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RURAL MARKETPLACES AND LOCAL DEVELOPMENT

Tillmann von Carnap

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Abstract

Marketplaces are an age-old way to connect geographically separated producers and consumers, and they remain widespread in rural areas of low-income countries. How do these gatherings shape development around them? This question is not easily answered, since we typically lack comprehensive market maps and localized indicators of development. To address these long-standing data gaps, I combine historical sources with novel satellite-based methods to map marketplaces and measure local population density. I focus on Kenya over the last five decades and establish three stylized facts. First, while rural population quadrupled, two thirds of weekly markets operating in 1970 no longer do so today. Second and despite many markets no longer operating, population concentrated on average around markets that were active in 1970. Third, markets further from large cities saw the most population concentration relative to their surroundings. To rationalize these findings and derive implications for policy design, I extend a model of rural-urban trade with markets as population-independent locations that aggregate otherwise sparse supply and demand and enable economies of scale in transportation. The model explains when new markets emerge, why some markets decline, and which complementary policies catalyze markets for local development.

[a]Email: tillmann.voncarnap@iies.su.se; Institute for International Economic Studies, Stockholm University. I thank my advisors Anna Tompsett and Jakob Svensson for their guidance. I also acknowledge Leslie Wood and Anna Tompsett for sharing historical data, and Paul Mukwaya for giving me access to the collection of Makerere University's discussion paper series. The paper benefitted from discussions with Tessa Bold, Lauren Falcao Bergquist, Konrad Burchardi, Davide Cantoni, Donald Davis, Mitch Downey, Jay Eujiung Lee, Alexander Danzer, Jonathan de Quidt, Jonathan Dingel, Cecile Gaubert, Ted Miguel, Alessandra Peter, Michael Peters, Tommaso Porzio, Raúl Sanchez de la Sierra, David Schönholzer, Nick Tsivanidis and Horng Chern Wong, as well as feedback from participants at the IIES Development Tea & Brown Bag, the Oxford Workshop on Development Economics, the STEG Workshop on Agriculture & Spatial Frictions, the NEUDC conference, the ASWEDE conference and the UNU-WIDER PhD Workshop. The STEG initiative and Handelsbanken provided generous financial support.

1 Introduction

The idea of meeting at a specific place and time to trade is so deeply intertwined with the idea of goods exchange itself that in many languages, the word 'market' has both meanings. Such dedicated trading sites are long-standing and widespread features of economic geography, and remain central to rural livelihoods in many low-income countries today. Here, farmers sell their products and access otherwise unavailable goods and services. As places where rural populations interact with the broader economy, marketplaces are focal points of the 'market access' that both researchers and policymakers have argued is necessary to improve rural living standards (World Bank, 2009; FAO, 2018). Despite their ubiquity and centrality to rural economies, however, the role of rural marketplaces for local development is poorly understood from both an empirical and policy perspective.

Research on the topic has faced at least two constraints: First, we lack data both on where markets are located and on how local growth patterns evolve, especially over longer time frames and large geographies. This lack of data does not necessarily reflect a lack of interest in marketplaces and rural growth, but rather is a consequence of rural economies being largely informal and, by definition, distant from urban centres. This informality and remoteness imply that it is costly to consistently record accurate data, including market maps and indicators for local economic conditions.

Second, widely-used theoretical models of domestic trade focus on the geography of production and consumption rather than the geography of trade itself. Marketplaces – connecting geographically separated producers and consumers at intermediate, possibly unpopulated locations – are therefore not well captured in these models. This limits our ability to understand the role that marketplaces play for the distribution of economic activity and how they interact with other means of increasing market access.

In this paper, I study how rural marketplaces shape local development. I address the first constraint, data availability, in the context of Western Kenya over the last five decades by combining historical records and modern data based on satellite imagery to document patterns of marketplaces and, as a measure of local development, population density around them. Using this data, I establish three stylized facts on marketplaces and local development. I address the second constraint by developing a spatial model in the New Economic Geography tradition that includes rural marketplaces as population-independent locations of trade. The model allows me to identify possible mechanisms behind the stylized facts and to qualitatively examine trade-offs and complementarities between marketplaces and road infrastructure as another means of creating market access.

I focus on Western Kenya as an agricultural region where periodic – typically weekly – markets have been and continue to be widespread. Such periodic markets are especially relevant in this and similar contexts where demand is often too dispersed to make daily trading from fixed stalls economical, but high enough on aggregate to make such regular meetings viable. Since Kenyan independence in 1963, the region has seen rapid population growth in rural areas, but also a transformation towards a more urbanized, diversified economy. In this respect, Kenya's development experience over the last five decades is exemplary for similar transitions, both historic and ongoing, around the world: for example, Kenya in 1970 had the same level of urbanization as England around 1600 (10%), while just 50 years later it had reached England's level of around 1800 (28%) (Davenport, 2020). Today, a third of the population in Sub-Saharan Africa lives in countries with a level of urbanization similar to or lower than that of Kenya[1].

Similar to most rural areas in developing countries, consistent and comprehensive market maps for Western Kenya are not available. To map historical market locations, I digitize and georeference a unique, comprehensive and extensively validated census of marketplaces collected in 1970 and listing more than 450 weekly markets (Wood, 1973b). To map marketplaces today, I use a novel method to detect their locations based on high-frequency satellite imagery (von Carnap, 2021). The method exploits markets' highly distinctive visual signature due to their periodic nature which, beyond allowing their detection, is also informative about short-run activity within markets. I use this novel high-frequency measure of local economic conditions to characterize markets' contemporary functions and to validate some of the predictions of the spatial model.

To assess the market maps' quality and comparability over time, I confirm that the remotely-detected areas are indeed weekly markets and not other periodic phenomena, such as gatherings around religious buildings. Moreover, I show that a large share of known markets in the region are accurately mapped. Finally, I confirm that the share of days of the week at which markets are operated is highly similar between the historical and contemporary datasets, suggesting that they indeed cover the same qualitative phenomenon.

Having established where markets are, I then turn to measuring economic development around them. We generally lack long time series of wealth or income in most developing countries, especially at high spatial resolution. To make progress, I follow the literature in economic history and urban economics that uses population density as a proxy for local living conditions (Acemoglu et al., 2002; Ashraf and Galor, 2011; Hanlon and Heblich, 2022). Intuitively, among places with similar geographic fundamentals, those able to sustain higher population densities must be more productive through either better agricultural technologies or non-agricultural income sources.

