Canals and Orchards: The Impact of Transport Network Expansion on Agricultural Productivity in 19th Century Bangkok*

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Abstract

This paper assesses the impact of Bangkok's nineteenth century canal network expansion on household cash crop cultivation decisions. Using a unique household-level dataset constructed from 1880s Bangkok orchard land deeds/tax records, we test whether the productivity of cash crop cultivation was higher when gaining better access to transport due to the expansion of Bangkok's canal network between 1826 and 1878. Under various measures that address potential endogeneity concerns, the results indicate that landowners with properties located adjacent to canals in sub-districts cross-cut by new canal infrastructure cultivated cash crops more intensively than landowners whose plots had no direct canal access. We conclude that increased access to transport networks as a result of major canal infrastructure projects for defence and international trade purposes incentivised cultivators to intensively cultivate locally consumed cash crops, which in turn had implications for the improvement in cultivators' standard of living.

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1 Introduction

What is the impact of transportation infrastructure expansion on economic development? Following Fogel's (1964) seminal work on the impact of the United States' rail infrastructure investment on various economic measures, there has been a resurgence of interest in empirical investigations into the impact of transport infrastructure on economic development using historical data. Basic transport network expansion, such as railways and roads, is seen as a means to increase market access, reduce transaction costs and provide more incentives for productivity improvements and market-oriented economic activities. Transport network expansion is not only found to be significantly linked to historical improvements in agricultural activities (Atack & Margo, 2011; Donaldson & Hornbeck, 2016; Donaldson, 2010), it is also shown to be important for industrial development (Tang, 2014; Banerjee, Duflo, & Qian, 2012). Nevertheless, constrained by the availability of micro-level historical data, the existing literature focuses on the impact of transport infrastructure at an aggregate level. Although previous studies shed light on the aggregate spillover effects of transport network development within an agent's locality, there is little discussion to what extent the aggregate effect is driven by those agents located directly adjacent to new transport infrastructure.

This paper takes the research question to a more micro level using a unique dataset constructed from Bangkok household-level orchard land deeds/tax records from the 1880s. We empirically test both the impact of a household being located in an area cross-cut by new transportation infrastructure (aggregate effect) and the impact of being located directly adjacent to the transportation network (direct effect) on agricultural productivity. In particular, we assess the impact of the expansion of Bangkok's canal network in the nineteenth century on household cash crop production decisions for domestic markets.

Throughout the nineteenth century, canals provided the primary means of transport both within Bangkok and between the city and outlying regions, earning the city its nickname, “Venice of the East”. As Bowring (1857, p. 402) noted during his stay in Bangkok in 1855, “[t]he highways of Bangkok are not streets or roads, but the river and the canals. Boats are the universal means of conveyance and communication.” Large infrastructure projects throughout the nineteenth century greatly expanded the canal system primarily to facilitate defence, the flooding of rice paddy fields, and transporting rice and sugar for international trade. Although the canals were built for defence and international trade purposes, it is possible that the new canals afforded households greater access to transport, which could have contributed to the development of domestic market activities. We exploit the expansion of Bangkok’s canal network as an exogenous source of variation in access to transport infrastructure. From the historical record, we can determine whether households engaged in orchard agriculture abutted navigable canals and whether they were situated in an area cross-cut by new canal infrastructure.

Although it can be ascertained from the background literature that new canals were built for purposes unrelated to orchard cultivation, there is concern that relatively productive orchardists might sort onto plots adjacent to newly dug canals, which could hamper the validity of the results. To mitigate this concern, we employ various empirical measures, including (i) limiting the sample to properties in areas identified as densely populated throughout the nineteenth century to minimise the case of post-new canal construction population sorting and new land reservation, as well as (ii) using propensity score matching to compare productivity differences between properties on and off canals with similar observable owner and plot characteristics.

The baseline results and the robustness checks confirm that landowners with prop-

erties located adjacent to canals in sub-districts cross-cut by new major canal projects cultivated cash crops more intensively than landowners whose plots had no direct canal access. More specifically, properties with direct canal access in sub-districts cross-cut by new canals had 20 to 28 per cent higher output and 16 to 24 per cent higher cultivation intensity than properties that did not border canals in those same districts. Furthermore, the productivity advantage afforded by direct access to canals was higher for properties in sub-districts cross-cut by new canals than for properties in sub-districts that did not experience canal network expansion.

The rest of the paper is organised as follows. Section 2 covers the historical background of the development of Bangkok's canal network and how it can be taken as exogenous to orchard agricultural production. Section 3 explains the data and variables used the paper. Section 4 describes the empirical methodology, including how we mitigate possible endogeneity concerns from potential self-selection problems. Section 5 covers the main empirical results, while section 6 covers the robustness check based on propensity score matching. Section 7 concludes.

2 Historical Background: Development of Bangkok's Canal Network

Waterways–both natural and manmade–have long been the primary means of transport in central Siam. Many canals in the vicinity of Bangkok predate the removal of the capital from Ayutthaya in 1767. After the establishment of Bangkok as the capital in 1782, the development of Bangkok's canal network accelerated, especially during the reigns of King Rama III (1824-1851), King Rama IV (1851-1868), and King Rama V (1868-1910). It is

well documented that new canals were built to serve various purposes, all of which could be identified as unrelated or exogenous to production decisions of individual orchard landholders. The purposes of building manmade canals can be grouped into four main categories: (i) moats for defensive purposes; (ii) regional transport routes and travel time reduction; (iii) shipping routes for specific internationally traded goods (i.e. rice and sugar); and (iv) enlarging arable frontier land for rice farming.

The government constructed a series of manmade canals around Bangkok as a defensive strategy against foreign threats during the Thonburi and the early Rattanakosin kingdoms.[1] The city moats were seen as necessary until the early period of King Rama III's reign since Siam engaged in frequent warfare with the neighbouring Konbaung (Burmese) and Vietnamese kingdoms. Owing to the fall of these neighbouring kingdoms to British and French colonisation in the region, building city moats was no longer necessary. The last canal built explicitly for defensive purposes was Padung Krung Kasem Canal built in 1854 during the reign of King Rama IV.

Although the system of moats was also used for transport linking districts within the inner city, many canals were built specifically to transport goods and to reduce travel time for people. These canals include Bang Khun Thian (1831), Phra Khanong (1840), Hualampong (1857), and Thanon Trong (1857). The Thanon Trong canal in Bang Rak sub-district, in particular, was demanded by the Western expatriate community to reduce the expatriates' travel time into the inner city (Bunnag, Nopkhun, & Thadaniti, 1982).

