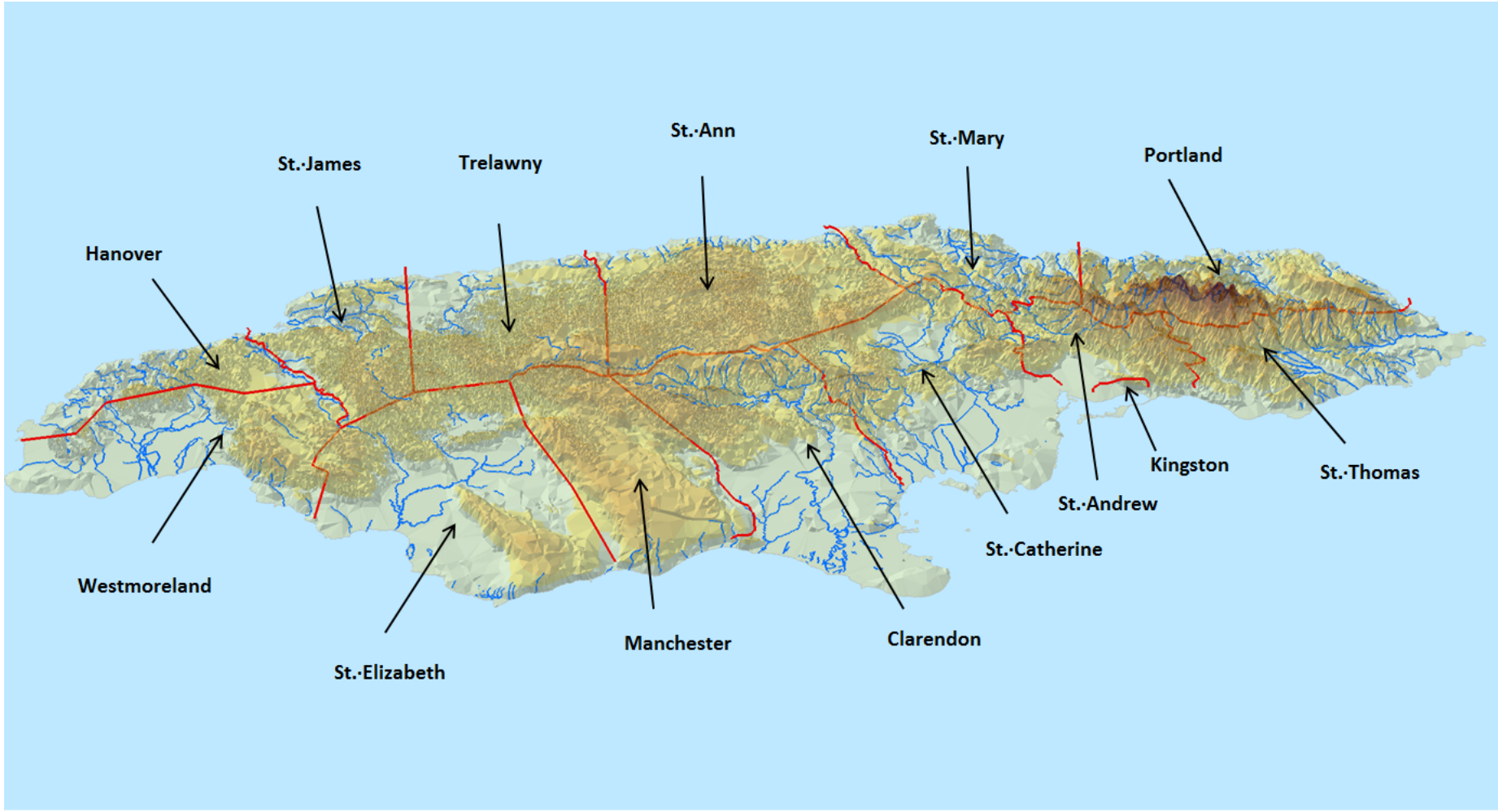
Dependent Variables:	STOTAL	HOUSET	PROPT	RUMD	SPIRITL	TRADEL	AGRIL	CROPS
Variables								
MA_t	0.0012	0.0184**	0.0185**	0.0184***	0.0141**	0.0114**	0.0034*	-0.0059
	(0.0011)	(0.0089)	(0.0082)	(0.0064)	(0.0068)	(0.0055)	(0.0017)	(0.0071)
MA_{t-1}	0.0040**	0.0215**	0.0219***	0.0182***	0.0164**	0.0130**	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