While previous research has used population data as recorded in censuses, this source is not useful for my purposes since censuses typically record population at the level of administrative units that cannot be uniquely mapped to markets. Instead, I again use remote sensing, now to identify the locations of individual houses both historically and contemporaneously. To map historical population density, I digitize topographical maps from the years around 1970, which were hand-drawn based on comprehensive high-resolution aerial photography and indicate the locations of individual houses throughout the study region. I extract house locations using a pattern detection algorithm and complement these historical population density measures with their modern computer vision-based equivalent to identify houses in high-resolution satellite imagery (Facebook, 2019).

[1] 31% of the population in Sub-Saharan Africa live in countries with less than 35% urbanization. Author's calculation based on data from World Development Indicators

Equipped with this data, I build a panel of over 5,200 $2.5km \times 2.5km$ gridcells covering Western Kenya in 1970 and 2020, where I observe distance to marketplaces and population density, complemented with a measure of access to large urban centres using standard approaches in the literature (Donaldson and Hornbeck, 2016). I use this dataset to establish three stylized facts about marketplaces and local development.

First, despite a fourfold increase in rural population and liberalization of agricultural trade post-independence, there are 30% fewer active marketplaces today than in 1970. This number masks substantial spatial shifts. Half of the marketplaces existing today emerged in areas previously farmed by Europeans where large-scale plantations dominated agriculture and rural markets were largely absent. At the same time, two thirds of marketplaces that operated in 1970 no longer do so today. Finally, only a fraction of the previously operating weekly markets have developed into daily ones.

While this first finding may suggest that periodic markets have been losing importance, the second stylized fact points to their continued relevance: locations where markets operated in 1970 saw their population increase on average relative to adjacent areas. This population concentration occurred both at the market location itself – through the emergence and growth of rural towns – and in the vicinity of markets – through higher rural population density.

One might be concerned that markets are drivers of development rather than symptoms of it: perhaps marketplaces exist in places featuring geographical advantages that let population grow for other reasons than the marketplaces themselves. While marketplaces surely benefit from local growth, two additional observations suggest that they indeed contribute to local development. To begin with, population concentrated around marketplaces even within small groups of locations that had a similar population density and access to large cities in 1970. Here, location fundamentals existing prior to 1970 should already be reflected in a higher population density at that point in time. Furthermore and focusing on areas without larger population agglomerations in 1970, market locations tended to grow in population if their market persisted, but shrank relatively if their market declined. These observations – population concentration at marketplaces across the range of 1970 population density – suggest that some marketplaces may have formed the nuclei of small-scale urbanization where the population was initially scattered, and also contributed to the growth of already existing towns.

Third and finally, population concentrated the most around markets if these were neither directly adjacent to larger cities nor in the most remote areas. This suggests that markets are especially relevant for local development where agriculture and informal enterprises remain central to the economy but where trading with larger cities is not excessively costly. As a corollary, marketplaces' role in the local economy may change over time as their surrounding economies transform.

Taken together, the three facts suggest that marketplaces contribute to local development, but some marketplaces prosper more than others. I turn to a spatial model of rural-urban trade to understand how these patterns emerge. The model also provides a framework to examine how marketplaces interact with alternative means of creating market access, such as road infrastructure.

In particular, I extend the canonical New Economic Geography framework (Fujita et al., 2001) to include marketplaces as import and export hubs in rural areas. In contrast to most existing models, I assume that places of trade can be independent from both production and consumption locations.

The canonical version of the model features a central city surrounded by a rural hinterland. While workers in the central city produce goods with increasing returns to scale, farmers are uniformly spread throughout the hinterland and produce food using a constant returns to scale technology. Both workers and farmers have Cobb-Douglas preferences and gain utility from consuming both urban goods and food, which are shipped at a cost from their locations of production to where agents reside.

I extend this basic setup in two ways. First, I introduce marketplaces as locations where transport between the central city and the hinterland is cheaper. Specifically, I assume the existence of scale economies in transportation, with the cost of shipping food and goods between the central city and a given marketplace decreasing with the volume of goods traded there. This incorporates goods being bulked for transport to and from marketplaces (Startz, 2021) and larger marketplaces potentially offering better prices to rural populations (Bergquist and Dinerstein, 2020; Atkin and Donaldson, 2015).

Second, I extend agents' preferences to include a non-tradable good which is also produced with increasing returns to scale but can only be consumed at certain locations. Specifically, agents can purchase the non-tradable good exclusively either in existing towns or from itinerant vendors at marketplaces. This definition of non-tradables incorporates the intuition that certain goods or services can only be produced if a sufficiently large number of customers is within direct reach. Such a customer base is represented by the weekly gatherings at markets.

The first property of marketplaces, increasing returns to scale in transportation to and from them, can explain the market concentration I observe in the data. From an initial distribution of marketplaces varying by size, some may become more attractive than others, for example through improved transport infrastructure or locally provided goods and services. Farmers may then prefer travelling to a larger, more distant market over travelling to smaller, nearby markets. As a result, smaller markets may eventually cease to operate, while larger ones grow further. I confirm in the data that 1970 marketplaces are more likely to have ceased to operate if their closest persisting neighbor is in a location that saw relatively large population increases.

A key assumption linking economies of scale in transportation in the model and market concentration in the data is that farmers indeed choose between visiting different markets instead of exclusively relying on one. I use the remotely-sensed high-frequency market activity data to substantiate that farmers do substitute across markets using an application from the COVID-19 pandemic. Between March and June 2020, marketplaces in Kenya were restricted in their operations (Hale et al., 2021). Remotely-sensed data on market activity reveals that 15% of previously active markets have not resumed their operation since. I find that activity in marketplaces directly adjacent to these recently declined ones recovered faster than in the next adjacent ones. This suggests that at least some activity shifted from declined to neighboring markets, rather than all farmers abandoning trade in marketplaces. Furthermore, the reallocation of activity illustrates how an established network of marketplaces may be altered once the habit of meeting at a set place and time is disrupted.

Returning to the model, the lower transport costs to and from marketplaces not only support market concentration, but also make living near them attractive, since urban goods are cheap and agriculture relatively profitable. While this effect can explain higher population density around the marketplaces, it cannot account for the emergence and growth of rural towns where the economy is likely to be diversified away from agriculture. I therefore also use the model to predict where production of either the tradable or the non-tradable good may emerge away from the central city. Since marketplaces are locations where imports are cheap and farmers' reservation wages high, tradable goods are less likely to be produced at marketplaces than at nearby locations. For non-tradables, however, concentrated demand at marketplaces means that these locations hold a unique advantage in terms of accessing potential customers.