Manmade canals were also built to serve as shipping routes for specific internationally traded goods. For example, Phra Phasi Sombat, a prominent sugar mill owner, requested

[1]The Thonburi Kingdom was established after the downfall of Ayutthaya and existed as the capital from 1768 to 1782, at which point the capital moved from Thonburi on the west bank of the Chao Phraya River to Bangkok on the east bank. The Rattanakosin Kingdom lasted from the establishment of the new capital in 1782 and ended with the 1932 coup, which marked the end of the absolute monarchy.

to build the Phasi Charoen Canal (1872) out of future canal fare revenue to connect the Ta Chin and Chao Phraya Rivers for the specific purpose of transporting sugar and sugar cane (Bunnag et al., 1982). Branches of smaller canals, such as Bang Wa, Bang Ranae, and Bang Rane Noi, were also built as a part of the extended canal system from the main Phasi Charoen Canal. Maha Sawat (1860) and Damnoensaduak (1868) canals were built to link Bangkok to Nakhon Chai Si and to Ratchaburi, respectively, to transport sugar and sugarcane, which were Siam's primary export goods before the Philippines captured the international market for sugarcane towards the end of the nineteenth century.

Besides shipping major commodities, canals were also built for shipping eclectic goods. For example, the San Canal and the Somdej Chao Phraya Canal (today, Wat Anongkaram Canal) in Klong San sub-district on the west side of the Chao Phraya River were built during the reign of King Rama III. The San Canal was built specifically to transport Siamese constructed western-style ships from the nearby dock to the Chao Phraya River, while the Somdej Chao Phraya Canal was built to transport equipment for the construction of the Phichaiyatikaram and Anongkaram temples (*The Bunnag Lineage Club*, n.d.).

Lastly, new canals were dug to open frontier land for rice farming. The 1855 Bowring Treaty between Siam and Britain and similar subsequent treaties signed between Siam and other countries effectively opened Siam to international trade. Siam experienced unprecedented growth in rice exports in the decades following the conclusion of the Bowring Treaty. Rice exports grew from 1,830,000 to 2,580,000 piculs, and the value of rice exports increased from 3,510,000 to 6,520,000 baht between 1867 and 1870 (Bunnag et al., 1982).[2] To support the growing market, King Rama V ordered more canals to be dug in order to increase the amount of arable land for rice farming around Bangkok and

[2]A picul is equivalent to 133 pounds (Zimmerman et al., 1931).

the Chao Phraya River Delta. In other words, the canals were built for the purpose of flooding paddy fields (i.e. inundation or flooding canals) for rice cultivation. Bunnag et al. (1982) point out a strong relationship between rice exports and the initiation of new canal dredging projects. For example, during the period between 1869 and 1879 when rice exports increased from 1,870,000 to 3,530,000 piculs annually and the price per unit rose from 2.70 to 2.90 baht, the government ordered the commencement of four new canal building projects. However, between 1880 to 1884 when the price per unit fell back to 2.70 baht and export volume only increased by 0.14 per cent, the government halted canal digging projects. New canal projects commenced again only in 1886 when rice prices started to rise from 3.30 to 4.60 baht per picul. Examples of new canals of this type include: Prem Prachakon (1870), which opened up old jungle area north of the city; Taweewattana (1878) together with its branches, Bang Weak and Bang Phroam, which increased the frontier land on the western side of Thonburi; and Prawesburirom (1880), which increased potential paddy land between Bangkok and Chachoengsao.

It is clear from the historical background that the canal network constructed between 1826 and 1878 was built for purposes exogenous to orchard cultivation. In our empirical approach, we thus exploit the exogenous variation in households' exposure to the new canal network to assess the impact of the expansion of the transport network on orchard productivity improvements.

3 Data and Variables

To assess the impact of canal transport network expansion on household-level orchard agriculture productivity, we use a unique household-level dataset constructed from Bangkok

orchard land deeds/tax records (also known as "garden title deeds") issued in the 1880s.[3] The deeds, which functioned as both ownership and land tax documents, are part of the Department of Lands Museum document collection. We are interested in orchard productivity, as orchard cultivation was one of the most important economic activities in Bangkok during the period under review (Sternstein, 1966). It is estimated from the 1883 Postal Census that 44 per cent of Bangkok households in canal communities engaged in orchard agriculture (Department of Post and Telegraph, 1883). Learning about orchard productivity, as a consequence, can provide insights into the standard of living of the majority of economic agents in Bangkok during that time. In addition, since orchard products (fruit) are subject to spoilage, the incentive to increase its production or productivity is likely to depend heavily on the ability to reduce costs due to perishability. Canal network expansion could potentially reduce both travel time and increase access to markets leading to a reduction in costs due to spoilage. As a result, transport network expansion could be seen as one of the mechanisms that improves incentives for orchard productivity enhancements.

The sample used in this study contains 8,638 orchard deeds covering 20 districts and 50 sub-districts in Bangkok.[4] The majority of the properties are located on the west side of the Chao Phraya River, across from the new Bangkok settlement.[5] Unlike the east side that is characterised as a floodplain, the west side of the Chao Phraya River is well-known as an area densely packed with various types of orchards since the Ayutthaya period (Sternstein, 1966; Skinner, 1957). The geographical distribution of

[3]The primary deed document collection indicates that households typically owned only one plot of land, thus plot-level analysis is equivalent to household-level analysis in this case.

[4]The original deed documents list a historical sub-district called a *tambon*. The 61 historical *tambons* listed in the land deeds were matched up with 50 current sub-districts and 20 current districts in Bangkok. While there may be some misclassification, the general distribution of properties is expected to be a close approximation. The authors are currently making further inquiries into the historical *tambon* locations.

[5]The west side of the Chao Phraya River is generally known as the Thonburi side after the Thonburi Kingdom. The west side contains older settlements that can be dated from the Ayutthaya period.

the sub-districts covered in the sample is depicted in Figure 1 below, and the summary statistics calculated from the land deeds is provided in Table 1.

[Figure 1, here]

[Table 1, here]

3.1 Transport Network Expansion

To capture the impact of exogenous canal network expansion on household orchard agriculture productivity, we exploit the fact that, according to historical accounts, the major nineteenth century canal projects were built to serve purposes unrelated to market access for domestically produced and traded orchard fruits. In particular, we use two binary variables to capture the exogenous canal network expansion: (i) a binary variable indicating whether a property is located in a sub-district that was cross-cut by a new canal and hence gained access to the transport network and (ii) a binary variable indicating whether a particular property directly bordered at least one canal.

Similar to the existing literature, we identify whether a locality encompassing the economic activity of interest was affected by the new transport network, in this case, new canals. New canals are defined as canals that were built between the signing of the Burney Treaty in 1826 during the reign of King Rama III (1824-1851) and just prior to King Chulalongkorn's orchard tax assessment and deed issuance in 1884-1889. This period is notable in that Siam had (again) started to integrate into the world community, mostly through trade. The Burney Treaty – signed between Siam and Britain in 1826, making it Siam's first treaty to be signed with a Western country – marked the beginning of "modernisation" to accommodate increased international trade. This makes all of

the "new" canals under 60 years old at the time of the orchard land tax assessment. This implies that our "new" canals were not too well-established to be overwhelmingly confounded by other development factors, discussed below, and yet the span of 60 years still allows the fruit trees in the localities of these "new" canals to be mature enough for tax assessment. Most importantly, it can be clearly identified from the historical record that these canals were built for purposes that were truly exogenous to orchard productivity enhancement (Bunnag et al., 1982).