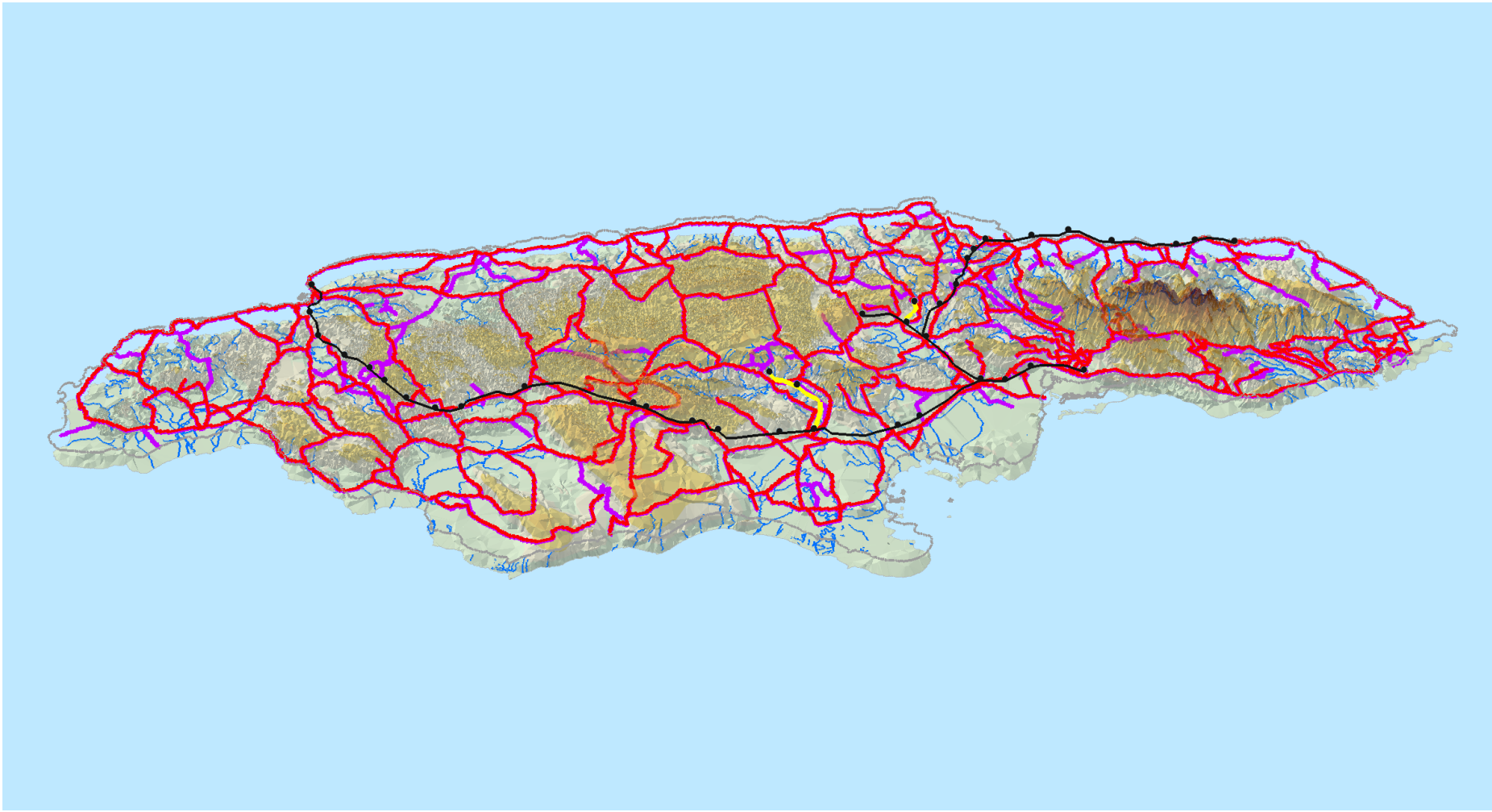
Notes: (a) Dependent variables are the inverse hyperbolic sine transformations of each tax revenue component; (b) Parish and time specific fixed effects, parish specific time trends, and mean annual rainfall as well as its interaction with sugar, cassava, banana, and coffee suitability measures are included 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.