This emergence of local production of non-tradables provides a channel for higher levels of population density at markets themselves. It also provides an explanation for why marketplaces in the data grew most at intermediate distances from cities. Here, proximity to the central city lets farmers realize higher prices for their crops, increasing their demand for manufactured goods and services, while at the same time, distance from the central city shields local enterprises from import competition. The model thus suggests that marketplaces are especially likely to be the production site for services, rather than manufactures. This sequencing of transformation at the local level represents a stark difference to classical models of development at the macro-level, where more productive agriculture contributes to the growth of manufacturing (Lewis, 1954).

After having established that the model can qualitatively replicate the empirical patterns, I employ it for a set of policy exercises. I first ask under what transport cost regime marketplaces provide the largest benefit and find that the efficiency gains provided by marketplaces through enabling cheaper transport increase with the cost of shipping goods directly. In such an environment, a dense network of marketplaces can substitute for poor infrastructure by exploiting the more efficient transportation sector based at marketplaces.

The second exercise focuses on how marketplaces can be catalyzed for local development and structural transformation away from agriculture. Non-agricultural production in rural areas may be desirable since such industries and the towns they operate in provide accessible income opportunities (Christiaensen and Todo, 2014; Ingelaere et al., 2018) while avoiding some of the disadvantages of congestion associated with large cities (Glaeser, 2014; Gollin et al., 2016). One way to support such a transformation may be to improve transport between economic hubs and rural areas: policymakers indeed motivate road investments with the prospect of creating rural, non-agricultural jobs (Africa Transport Policy Program, 2022). Empirical research on the effects of lower transport costs, however, has typically found that road construction increases specialization in agriculture instead of fostering rural industries (Faber, 2014; Asher and Novosad, 2020; Baum-Snow et al., 2020). These findings are in line with predictions from canonical spatial models, where cheaper transport consolidates the advantage of existing, relatively efficient industries in large cities.

Adding marketplaces to the picture, however, suggests that roads can indeed foster rural industries, depending on the types of places to which they connect. Specifically, better connections between the marketplace and the central city expose aspiring entrepreneurs at markets to import competition, reducing the incentives for local production in a similar way as in the canonical model. But better connections between the marketplace and its hinterland enlarge the customer base and foster local non-agricultural production. These results suggest that policymakers who wish to promote rural structural transformation should invest in local access to trade hubs, rather than solely focusing on connections to established economic centres.

Overall, incorporating a deeper understanding of how rural trade is structured and where it occurs could amplify the development gains that projects aimed at increasing 'market access' entail.

Related literature

This paper contributes to four distinct strands of literature. Firstly, it follows up on an early body of work by geographers and anthropologists on rural market systems in developing countries (Hill, 1963; Jackson, 1971; Wood, 1973a; Bromley et al., 1975; Good, 1975; Smith, 1978; Mukwaya, 2016). These studies were mostly concerned with documenting different spatial, temporal and functional configurations of marketplaces. Despite great attention to local detail and ingenious approaches to market mapping, this literature was limited by similar data scarcities as usually exist today in the absence of widespread maps and monitoring systems. In this paper, I provide evidence on marketplace existence over a longer time horizon and link them to development outcomes.

Secondly, the paper speaks to an active literature using market-level experiments to understand the structure of and frictions within rural value chains (Renkow et al., 2004; Fafchamps, 2004; Casaburi et al., 2013; Atkin and Donaldson, 2015; Allen et al., 2020; Bergquist and Dinerstein, 2020; Startz, 2021; Aggarwal et al., 2022; Bergquist et al., 2022; Bold et al., 2022; Chatterjee, 2022). This literature has highlighted search and contracting frictions as primary drivers of why price gaps between producers and consumers are large in developing countries. Marketplaces represent an age-old mechanism to reduce these frictions by physically bringing together buyers and sellers. While existing research has examined the structure of competition within marketplaces, my focus is on the spatial interaction between marketplaces as well as their importance for long-run outcomes.

Thirdly, the paper speaks to the literature on the link between trade and urbanization, complementing previous empirical work set during the formation of the United States (Bleakley and Lin, 2012; Nagy, 2020), Hungary post-World War I (Nagy, 2022) or Argentina in the late 19$^{\text{th}}$ century (Fajgelbaum and Redding, 2022). This literature has mostly considered relatively large trade infrastructure, such as ports, highways or canals (Ganapati et al., 2021). Here, I instead focus on a trade technology independent of physical transport infrastructure that is potentially more malleable by policy than some of the natural advantages underlying other trade infrastructure.

Finally, the paper speaks to an active empirical literature on the effects of rural infrastructure for local development and structural transformation (Michaels et al., 2012; Faber, 2014; Storeygard, 2016; Christiaensen et al., 2017; Aggarwal, 2018; Asher and Novosad, 2020; Baum-Snow et al., 2020; Brooks and Donovan, 2020; Gebresilasse, 2020; Moneke, 2020; Asher et al., 2022; Fan et al., 2022; Blakeslee et al., 2022). This work has shed light on how projects such as roads or irrigation canals alter the economic choices people make. Typically, however, these studies have found that rural productivity increases, for example through lower transport costs, only rarely translate into local economic diversification and urbanization, and rather deepen existing specialization across space. Marketplaces with their concentration of economic activity, however, may reasonably influence the local effects of transport infrastructure investments. My empirical context and the extended spatial model open up the possibility to study the interaction between marketplaces and other rural policies.

The following section provides background information on marketplace origins, functions and surrounding policies with a focus on East Africa. Section 3 introduces the data sources I use and describes the novel methodologies underlying them. Section 4 establishes stylized facts around marketplaces and the development of local economies. In Section 5, I present a spatial model including marketplaces, building on the functions described in Section 2. In Section 6, I examine whether the model is consistent with the observed patterns. Finally, in Section 7 I use the model to characterize trade-offs between providing marketplaces and other forms of rural-urban linkages.