We distinguish between newly built canals from older, well-established canals. Unlike newly built canals that potentially only capture the effect of access to a transport network, old and well-established canals might be confounded by other development factors that are no less essential for investment incentives and productivity improvements. Traditional communities in Siam usually flourished along and around the system of waterways (Bowring, 1857; Zimmerman et al., 1931). As such, being adjacent to canals, more specifically old canals, usually means that the properties were situated in well-established communities that were relatively more developed and urbanised with higher levels of market exchange and commodity transactions. Thus, orchard properties next to old canals were more likely to be located in more developed and urbanised areas compared to those that were not. To serve the communities, such orchards were likely to be endogenously more intensively cultivated due to those time-invariant omitted factors related to development and urbanisation.

A number of canals passing through the sub-districts in our sample were established long before the turn of the nineteenth century. For example, Bangkok Yai and Bangkok Noi canals were actually the old meandering stretches of the Chao Phraya River. When the river shortcut was constructed in 1525, the tide was turned and the shortcut was

widened, making the shortcut a proper stretch of the river passing through Bangkok (Bunnag et al., 1982). The two canals became narrower and communities, which can be traced back to the Ayutthaya period (1351-1767), have flourished along them ever since.

Although we cannot exactly identify from the land deeds which canals the properties abutted, the deeds do list the historical sub-distircts (*tambons*) in which the properties were situated. Using previous scholarship on the historical background of canal infrastructure projects (for example, see Bunnag et al. (1982)), we can identify the construction dates of canals relevant to our sample. Using contemporary and historical maps and records, we can approximate which sub-districts encompassed the new canals dug between the signing of the Burney Treaty in 1826 and the time just prior to the orchard tax assessment and deed issuance in 1884-1889. Out of 50 sub-districts in our sample, 19 were cross-cut by new canal projects. From Table 1, approximately 31 per cent of the properties were located in sub-districts with new canals. Being located in a sub-district with a newly built major canal should provide a proxy for gaining access to the expansion of the transport network.

In addition, to complement what is lacking in the existing literature, the household-level land deeds/tax records used in the analysis enable us to further distinguish between the direct effect of being located exactly on a new transport route from the generally considered effect of being situated in a locality with new transportion infrastructure. In particular, the land deeds record whether each property directly bordered a canal. From Table 1, 46.6 per cent of the properties in the sample bordered at least one canal. Moreover, considering this variable together with the variable indicating whether the properties were located in a sub-district with new canals, we can create an interaction variable that approximates whether properties were situated directly on a newly built

canal. According to Table 1, 15.8 per cent of the properties in the sample were adjacent to canals as well as located in sub-districts with new canal infrastructure. This interaction variable is the main variable of interest in the subsequent empirical analysis.

3.2 Productivity

To measure orchard cultivation productivity, we make use of tax assessments recorded on the 1880s orchard land deeds or "garden title deeds". Garden title deeds played a dual role as both an ownership and a tax document for orchard lands in Siam's Central Plain. The Siamese government granted ownership rights (technically, secure usufruct rights) to anyone who cleared the land, planted crops within the first three years, and paid annual land taxes. In the case of orchard lands, taxes were paid on a per tree basis, where the tax rate was set based on the value of each type of tree's produce in the market. Orchard taxes were assessed on mature trees that produced cash crops, including five types of areca nuts, coconuts, betel leaf vines, mangos, durian, mangosteen, *maprang*, and *langsat*.[6] Since assessing taxes on orchard lands was a labour intensive and time-consuming process, orchard land taxes were assessed only once per reign (Nabarath, 2000, 74). The documents used in this study are copies of the garden title deeds issued during King Rama V's land tax reassessment ordered in 1882 and executed between 1884 and 1889 (*Directory for Bangkok and Siam, 1914*, 1914, p. 40, 61-62). These copies made up the central registry of orchard lands overseen by the Ministry of Agriculture (*krom na*) and were in use between 1884 and 1908.

The portion of the deed document that was issued to the owners included an inventory of mature fruit trees and the total tax assessment based on the total number of trees

[6]Based on 195 surviving tree inventories from replacement garden title deeds issued between 1901 and 1906, approximately 90 per cent of the trees assessed for taxes were areca nut.

enumerated. Although the Ministry of Agriculture copies used in this study do not include the tree inventories, the total tax assessment is highly correlated with the total number of trees cultivated, and thus reflects orchard productivity.[7] Table 2 shows the orchard tax schedule in use between 1856 and 1900.

[Table 2, here]

To capture the extent of productivity, two variables are used in the subsequent analysis. First, total tax paid on each property is used as a proxy for household productivity. Secure usufruct rights imply that expansion of cultivation on the extensive margin is limited by a household's available labour resources. Total tax thus potentially measures the productivity of a production unit, which is the household in this case. Based on Table 1, the average total tax assessment in the sample is 5.82 Baht, which is equivalent to growing 290.5 class 2 areca nut trees according to the tax schedule in Table 2.

In addition, the total land area in *rai* can be calculated from the plot dimensions (*sen*, *wa*, and *sawk*) recorded for each of the four cardinal directions.[8] Thus, the tax rate divided by the land area, or baht per *rai*, provides an additional proxy for the intensity of orchard crop cultivation or land productivity. From Table 1, the mean tax assessment per *rai* is 1.68 baht. To put this in perspective, based on the information from Table 2, this is equivalent to the taxes assessed for about 84 class two areca nut trees on 1 *rai* of land. Tax assessment per *rai* would generally be higher for a more productive or a more intensively cultivated orchard. The distributions of total taxes and tax per *rai* are shown in Figures 2 and 3.

[7] In a sample of 195 surviving tree inventories, the correlation between the total tax assessed and the total number of trees enumerated is 0.63.

[8] One *sen* equals 40 meters, one *wa* equals 2 meters, one *sawk* equals 0.5 meters, and one *rai* is equivalent to 0.16 hectares.

[Figure 2, here]

[Figure 3, here]

The garden title deeds contain other information, including the size, location (province and sub-district), and the nature of neighbouring properties or land features. The deeds also contain limited information about the plot owners, including sex, social class, and relationship with other owners listed on the deed. From Table 1, the orchard properties in late-nineteenth century Bangkok were of relatively modest size, averaging 4.58 *rai* (0.73 hectares).[9] Orchard properties were largely owned by "ordinary" Thais, meaning that the nobility, civil servants, and the growing Chinese community held the minority of properties (14.6 per cent in total). Almost half of the properties border some type of transport network, including canals (*klong*) (47 per cent), roads (6 per cent), and the Chao Phraya River (1.5 per cent). Another 8.3 per cent of the properties bordered non-navigable irrigation ditches and canals.