Figure 1: Parishes of Jamaica



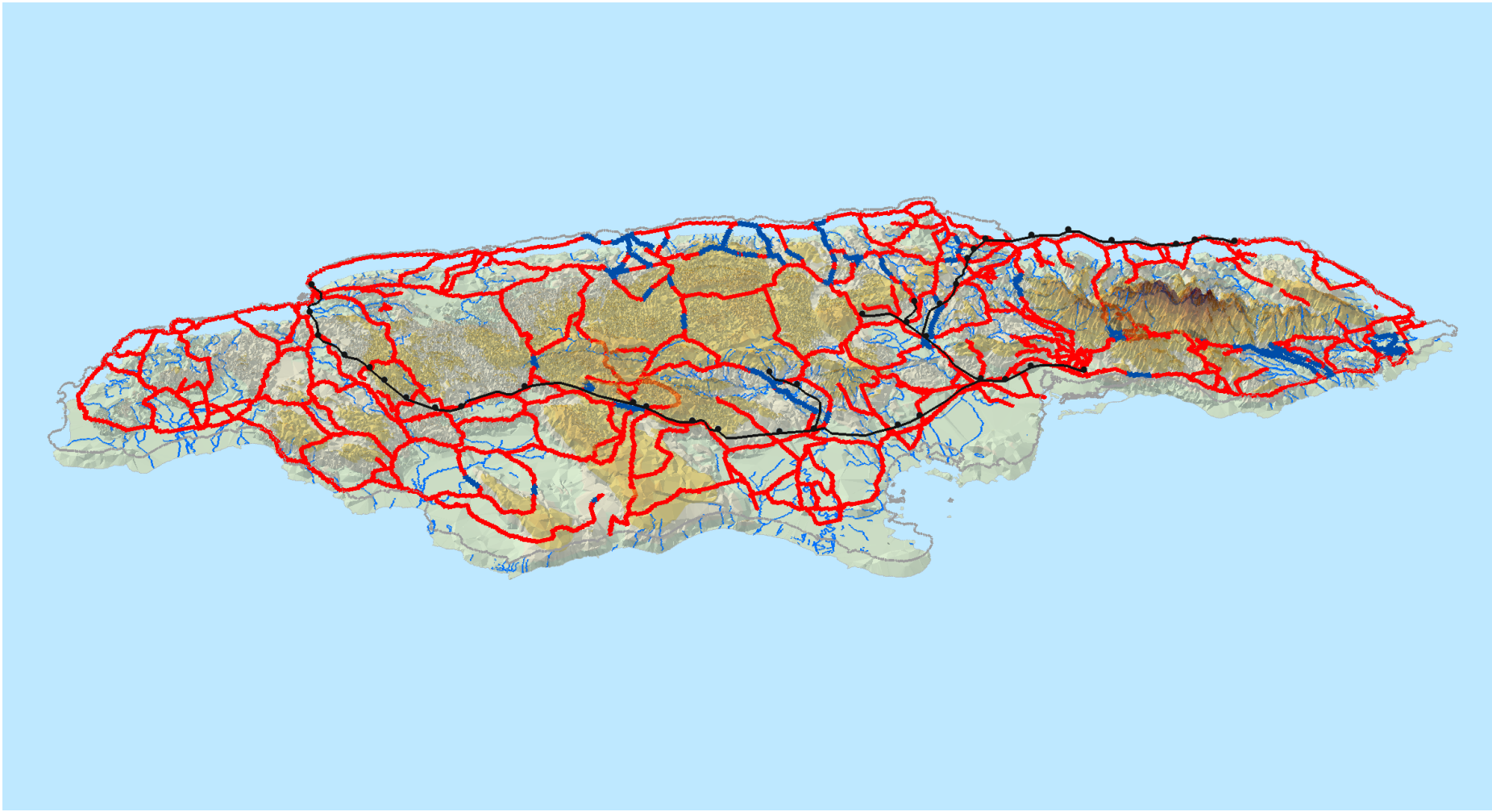
Notes: (a) Red lines delineate parish boundaries. Light blue lines identify river system; (b) Increased background shading of brown indicates higher elevation.

Figure 2: 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.