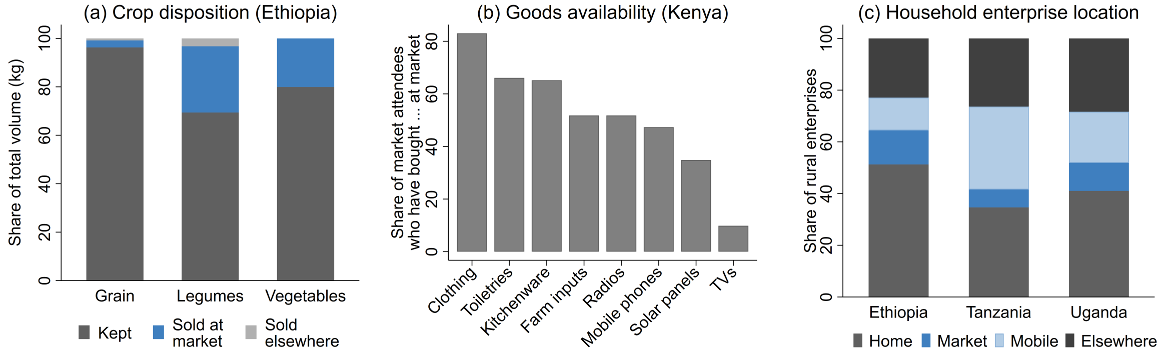
2 Context

By matching buyers and sellers at a set time and place, periodic markets represent one of humanity's most fundamental mechanisms to facilitate trade. Such arrangements, at weekly, monthly or other frequencies, have been documented throughout history, from the Roman Empire (de Ligt, 1993) to medieval Europe (Braudel, 1983), the Aztec and Inca empires (Stearns et al., 2015), pre-colonial West Africa (Hill, 1966) and Mughal-era India (Gajrani, 2004).

Periodic markets' ubiquity and persistence can be linked to at least three enduring characteristics of non-urbanized regions. Firstly, a dispersed population outside of larger cities makes finding buyers for one's goods time-consuming and costly (Casaburi et al., 2013; Linard et al., 2012). Secondly, weak legal systems promote a preference for face-to-face transactions (Haggard et al., 2008). And thirdly, with agriculture in the hands of smallholders selling small volumes and lacking access to individual motorized transport (Sheahan and Barrett, 2017), bulking goods can be efficient. Marketplaces with their periodic gatherings at set times and places address these constraints. Marketplaces' advantages persist even in the face of recent advances in communication technologies which represent an alternative way to match buyers and sellers, but so far appear to only be viable for the largest producers (Bergquist et al., 2022).

While the share of goods that gets exchanged through periodic markets likely decreases as economies get richer and trade formalizes, they remain central to rural economies and livelihoods in many developing

Figure 1: Market functions in East Africa



Panel (a) uses LSMS-ISA data from 2018/19 to sum up harvested volume (kg) for the two main crops in each region within Ethiopia falling into either crop category. The stacked bars correspond to the share of total harvested volume per disposition mode. Panel (b) shows for a sample of market participants interviewed in Kithuka et al. (2020) the share of respondents who have previously bought the listed goods at marketplaces. Panel (c) shows the most common locations for households to operate their businesses at in the most recent survey round from the respective country.

countries today. Here, rural populations sell their crops, access otherwise unavailable goods and operate non-farm enterprises. This is reflected for East Africa in data recorded in recent LSMS and other surveys (Figure 1). Panel (a) shows that in Ethiopia, the majority of the crop volume that is produced for sale gets sold at markets as opposed to other channels, such as fixed shops, cooperatives or at the farmgate. This outlet is especially relevant for goods with relatively higher value per weight, such as legumes and vegetables. Panel (b) illustrates the kinds of goods that are typically obtained at marketplaces using data from a survey of market participants in Kenya (Kithuka et al., 2020). Common goods include including clothing, kitchenware and small electronics. They have in common that, unlike widely available consumer goods such as batteries or soap, households do not buy them frequently and storing them adequately over time is challenging. Furthermore, their value-to-weight ratio is high compared to, e.g., building materials. Both factors contribute to them being provided through itinerant vendors rather than fixed shops. Finally, panel (c) shows that across Ethiopia, Tanzania and Uganda, a substantial fraction of household enterprises operates at markets, typically in retail but also in the provision of small-scale services such as food stalls or barber shops.

Focusing on Kenya, weekly markets are a relatively recent phenomenon. In pre-colonial times, less frequent fairs developed at caravan intersections for the exchange of high-value goods such as textiles, ivory and salt. There is little evidence for the existence of local or intra-regional exchange in East Africa before the colonial era[2]. The colonial government accelerated the development of periodic markets, most notably with the introduction of the Trading Center Ordinance in 1932, creating the legal framework for local authorities to request permission for markets to be held at a set time and day of the week (Good, 1973; Obudho, 1976). While initially placed by decree, later on "the forces of supply and demand [...] determined the actual mode and locale of operation" (Obudho, 1976) and subsequent research noted that

[2]This late development of markets is reflected in that, in contrast to West Africa, markets in East Africa usually adhere to schedules based on the seven-day-week. Other market schedules in West Africa, based on 4-day or 8-day cycles have been interpreted as evidence for pre-colonial origins there (Bromley et al., 1975).

many marketplaces struggled to maintain their operations, especially in more remote regions (Kongstad and Mönsted, 1980). This decrease in the number of markets post-independence coincided with a time where rural population quadrupled, urbanization rose to 30% and agricultural trading was liberalized, for example through the abolishment of marketing boards.

Marketplaces remain important features of Kenya's economic geography today. The remotely-sensed market activity data I introduce in Section 3 reveals that a proxy for the number of market participants was growing at about 8% per year prior to the COVID-19 pandemic (Figure A.6).

Furthermore, local governments acknowledge markets' relevance for rural livelihoods in policy documents. For example, each of the 47 counties in Kenya mentions policies related to 'market access' in their development plans and 42 mention concrete projects to establish new or upgrade existing markets[3]. For example, the government of Kisumu county lists the 'construction of five modern markets', 'construction of 50 market sheds [at existing marketplaces]' and 'rehabilitation of 90 market toilets' as goals under its 'trade development program', with these marketplace-oriented policies making up 50% of the program budget. Despite this policy focus, however, previous research has found that market lists provided by governments are often outdated (Bergquist and Dinerstein, 2020), providing a motivation for the satellite-based detection method I introduce in the following section.

3 Data

I now introduce the various data sources I employ for the empirical analysis. I focus on Western Kenya (see Figure A.1 for an overview map), as this part of the country is the most densely populated and rural marketplaces are most widespread, as opposed to the more urbanized and less agriculturally dependent regions around Nairobi and by the coast[4]. Also, the historical topographical maps which I introduce below are available at the required high resolution for this region, in contrast to some of the less densely populated regions in Kenya's North and West. The selected counties make up 6.4% of Kenya's land area and 40% of its 2009 population outside Nairobi (15 million people). I compile data on market locations, population density and transport infrastructure throughout the region in both 1970 and today. I introduce each of the sources and associated methods in turn before detailing their aggregation.