4 Empirical Strategy

In order to test the impact of gaining access to the transport network on orchard productivity, the following empirical model is exploited.

$$y_{is} = \beta_0 + \beta_1 canal_{is} + \beta_2 newcanal_s + \beta_3 canal_{is} * newcanal_s + \mathbf{X}'_{is}\gamma + \delta_s + \epsilon_{is} \quad (1)$$

The dependent variables are two different measures of orchard productivity, including the

[9]In contrast, Feeny (1982) estimates average paddy plots to be 9-22 *rai* in the central region at the turn of the twentieth century.

natural log of total tax and the natural log of tax per *rai* for landholding i in sub-district s. Both are measures of orchard productivity, but capture slightly different productivity concepts. The total tax measure can be thought of as household productivity as it captures the total output of a household's property, whereas tax per *rai* captures land productivity.

The variable $canal_{is}$ is a binary variable indicating whether landholding i in sub-district s borders a canal, and $newcanal_s$ is a dummy variable indicating whether the property is in a sub-district with new canals constructed between 1826 and 1878. The main variable of interest is the interaction term, $canal_{is} * newcanal_s$, specifying whether the landholding is located adjacent to a canal and in a sub-district that gained new canal infrastructure. In the main specification with the results reported in Tables 3 and 4, we include a full set of sub-district fixed effects (δ_s), where the sub-district is the smallest administrative level that we can identify, to take into account as much unobserved differences across localities as possible. As a result, with the inclusion of sub-district fixed effects, $newcanal_s$ is necessarily dropped. In an alternative specification with the results reported in Appendix Tables 1 and 2, we alternatively include district fixed effects as a control for locality, and thus are able to give some interpretation to the estimated relationship between $newcanal_s$ and productivity.[10]

$\mathbf{X}_{is}$ is a vector of controls that includes whether the property borders the Chao Phraya River, roads or bridges, villages or temples, and irrigation canals. We also control for the property size (total *rai*), and owner characteristics (being a member of the nobility and/or a civil servant, Chinese, single female owner, and single male owner). The error term (ϵ_{is}).

[10]Note that the district controls used in the alternative specifications are based on current administrative units, and thus are arbitrary designations given the use of nineteenth century data.

To help separate the effect of irrigation from transport, we make a distinction between navigable and non-navigable canals. Non-navigable canals, usually dug by individual orchardists, acted as irrigation canals channeling water from the main waterways into the orchards. These irrigation canals also acted as gravity dams, which were used to control the amount of fresh water coming from the north, especially during the monsoon season, and sea water coming from the river mouth to get the right amount of brackish water that is conducive to each type of orchard cultivation. The specific Thai term, *lamgradong*, is used to differentiate irrigation canals from other navigable canals *klong*, and hence makes it possible for us to separately identify irrigation canals in the land deeds.

Although it can be ascertained from the background literature that new canals constructed after the Burney Treaty (1826) were built for purposes unrelated to orchard cultivation, the concern that orchardists may sort into plots adjacent to newly dug canals, which could call into question the validity of the results, remains. In other words, although new canals can be identified as exogenous, due to the time lapse between the period that the canals were built and the period the deeds were recorded, we are concerned that certain types of orchardists might sort themselves into areas next to the new canals. In particular, highly productive cultivators might sort themselves to locate next to newly cut canals, leading to an upward bias of the productivity estimation. Alternatively, inexperienced cultivators could constitute a group that claimed newly opened land by new canals, leading to a downward bias of the productivity estimation. This is especially a concern in the case of Siam since manual labourers who dug the canals later in the nineteenth century, especially immigrant Chinese workers, were granted plots adjacent to the canals as part of their compensation.

Ideally, plot-level panel data with measures of both pre- and post-new canal construction orchard production would mitigate self-selection concerns. However, with limited historical data of a cross-sectional nature, this is not possible. Alternatively, we address the self-selection issue in two ways. First, we investigate whether there is a relationship between owning property bordering navigable canals and other observable owner and plot characteristics that could potentially lead to systematic productivity differences. For instance, the nobility and civil servants are generally understood to hold more wealth and hence could both sort themselves into highly valued canal-cut properties and have greater means to make productive investments, leading to an upward bias. On the other hand, inexperienced cultivators could claim new canal-cut lands due to the method of distributing property along the newly dug canals in frontier areas, leading to a downward bias. The results of a series of probit regressions reported in Appendix Table 3 reassuringly indicate that the nobility, civil servants, and Chinese landowners were no more likely to be located directly on canals compared to ordinary Thai landowners, suggesting that the relatively wealthy and former canal workers did not disproportionately capture land along canals.

Additionally, we attempt to limit the bias introduced by population sorting into areas next to new canals by limiting the analysis to areas densely populated throughout the nineteenth century, which should ensure that the new canals cross-cut settled communities rather than empty land. We limit the sample in two ways: (i) populated districts along the Chao Phraya River and (ii) populated areas defined by the existence of temples built prior to 1826, the year the Burney Treaty was concluded.[11] Compared with frontier areas, relatively populated areas are less likely to experience population shifting and

[11]Districts along the Chao Phraya River include Bang Sue, Dusit, Phra Nakorn, Pom Prap Sattru Phai, Bang Rak, Sathorn, Bang Koh Laem, Bang Phlat, Bangkok Noi, Thonburi, Klongsan, and Rat Burana.

new land reservations. With a small probability of sorting in densely populated areas, an investigation of productivity differences due to exogenous changes in access to the transport network is less likely to be hampered by the self-selection problem.

[Figure 4, here]

Figure 4 illustrates the distribution of old and new temples, where old temples are defined as those constructed prior to the signing of the Burney Treaty in 1826. Buddhist temples are traditionally at the centre of community activities. Thus, temples can serve as a proxy for areas with population densities large enough to constitute a village or community. From Figure 4, sub-districts with no old temples, i.e. no presence of communities and more likely to be a sparsely populated areas, are also further away from the Chao Phraya River.

5 Empirical Results

Tables 3 and 4 report the main regression results based on the empirical strategy outlined in the previous section. Table 3 reports the results for regressions with total tax (proxy for household productivity) as the dependent variable, while Table 4 reports the results for the regressions using total tax per *rai* (proxy for land productivity).

[Table 3, here]

[Table 4, here]

Columns (1) and (2) in both tables cover the full sample. The results for column (1) captures the average impact of a property abutting a navigable canal on productivity, but does not differentiate between whether a plot is located next to older or newer canal

infrastructure. The results show that properties that bordered navigable canals were likely to pay about 12 per cent higher taxes per property and about 9 per cent higher taxes per *rai*, implying that these properties were more intensively cultivated compared to properties that were not adjacent to canals. These are the effects that are over and above the impact of canals acting as irrigation input.