Figure 3: 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 4: Total Internal Tax Revenue & Components

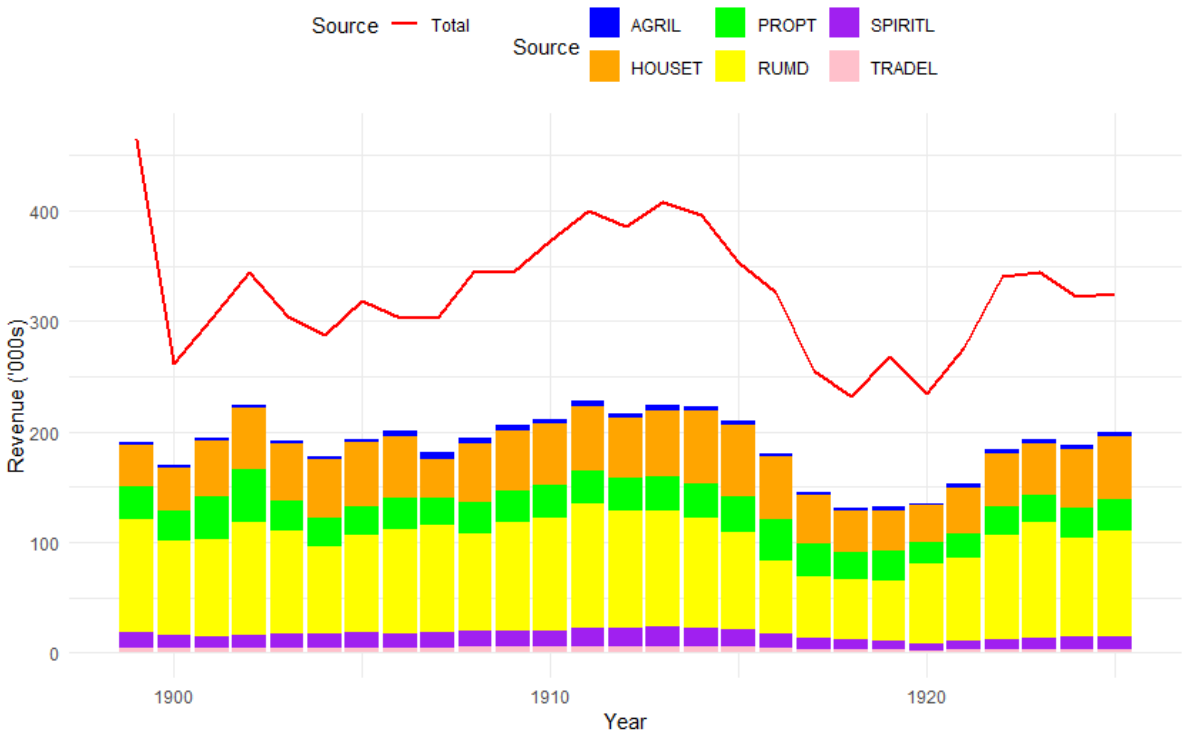


Figure 5: Share of Parishes affected by a Flood over time.