3.1 Markets

Historical market locations To map historical market locations, I digitize and georeference a unique list of markets for Kenya from 1970. The list was compiled by Wood (1973b) and details place names and days of operation for the 984 official markets throughout the country in the, to my knowledge, last conducted administrative mapping. I obtained these lists from the author and georeferenced the individual markets based on the coordinates and place names associated with each market. Figure A.2

[3] Obtained from www.cog.go.ke/downloads/category/106-county-integrated-development-plans-2018-2022

[4] I specifically select the following counties: Bomet, Bungoma, Busia, Elgeyo Marakwet, Homa Bay, Kakamega, Kericho, Kisii, Kisumu, Nandi, Nyamira, Migori, Siaya, Trans Nzoia, Uasin Gishu, Vihiga

shows an example of a market list. The mapping itself was part of the preparations for the 1970-1974 development plan (Republic of Kenya, 1969) which included a functional classification of rural places, including marketplaces[5]. The market lists were summarized and described in Wood (1974a) and Wood (1973a).

One may be concerned about the accuracy of the historical market lists and their completeness. The list served as the sampling frame for empirical geographical research at the time. Wood (1975) found that in Kisii district in Western Kenya, all 65 officially licensed markets from the list were indeed opearting, but since 'council control of market activities in the district is lax', he found an additional 24 informal markets. These were likely of smaller size or within the same locations as the formal ones but held on non-licensed days and without any obvious functional differentiation with respect to the official ones. In Meru district in the central part of the country, Wood (1974b) similarly found all listed markets to exist, and reports 'strict market control which means that there are few unofficial markets and there is almost no use of official market places on unofficial days'. Similar conclusions were made by Obiero (1975) and Ocharo (1975). There is thus no evidence that the market list undercounted markets at the time.

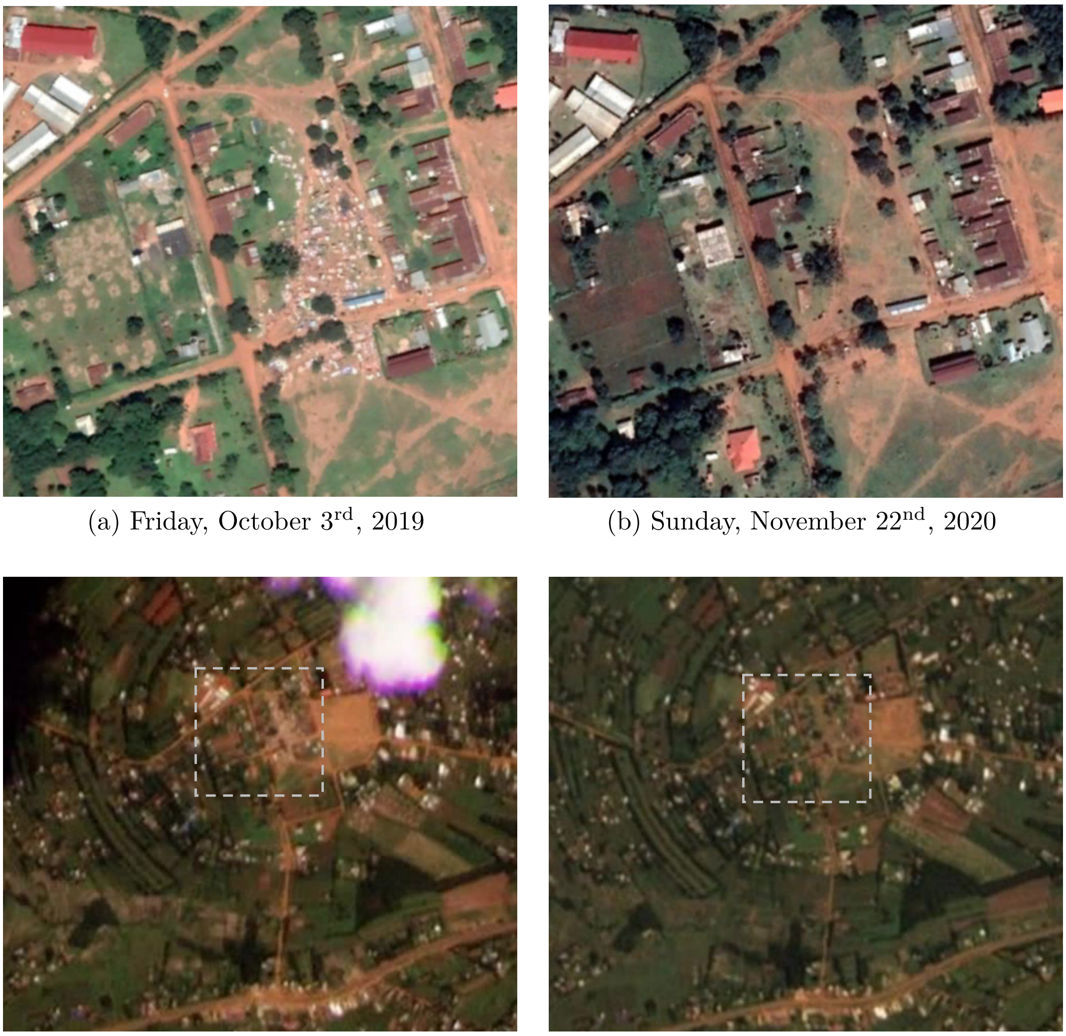
Contemporary market locations I complement the historical market locations with modern market maps derived from a novel methodology to detect rural marketplaces and track their activity. Figure 2 illustrates the visual pattern underlying the market detection method. It shows in the top row two very-high-resolution images from the Google Earth archive for a Kenyan village, acquired on a Friday and a Sunday. In panel (a), the village square is covered in white, blue and red structures - such as stalls, vehicles and tarps for goods display - that are typical of periodic markets in the context. While in principle it would be possible to scan an archive of similar imagery for places that look like marketplaces using machine learning, in practice images at the required resolution are only rarely acquired and made publicly available more than a few times per year.

Infrequent captures imply that the few available images may not show a market if they are not taken on market day. This is the case in panel (b): here, the village square appears only as bare ground, indistinguishable from other open-air public areas. My method therefore uses PlanetScope as an alternative source of satellite imagery. This imagery has a slightly lower resolution (3 meters per pixel) than for example the GoogleMaps basemap, but a very high, up to daily revisit frequency at around 11am local time. This allows me to exploit the relative brightness of markets on market days - evident from comparing panels (a) and (b) - as well as the periodic nature of this visual signal - e.g. taking place every Friday, but not on Sundays - in globally available high-frequency imagery.