As mentioned earlier, the estimated coefficients on bordering canals may be biased upwards since they also capture other confounding development and urbanisation factors besides proximity to transport networks. In columns (2), (3) and (4), as a consequence, the interaction term, $canal_{is} * newcanal_{s}$, is added.[12] From column (2), the interaction term, however, does not exert any significant explanatory power. Nevertheless, once we restrict the samples to relatively densely populated areas to mitigate the self-selection concern as mentioned in the empirical strategy section, the results in columns (3) and (4) show that not only does bordering a canal significantly increase both household and land productivity, but being on a canal in a sub-district with new canals also provides an extra marginal benefit for productivity improvements. This additional impact ranges from 10 to 21 per cent in the case of household productivity and ranges from 7 to 16 per cent in the case of land productivity. Thus, the overall average productivity enhancement for properties that gained direct access to new canals compared to inland properties in the same sub-districts was 20 to 28 per cent higher plot-level productivity and 16 to 24

[12]Controlling for sub-district fixed effects, $newcanal_{s}$ is consequently dropped. To provide an insight into the impact on generally being in sub-districts with new canal network, Tables 1 and 2 of the Appendix make use of an alternative specification with district fixed effects instead of sub-district fixed effects as a set of control variables. The results show that properties in the sub-districts with newly expanded canal networks paid significantly lower taxes per *rai* (22 to 23 per cent less). This implies that orchards in these sub-districts were less intensively cultivated. This, however, is not counterintuitive. Sub-districts with new networks of canals were more likely to be neither as well-established nor populated. They were frontier districts expanding out of old communities. Frontier land tends to be relatively less productive on average when compared with land in well-established communities. The fact that it did not attract settlement in the first place could be due to its relatively lower land fertility, lower accessibility, and lower skills among newly established orchardists – all of which could have led to relatively lower productivity.

per cent higher cultivation intensity.

This result clearly illustrates the significance of access to transport networks on orchard cultivation decisions. In the face of new transport network expansion, properties that were better linked to the new network – in this case situated along a new canal – and hence could exploit the benefits from transport access, were found to be more intensively cultivated than properties that did not border the new canals. The absence of a significant new canal effect when the full sample is considered is likely due to the two types of sorting, mentioned in the previous section, that cancel each other out.

Other location variables are also important in explaining a plot's productivity. In terms of other transport networks, we find that plots located along the river did not incentivise orchardists to cultivate more intensively. This may be due to the fact that only 1.5 per cent of the properties in the sample were located next to the river. In fact, Bowring (1857, p. 403) describes the environment along the river not as a location for agriculture, but an area of dense inhabitance: "[o]n the borders of the river there are scarcely any but floating houses, which can at any time be detached and removed bodily, and without any inconvenience, at the will of the owner."

In addition, we find no difference in cultivation intensity between properties located adjacent to roads or bridges and those that are not. Roads and bridges represent yet another type of transport network that was new during the period, but was much less important than the canal network for transporting agricultural goods. Chareonkrung Road, the first proper road built outside the immediate palace area, was built only in 1871 and was largely lined with shophouses and diplomatic missions. A French traveler described the road infrastructure in 1892: "[r]oads and avenues are a recent luxury in Bangkok; not many years ago, there was no vehicle to be seen in the city, and there were

no roads, bar a few impassible paths" (Fournereau, 1998). Since roads were new at the time of the tax assessment in the 1880s, it is probable that any changes in household production decisions had yet to be realised since fruit trees take a decade or more to mature for tax purposes.

Another result of note is that we find significantly higher intensity of cash crop cultivation among properties that were adjacent to temples and villages, which were centres for local trade and commerce during the nineteenth century. On average, in the full sample, we find that the tax per *rai* was about 12 per cent higher for properties adjacent to temples and villages than for properties that did not border these population centres. This finding points to a vibrant market for the cash crops grown on these properties, such as areca, betel leaf, mangos, and durian. Higher cultivation intensity on properties adjacent to population centres is consistent with the previous result showing higher cultivation intensity for properties adjacent to canals with direct access to markets. We also find, in line with the existing literature, properties of larger size tended to have significantly lower land productivity.

6 Further Robustness Check for Potential Self-Selection Problems

To further mitigate the concern that the estimated impact of canal network expansion on productivity improvements reported in the previous section may be an artefact of systematic differences in owner characteristics between those who held land next to the canals and those who held inland plots, we employ propensity score matching to estimate average treatment effects on the variable, "borders canal". Propensity score matching

enables us to compare productivity differences between plots on and off canals that are "similar" based on observable owner and plot characteristics. Statistically significant productivity differences would suggest that the previous OLS results are not driven by systematic differences in productive characteristics.

[Table 5, here]

From Table 5, for the sample in sub-districts with new canals, under the propensity score matching, it is still found in general that having a property that is directly connected to a transport network incentivises orchardists to be more productive. More specifically, when we restrict our sample to only densely populated areas to further mitigate the sorting problem, tax per *rai* is about 11 per cent to 13 per cent higher for properties abutting canals in sub-districts with new canal infrastructure.

Although the results also generally hold for sub-districts with no new canals (column (2)), the magnitudes are smaller than that of sub-districts with new canals. This suggests that the productivity difference between properties on and off canals in sub-districts with new canals is larger than the difference observed in sub-districts without new canals. It appears that the expansion of Bangkok's canal network had the unintended consequence of encouraging orchardists who gained direct access to the new canal network to be more productive cash crop cultivators, likely due to the lower cost of transport and greater access to local markets, which helped reduce costs owing to the perishability of orchard produce.

7 Conclusions

In his report on his 1934-35 survey of rural Siam, Andrews (1935) noted the following:

> In a commercialised agricultural community where the crops are raised primarily for sale, ... communication becomes almost or fully as important as the fertility of the land. It is clear that a farmer who raises crops for sale cannot afford to farm in a region where there is no opportunity for sale of his crops.... In an industrial or commercial community,– in, for example, the cities and market centres of rural Siam,– the communication factor is far more important than fertility.

Access to canals afforded orchardists access to communication, traders, and, ultimately, local markets. The empirical results support this view that canal access played a central role in individual household decision-making concerning orchard crop cultivation. We established that canal infrastructure development during the nineteenth century was exogenous to orchard production. Combined with various measures to mitigate possible self-selection problems, we can reasonably conclude that the expansion of the canal network projected a statistically significant impact on productivity improvement among the orchardists. More specifically, compared to inland properties, properties with direct access to canals in sub-districts with newly expanded canal networks cultivated 20 to 28 per cent more fruit trees per plot and 16 to 24 per cent more fruit trees per *rai*. Our results point to the critical role that the expansion of access to transport infrastructure can play in reducing transaction costs and hence incentivising households to cultivate crops more intensively. Also, the results suggest that much of the benefits of new transportat infrastructure accrue to those with direct access to the expanded network. Thus, it is possible that the positive average effects found in previous studies may be driven by productivity improvements accrued by those who gain direct access to the network.