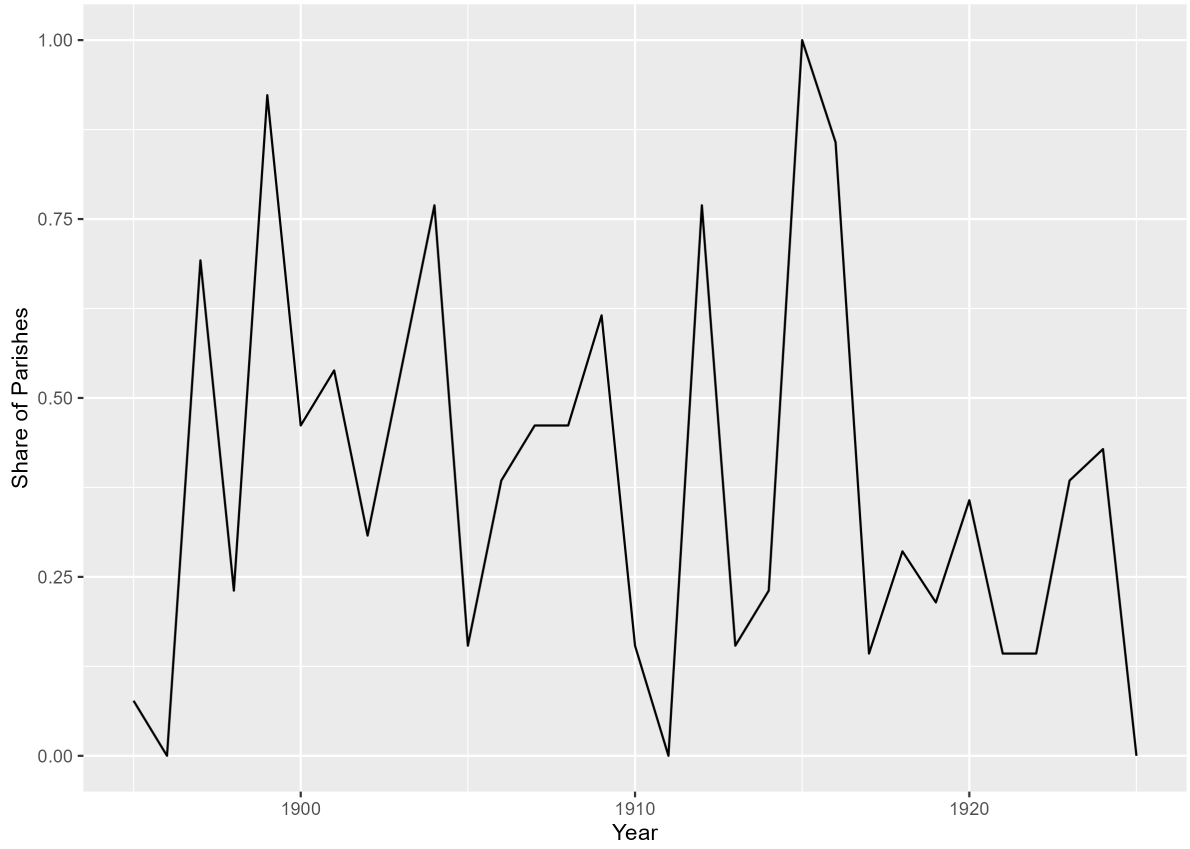
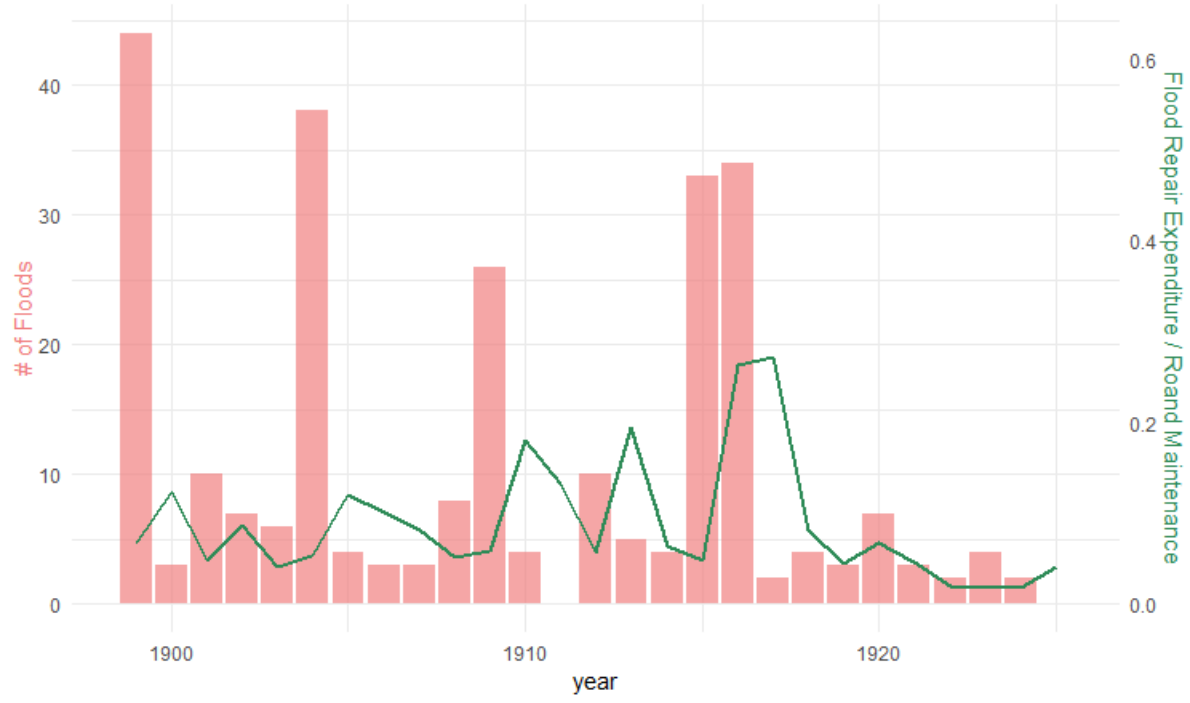


Figure 6: Evolution of Number of Floods per Year (total) and Share of Road Maintenance for Flood Repairs



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