Panels (c) and (d) of Figure 2 show examples of the PlanetScope imagery I employ. While the market is not clearly discernible with the bare eye due to the imagery's lower resolution, comparing the area within the grey dashed squares in the two images still reveals a brighter patch in the image taken on

[5] Kongstad and Mönsted (1980) underline the distinction between rural marketplaces and 'trading centres' of which there were five times as many in Kenya in 1972. The latter represent locations where vendors operate in fixed stalls every day of the week, and typically did not source produce.

Figure 2: Marketplaces and market days in satellite imagery



Very-high-res. imagery

(a) Friday, October 3rd, 2019

(b) Sunday, November 22nd, 2020

PlanetScope imagery

(c) Friday, August 27th, 2021

(d) Sunday, September 5th, 2021

Market day | **Not a market day**

The figure illustrates the market detection algorithm behind the contemporary market mapping. Panels (a) and (b) show Tongaren in Bungoma County, Kenya, in very-high resolution imagery from GoogleEarth. Panels (c) and (d) show the same location in PlanetScope imagery, with the grey squares indicating the extent shown in panels (a) and (b). The algorithm scans stacks of PlanetScope images for brightness deviations indicative of markets, as in the panels (a) and (c).

a Friday compared to the one taken on a Sunday. The basic idea of the method builds on this visual difference and its periodic nature: it screens large stacks of images for changes in brightness that - unlike the patch of cloud visible in the Friday image - occur at a regular frequency.

Identifying changes requires the definition of a reference image, ideally showing a non-market day. However, I cannot know ex-ante which weekdays are non-market days. I therefore construct median composites of imagery for each location – essentially representations of what a typical day looks like. Assuming that markets occur on less than half of the days of the week, the median composite will resemble an image taken on a non-market day. I construct the composite from all images falling into rolling 90-day windows around the date of each individual image in order to capture seasonal trends in how the area looks.

Equipped with this reference image, I subtract it from each individual image to get representations of brightness differences. The high frequency of the imagery then enables me to look for areas that frequently turn bright on a given day of the week, for example on Fridays. I extract these using two threshold values for what constitutes a change in brightness and when that change is frequent. The method is presented in greater detail in von Carnap (2021).

Ideally, the method would, when deployed over a large number of locations, detect a high share of existing markets - a high true positive rate - and not detect markets in a large share of locations that do not have markets - a high true negative rate. I rely on the set of markets studied in Bergquist and Dinerstein (2020) in Western Kenya as one of the very few available up-to-date market maps to assess the former and calibrate the method's parameters[6]. The authors specifically sampled periodic markets as opposed to other places of trading and recorded their location and days of operation. I define accuracy of the method as the share of markets in the sample where I detect at least one of the actual market days ('true positive') but no other days ('false positive'). I choose the method's parameters to maximize accuracy and detect 85% of markets under the best-performing parameter combination. The relatively small sample size limits my ability to create standard 'training' and 'validation' samples, possibly raising concerns of overfitting the data. The performance of the algorithm, however, is satisfactory across a wide range of parameters, alleviating such concern (see Figure A.4 for a summary for the calibration and validation exercise).

Furthermore, I provide two sets of evidence that strongly suggest that the detected areas indeed represent markets and not other periodic events. First, the areas predominantly lie along roads, in open village squares or surrounding larger public buildings, where markets would be expected to operate. Secondly, I validate that the method never detects the locations of known churches and mosques in the study area as recorded in the OpenStreetMap. These religious buildings could reasonably be expected to also feature periodic gatherings. The fact that I never detect them suggests, however, that these meetings occur mostly indoors or at other times than when the imagery is captured.

The method and its underlying imagery imply three limitations in terms of the kinds of markets that can be detected. First, they need to take place under open-air to at least some extent. This would be a concern if markets are held under structures, leading to false negatives. A frequent pattern in the data is, however, that the detected patterns lie around large buildings, suggesting that market activity typically spills out onto the surrounding streets.

A second limitation is as alluded to above that in order to define a valid non-market-day reference image, markets need to occur on less than half of the days of the week. This appears to be a weak assumption based on my sample of detected markets: those convening once per week (64% of markets) are thirteen times as common as those convening thrice (5%), suggesting that periodic markets occurring on four or more days are very rare. The definition of the reference image also excludes daily markets

[6]Other publicly available market monitoring dataset such as those maintained by actors like the WFP or IFPRI focus on aggregation markets in district capitals or other larger towns. Furthermore, the published data typically do not have measures of market extent or timing.

or those at other non-weekly frequencies. It may be the case that some of the periodic markets in 1970 have developed into daily markets and hence not be detectable. I address this by assuming that every county capital as well as every location within five kilometers of a daily market in 1970 is still home to daily markets in 2020 (see Figure A.5).[7]

Finally, the method can only detect markets operating around noon when the satellites pass the study region and acquire the imagery. This excludes evening markets, which according to anecdotal evidence are widespread but typically very small and serving only villagers in their immediate vicinity after the day's work. These markets are qualitatively different from the larger weekly meetings I study.

Having thus validated the method, I then deploy it over a large set of locations in Western Kenya, including all locations known to have a market in 1970, all road intersections between tertiary or higher-classified roads, all market locations mentioned in county development plans and additional clusters of houses as identified visually from satellite imagery. In total, I scan 1,210 candidate locations and detect 339 weekly markets in the study region.[8]

A concern may be whether the two sets of data indeed map the same types of markets. Both are decidedly geared towards measuring weekly, rural marketplaces as opposed to other forms of trading. This comparability is substantiated by the fact that the relative frequency of specific market days or combinations thereof is highly similar between the two sources (Figure A.7).

Market activity Beyond detecting markets as described above, the satellite imagery also allows me to track activity within the detected markets. Specifically, I use the brightness patterns underlying the detection to construct an indicator of daily market activity[9]. The intuition here is that on a busy trading day, the market will appear brighter than on less busy days, since market participants cover more of the market area. As shown in von Carnap (2021), the measure both captures large shocks to market functioning, such as violent conflict or COVID-19 lockdowns (Figure A.6), as well as smaller deviations linked to weather fluctuations within and across years. I use this measure to validate some of the spatial model's mechanisms later on.

[7]Non-weekly market frequencies, are not prevalent in the study area, while the method could in principle be adjusted to also detect such markets, as long as they are regular.