In addition, as orchard cultivation was potentially the main economic activity in

Bangkok during the period under study, the findings have further implications for the economic well-being of the general population. We know from the summary statistics that on average the orchardists in our sample paid around 1.68 baht of tax per *rai*, which, from the recorded tax schedule, is equivalent to 84 class 2 areca nut trees. An article entitled "About Orchards" published in the *Vachirayan Journal* in 1891, estimates that one areca nut tree generated revenue of 1 baht per year (Saibua, 2008). Together, this implies that on average the properties in our sample earned revenues of 84 baht per *rai* annually. With reference to our empirical results (Table 4), with the coming of the new canal expansion, those that saw their properties directly cross-cut by new canals saw their productivity increase by about 16.1 to 24.2 per cent compared with those without canal access. Using the calculated average revenue above, it means that gaining direct access to the new canals could improve the orchardists' annual revenue per *rai* by about 13.52 baht to 20.33 baht. Considering that on average landowners held about 4.6 *rai* of orchard land, an increase in annual revenue due to new canal expansion could be as high as 62.2 baht to 93.5 baht per household, which was much greater than the reported monthly salary of a district chief – a highly paid mid-ranking civil servant – at that time (Noranitipadungkarn, 2013). This is also equivalent to 83 to 125 days of manual wage labour, which, according to Feeny (1982), was paid about 0.75 baht per day during the 1880s. The estimated revenue increase found here further suggests a significant one-off improvement in the standard of living for agriculturalists in historical Bangkok due to the expansion of the transport network.

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Tables

Table 1: Summary Statistics

	mean	sd
Total Taxes (baht)	5.817	6.689
Tax Per Rai (baht)	1.676	1.750
Border Canal	0.466	0.499
SD New Canal	0.312	0.463
New Canal*Border Canal	0.158	0.364
Border River	0.016	0.124
Border Road	0.060	0.237
Border Irrigation	0.084	0.277
Border Temple	0.065	0.246
Total Rai	4.585	6.085
Chinese	0.054	0.226
Nobility/Civil Servant	0.092	0.290
Single Female Owner	0.123	0.328
Single Male Owner	0.142	0.349
Observations	8638	

Table 2: Tax Schedule for Plantations Crossed through by Ditches or Higher Lying Plantations

Tree	Size	Tax	Tax (Baht)	Unit
Areca palm (1st class)	Height of stems 3-4 wah	138 bia	0.022	1 tree
Areca palm (2nd class)	Height of stems 5-6 wah	128 bia	0.020	1 tree
Areca palm (3rd class)	Height of stems 7-8 wah	118 bia	0.018	1 tree
Areca palm (4th class)	Yields fruit	128 bia	0.020	1 tree
Areca palm (5th class)	Height of stem > 1 sok until they bear fruit	50 bia	0.008	1 tree
Coconut	Height > 1 sok	1 salueng	0.250	3 trees
Betel pepper vine	Height > 5 sok	200 bia	0.031	1 vine
Mango	Thickness of stem > 4 kam; height > 3 sok	1 fueang	0.125	1 tree
Maprang	Thickness of stem > 4 kam; height > 3 sok	1 fueng	0.125	1 tree
Durian	Thickness of stem > 4 kam; height > 3 sok	1 baht	1.000	1 tree
Mangosteen	Thickness of stem > 2 kam; height > 1.5 sok	1 fueang	0.125	1 tree
Langsat	Thickness of stem > 2 kam; height > 1.5 sok	1 fueang	0.125	1 tree

Source: Nabarath, 2000, 74-76.
Notes: 1 baht is equivalent to 4 salung, 8 fueang, or 6,400 bia.

Table 3: Impact of New Canal Infrastructure on Household Productivity (Ln(Total Tax))

	(1) Full Sample	(2) Full Sample	(3) Populated Districts on River	(4) Excludes Sub-districts with No Old Temples
Border Canal	0.122***	0.103***	0.069***	0.103***
	(0.021)	(0.024)	(0.026)	(0.025)
New Canal*Border Canal		0.060	0.206***	0.095**
		(0.042)	(0.060)	(0.044)
Total Rai	0.031***	0.030***	0.072***	0.050***
	(0.007)	(0.007)	(0.018)	(0.015)
Chinese	-0.177***	-0.178***	-0.174***	-0.162***
	(0.049)	(0.049)	(0.060)	(0.053)
Nobility/Civil Servant	-0.043	-0.043	-0.038	-0.061
	(0.039)	(0.039)	(0.043)	(0.039)
Border River	-0.131	-0.131	-0.145	-0.155*
	(0.096)	(0.096)	(0.096)	(0.094)
Border Road	-0.092**	-0.094**	-0.146***	-0.084*
	(0.045)	(0.045)	(0.051)	(0.046)
Border Irrigation	0.082**	0.083**	0.048	0.063*
	(0.035)	(0.035)	(0.041)	(0.036)
Border Temple	0.091**	0.091**	0.075*	0.057
	(0.037)	(0.037)	(0.044)	(0.039)
Single Female Owner	-0.031	-0.031	-0.020	-0.014
	(0.029)	(0.029)	(0.035)	(0.030)
Single Male Owner	-0.143***	-0.143***	-0.087***	-0.114***
	(0.030)	(0.030)	(0.033)	(0.031)
Sub-district Controls	Yes	Yes	Yes	Yes
Observations	8638	8638	5870	7781
Adjusted R^2	0.282	0.282	0.350	0.320

Notes: *** p<0.01, ** p<0.05, * p<0.1; Robust standard errors in parenthases; Coefficient for sub-district with new canal not estimated due to colinearity with sub-district fixed effects.

Table 4: Impact of New Canal Infrastructure on Land Productivity (Ln(Tax per Rai))

	(1) Full Sample	(2) Full Sample	(3) Populated Districts on River	(4) Excludes Sub-districts with No Old Temples
Border Canal	0.088***	0.085***	0.078***	0.089***
	(0.019)	(0.022)	(0.023)	(0.022)
New Canal*Border Canal		0.007	0.164***	0.072*
		(0.038)	(0.055)	(0.041)
Total Rai	-0.047***	-0.047***	-0.061***	-0.051***
	(0.007)	(0.007)	(0.011)	(0.011)
Chinese	-0.030	-0.030	0.001	0.010
	(0.041)	(0.041)	(0.047)	(0.041)
Nobility/Civil Servant	-0.106***	-0.106***	-0.079**	-0.086**
	(0.036)	(0.036)	(0.040)	(0.036)
Border River	0.023	0.023	-0.002	-0.000
	(0.073)	(0.073)	(0.077)	(0.074)
Border Road	0.002	0.002	-0.024	0.009
	(0.040)	(0.040)	(0.045)	(0.041)
Border Irrigation	0.056*	0.056*	0.048	0.044
	(0.031)	(0.031)	(0.036)	(0.032)
Border Temple	0.118***	0.118***	0.073*	0.070*
	(0.035)	(0.035)	(0.041)	(0.037)
Single Female Owner	0.071***	0.071***	0.066**	0.074***
	(0.026)	(0.026)	(0.030)	(0.027)
Single Male Owner	-0.019	-0.019	-0.032	-0.035
	(0.027)	(0.027)	(0.031)	(0.029)
Sub-district Controls	Yes	Yes	Yes	Yes
Observations	8638	8638	5870	7781
Adjusted R^2	0.406	0.406	0.347	0.404

Notes: *** p<0.01, ** p<0.05, * p<0.1; Robust standard errors in parenthases; Coefficient for sub-district with new canal not estimated due to colinearity with sub-district fixed effects.

Table 5: Comparison Between OLS Coefficient Estimates and Propensity Score Matching Average Treatment Effects on the Variable, "Borders Canal"

Sample	Subdistricts with Old Canals: OLS	Subdistricts with Old Canals: Propensity Score (ATE)	Subdistricts with New Canals: OLS	Subdistricts with New Canals: Propensity Score (ATE)
	Dependent Variable: Total tax (Natural Log)			
Full Sample	0.090***	0.056**	0.155***	0.128***
	(0.024)	(0.027)	(0.035)	(0.040)
	[5,940]	[5,940]	[2,698]	[2,696]
Populated Districts on River	0.065**	0.032	0.244***	0.146**
	(0.025)	(0.030)	(0.055)	(0.074)
	[4,941]	[4,941]	[929]	[929]
Excludes Subdistricts with No Old Temples	0.096***	0.060**	0.163***	0.080*
	(0.024)	(0.029)	(0.037)	(0.046)
	[5,788]	[5,788]	[1,993]	[1,993]
	Dependent Variable: Tax per Rai (Natural Log)			
Full Sample	0.076***	0.045*	0.086***	0.056
	(0.021)	(0.025)	(0.032)	(0.041)
	[5,940]	[5,940]	[2,698]	[2,696]
Populated Districts on River	0.071***	0.054*	0.228***	0.133*
	(0.022)	(0.028)	(0.051)	(0.073)
	[4,941]	[4,941]	[929]	[929]
Excludes Subdistricts with No Old Temples	0.082***	0.062**	0.173***	0.112**
	(0.021)	(0.026)	(0.035)	(0.045)
	[5,788]	[5,788]	[1,993]	[1,993]

Notes: Robust standard errors in parentheses and observations in brackets; controls: owner characteristics (Chinese, nobility/civil servants, single female owner, single male owner), plot characteristics (borders river, road/bridge, village/temple), and subdistrict fixed effects.

Table A1: Impact of New Canal Infrastructure on Household Productivity (Ln(Total Tax))– Alternative Specification

	(1) Full Sample	(2) Populated Districts on River	(3) Excludes Sub-districts with No Old Temples
Border Canal	0.096***	0.063**	0.102***
	(0.025)	(0.027)	(0.025)
SD New Canal	-0.141***	-0.101**	-0.188***
	(0.037)	(0.049)	(0.039)
New Canal*Border Canal	0.045	0.216***	0.071
	(0.042)	(0.063)	(0.045)
Total Rai	0.028***	0.069***	0.048***
	(0.007)	(0.017)	(0.014)
Chinese	-0.156***	-0.156**	-0.176***
	(0.049)	(0.061)	(0.052)
Nobility/Civil Servant	-0.044	-0.026	-0.066*
	(0.039)	(0.043)	(0.039)
Border River	-0.114	-0.152	-0.147
	(0.097)	(0.096)	(0.095)
Border Road	-0.090**	-0.085	-0.074
	(0.044)	(0.054)	(0.045)
Border Irrigation	0.055	-0.005	0.037
	(0.036)	(0.042)	(0.036)
Border Temple	0.074*	0.057	0.047
	(0.039)	(0.046)	(0.040)
Single Female Owner	-0.022	-0.008	-0.013
	(0.030)	(0.036)	(0.031)
Single Male Owner	-0.138***	-0.093***	-0.109***
	(0.031)	(0.034)	(0.032)
District Controls	Yes	Yes	Yes
Observations	8638	5870	7781
Adjusted R^2	0.231	0.307	0.279

Notes: *** p<0.01, ** p<0.05, * p<0.1; Robust standard errors in parenthases.

Table A2: Impact of New Canal Infrastructure on Land Productivity (Ln(Tax per Rai))– Alternative Specification

	(1) Full Sample	(2) Populated Districts on River	(3) Excludes Sub-districts with No Old Temples
Border Canal	0.056**	0.056**	0.070***
	(0.023)	(0.024)	(0.023)
SD New Canal	-0.280***	-0.218***	-0.327***
	(0.036)	(0.045)	(0.037)
New Canal*Border Canal	0.014	0.196***	0.066
	(0.040)	(0.057)	(0.042)
Total Rai	-0.051***	-0.068***	-0.055***
	(0.008)	(0.012)	(0.012)
Chinese	0.025	0.057	0.031
	(0.043)	(0.049)	(0.043)
Nobility/Civil Servant	-0.060	-0.010	-0.044
	(0.038)	(0.041)	(0.038)
Border River	-0.012	-0.058	-0.044
	(0.074)	(0.077)	(0.074)
Border Road	0.078**	0.119**	0.094**
	(0.040)	(0.048)	(0.041)
Border Irrigation	0.024	-0.010	0.014
	(0.033)	(0.038)	(0.033)
Border Temple	0.103***	0.067	0.065*
	(0.037)	(0.043)	(0.038)
Single Female Owner	0.099***	0.102***	0.094***
	(0.027)	(0.031)	(0.028)
Single Male Owner	-0.018	-0.040	-0.033
	(0.029)	(0.032)	(0.030)
District Controls	Yes	Yes	Yes
Observations	8638	5870	7781
Adjusted R^2	0.334	0.276	0.342

Notes: *** p<0.01, ** p<0.05, * p<0.1; Robust standard errors in parenthases.

Table A3: Check for Selection into Plots Bordering Canals (Probit Regressions)

	Dependent Variable: Borders Navigable Canal			Dependent Variable: Borders Irrigation Canal		
	(1) Full Sample	(2) Populated Districts on River	(3) Excludes Sub-districts with No Old Temples	(4) Full Sample	(5) Populated Districts on River	(6) Excludes Sub-districts with No Old Temples
Nobility/Civil Servant	0.049	0.031	0.063	0.148**	0.240***	0.174**
Chinese	-0.035	-0.104	-0.064	0.017	0.087	0.014
Border River	-0.425***	-0.388***	-0.396***	-0.376	-0.360	-0.361
Border Road	-0.279***	-0.490***	-0.397***	0.151*	0.198**	0.196**
Border Temple	-0.283***	-0.301***	-0.278***	-0.130	-0.068	-0.145
Total Rai	0.005	0.013**	0.007	-0.005	-0.004	-0.003
Single Female Owner	-0.034	0.003	-0.041	-0.017	0.086	0.001
Single Male Owner	-0.159***	-0.153***	-0.135***	0.080	0.106	0.046
Sub-district Controls	Yes	Yes	Yes	Yes	Yes	Yes
Observations	8623	5867	7768	8147	5652	7296
Adjusted R^2						

Notes: *** p<0.01, ** p<0.05, * p<0.1; Coefficients reported as marginal effects, robust standard errors in parenthases.