[8]I performed the search for markets between May 2021 and May 2022 where I screened candidate locations in various groups consisting of a mix of the categories described above. In the initial searches, I detected a market in about 60% of candidate locations while later this number fell to 6% in a search over all road intersections throughout the study area.

[9]The market activity on day d for a given location with market area A and and set of market days D is given by

$$mktAct_d = \sum_{a \in A} \frac{A_a}{\sum_{a \in A} A_a} \underset{p \in A_a}{median} \left(\underset{b \in r,g,b}{max} \left(\frac{v^b_{p,d} - \underset{j \in (d \pm 45) \wedge \overline{D},}{median} \left(v^{b,}_{p,j} \right)}{\underset{j \in T_{\overline{D}}}{sd} \left(v^b_{p,j} - \underset{j \in (d \pm 45) \wedge \overline{D},}{median} \left(v^{b,}_{p,j} \right) \right)} \right) \right)$$

where A is the number of detected market patches and A_a their respective areas. p identifies pixels, b spectral bands and T the set of imagery of non-market days in the location.

3.2 Population density

Empirical research on economic growth in developing countries is often limited by a lack of long-term time series of relevant indicators. Population density is a commonly-used proxy, grounded in the Malthusian idea that in a pre-industrial economy, higher productivity translates into higher population density at constant standards of living (Hanlon and Heblich, 2022). The required population data is often easily available through censuses stretching back in time.

Censuses as a data source are, however, of limited use when studying growth at detailed geographical scales, since they record population at the level of larger administrative units. These units, such as districts or provinces, often lump together smaller potential study units, such as locations with and without marketplaces. I therefore build on using population density as a measure of local development, but measure it using novel, spatially fine-grained data sources that record the locations of individual houses. Other spatially disaggregated direct measures of economic development for the region and periods I study are not available.

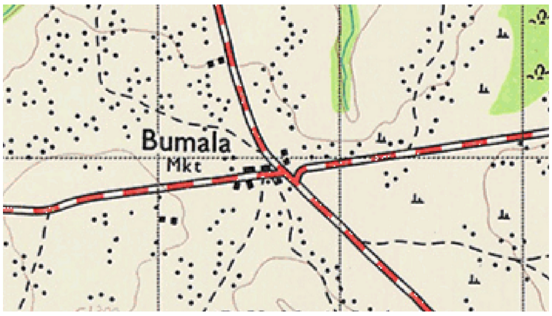
Historical population density I build on a unique mapping exercise conducted by the Government of Kenya and the the British Directorate of Overseas Surveys around 1970[10]. The program used high-resolution aerial photography to produce detailed topographical maps at a resolution of 1:50,000. Importantly, the aerial photographs were of such high quality that they allowed skilled interpreters to identify individual houses and record their locations in the maps. These are identified as black dots and rectangles, as shown in Panel (a) of Figure 3.

I use a machine learning algorithm and exploit the shape of the house symbols to extract their locations from the maps. Specifically, I first apply k-means clustering at the pixel-level of the georeferenced maps to group pixels by color, allowing me to isolate the black symbols within forests signifying trees. Further processing steps detailed in Appendix B exclude large black areas like those around the letters in the center of panel (b) of Figure 3, or narrow ones along the dashed paths. Mirroring the structure of the contemporary population density measure I introduce momentarily, I aggregate the individual houses in panel (b) of Figure 3 into a raster of 30m resolution with each pixel containing information on whether it include a house or not.

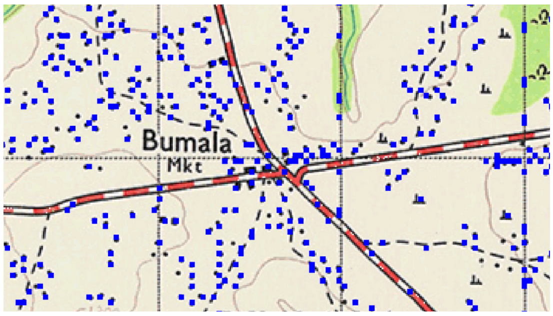
In order to validate this historical measure of population density, I compare it to the population levels recorded for my study area in the 1969 census. Specifically, I use the lowest level of geographic disaggregation recorded in that census, districts, and compare the ranking by population density when aggregating the derived population raster to the level of districts to the one from the census. As Figure B.2 shows, I find that the two measures have the expected positive correlation across the twelve districts

[10]The underlying aerial photography was taken between 1956 and 1974. Specifically, 79% of the study areas was captured in 1967, 16% in 1961, 3% in 1974 and 1% each in 1956 and 1959. The different base years introduce some measurement error when calculating population density for one year. There is, however, no straightforward way to smoothen density across boundaries of map sheets that would take into account the spatial structure of population. Furthermore, the boundaries of the rectangular map sheets are highly unlikely to correlate with meaningful geographical separations at the fine level I study. I therefore treat the map sheets as if they stem from one year.

Figure 3: Historical and contemporaneous population density measures

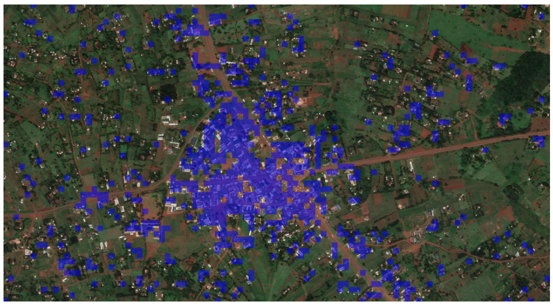


(a) 1:50,000 topographical map 1969



(b) Extracted house locations

(c) High resolution satellite imagery, 2022



(d) Population raster (Facebook, 2019)

Panel (a) shows part of a topographical map sheet from 1969 of a market location in Western Kenya. Black dots indicate buildings. The blue pixels in panel (b) identify detected houses based on the map, using machine learning and a pattern detection algorithm. Panel (c) shows a recent high-resolution satellite image of the same location. The blue pixels in panel (d) identify areas in which a computer-vision algorithm has detected at least one house.

($\rho = .39$). This correlation increases to $\rho = .87$ when I exclude the two districts for which maps were based on imagery taken in 1961. These outliers likely reflect lower population density at the time the underlying images were detected. I account for this difference in base years when constructing my measure of changes in population density, as described below.