Figures

Figure 1: Bangkok Sample Coverage

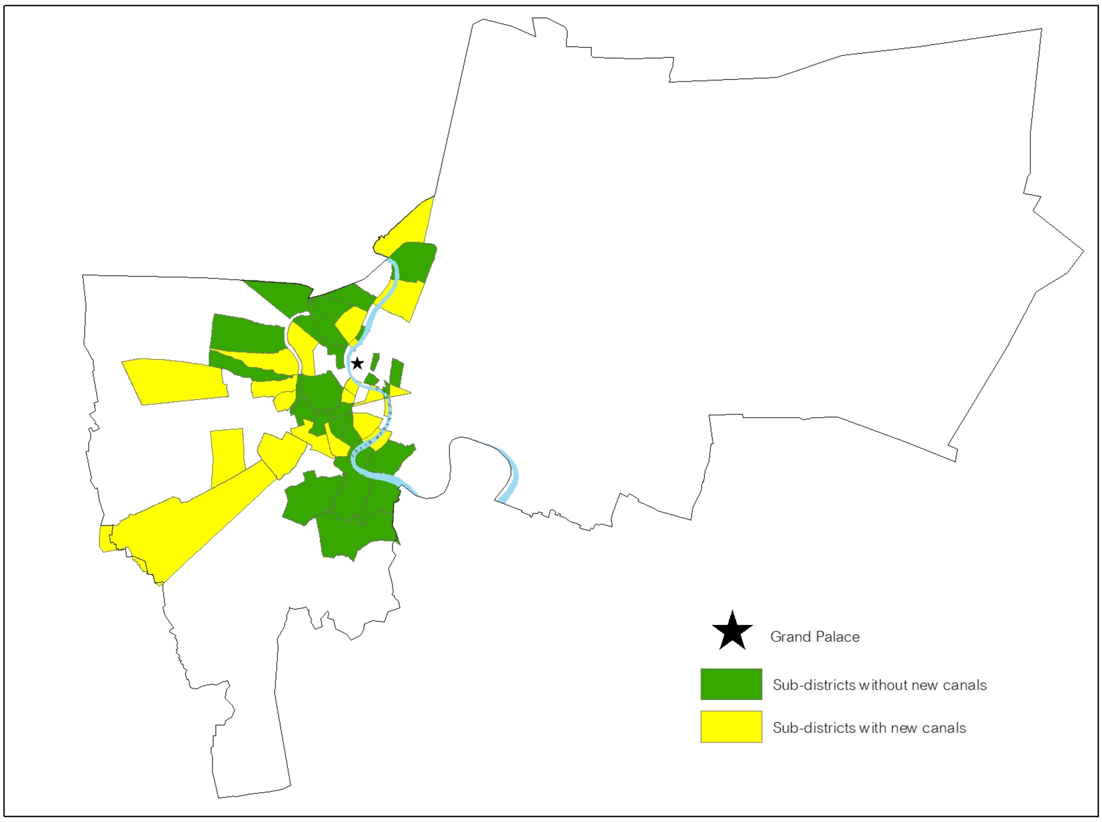

Figure 2: Distribution of Total Tax Assessments (Baht)

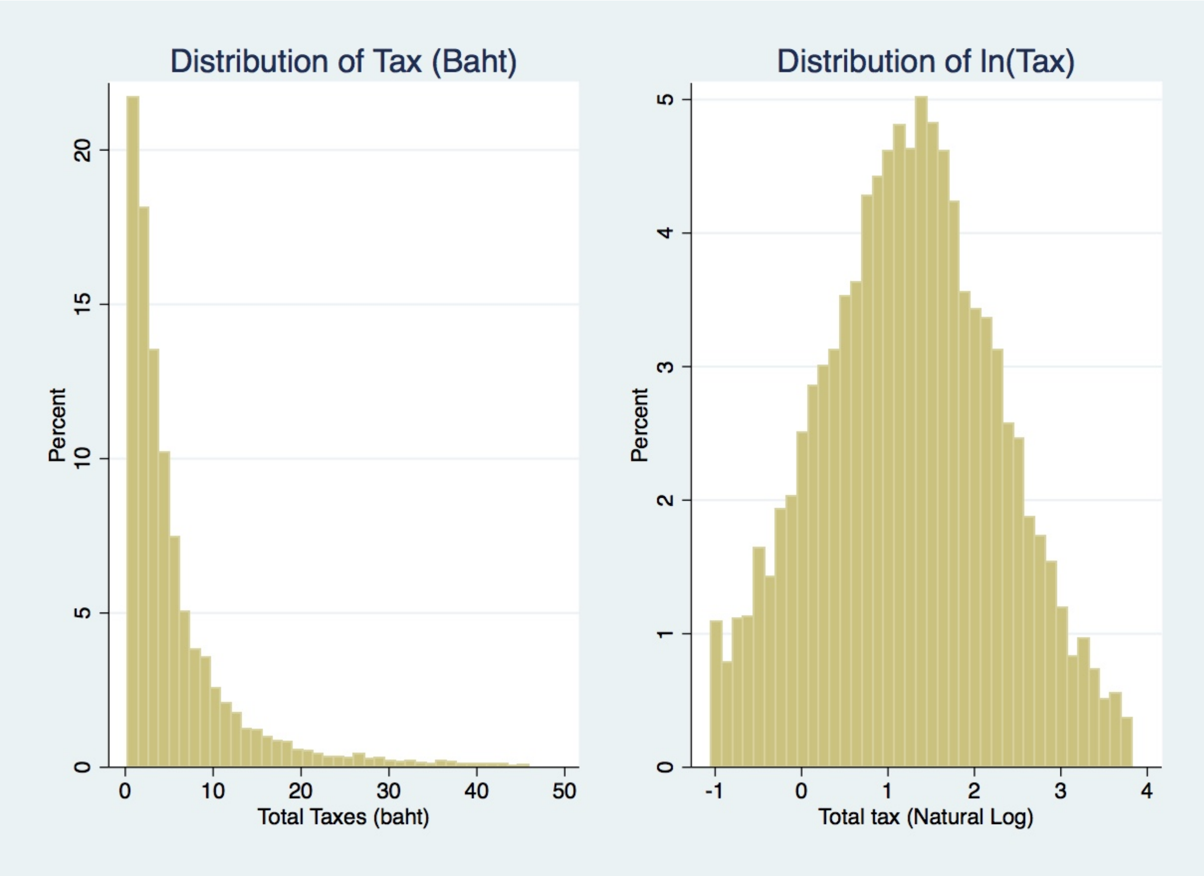

Figure 3: Distribution of Total Tax Assessments (Baht)

Figure 4: Distribution of Old and New Bangkok Temples