Contemporary population density To measure contemporary population density, I use a raster provided by Facebook (2019) that indicates at a 30m-pixel level whether a computer vision algorithm has detected at least one building within that pixel (see panel (d) of Figure 3). This algorithm was found to track population accurately in Malawi where the same methodology has been applied (Kilic et al., 2016).

3.3 Access to urban centers

Beyond market locations and population density, I construct a measure of access to large cities, taking into account road distance and the size of each city. Here, I borrow information on the road network from Jedwab and Storeygard (2022)[11]. I follow the authors and distinguish between 'improved roads', 'paved roads' and 'highways', assigning travel speeds of 30, 50, and 70km/h respectively. Away from roads, I assume that travel at 10km/h is possible.[12] I combine this with population counts for urban centers, using

[11]The last year in which the road network is documented in this dataset is 2012. I assume that no major changes happened to the road network between then and 2020.

[12]While this assigned speed for off-road travel may seem high, the road network data I use does not include smaller rural roads and trails which would allow faster travel than by foot.

data from the Kenyan census and following its definition of urban centers (Citypopulation.de, 2022).

I combine the road network and population data to calculate a finely gridded measure of 'urban access' based on Donaldson and Hornbeck (2016) [13]. The measure calculates the urban access for each origin o to be a population-weighted sum of the travel times to all possible destination towns d, scaled by the trade elasticity θ[14].

$$UA_o = \sum_d \text{traveltime}_{od}^{-\theta} N_d$$

3.4 Dataset structure and constructed variables

I aggregate the above data at the level of $2.5km \times 2.5km$ gridcells throughout Western Kenya (Figure 4). I assign to each gridcell the distance from its centroid to the closest existing market, the average population density throughout the gridcell, and the maximum urban access throughout the gridcell, all measured in 1970 and 2020. I exclude gridcells falling completely into natural water bodies or forest reserves and national parks.

As my main measure of development, I calculate the change in a gridcell's within-district rank in terms of population density between 1970 and 2020. I use ranks instead of the raw data to account for the different origin of the population density measures, and rank cells within districts to account for the different years in which the underlying aerial photography was captures, as well as differing population structures between districts. For example, in 1970, some districts, for example around Kisumu, were relatively urbanized while others had the bulk of population living in workers' quarters around large-scale plantations.

4 Stylized facts: markets & urbanization

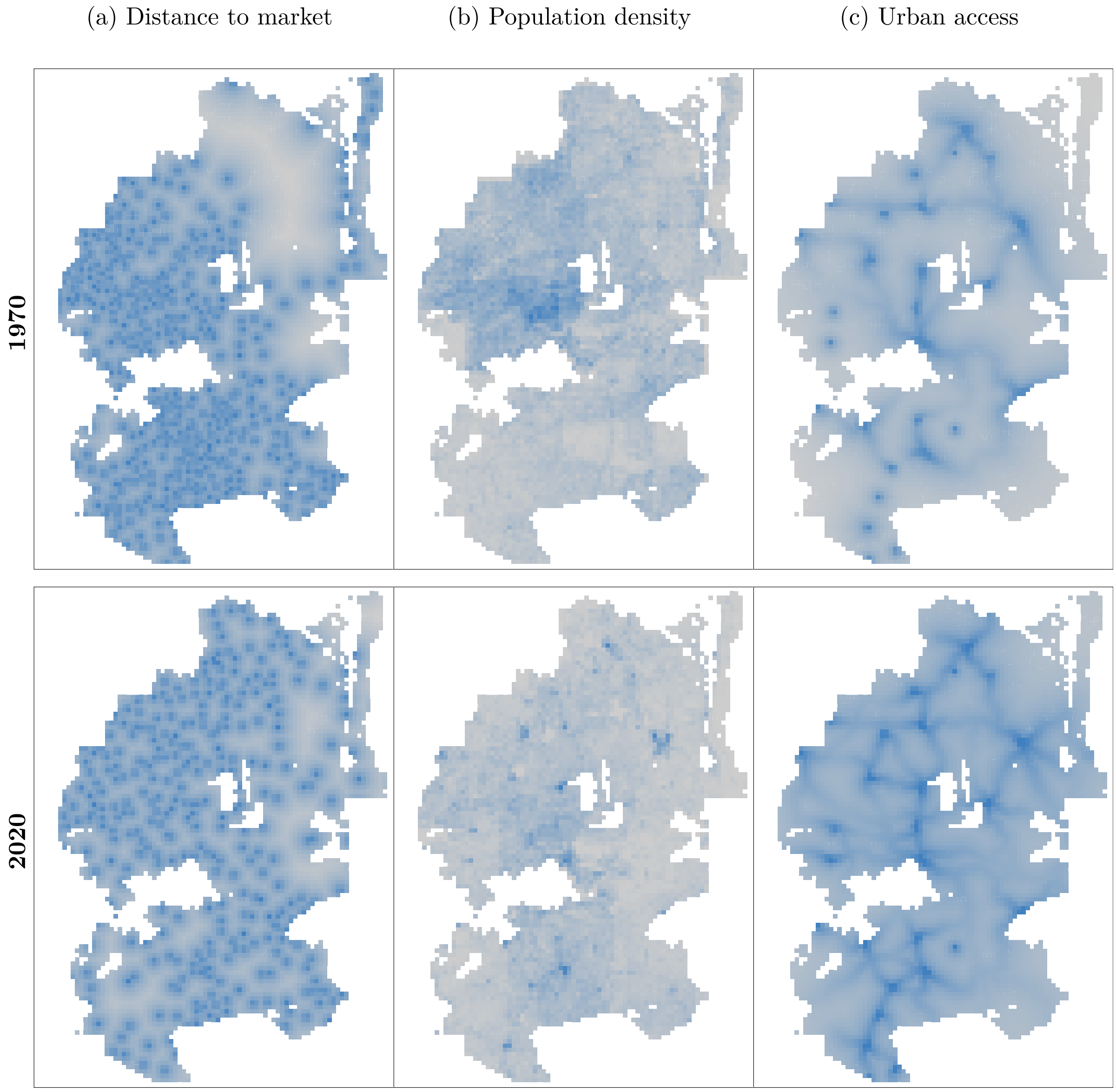
Equipped with the panel on market locations and population density, I now present three novel stylized facts on marketplaces and local development.

Market concentration: Figure 5 summarizes the data on historical and contemporary market locations. Despite liberalization of agricultural trading post-independence and a fourfold increase in rural population since then, 60% of officially registered markets in 1970 are no longer operating today. Only a small fraction of weekly markets have turned into daily ones, while approximately half of all markets existing today already were located in the same place, and indeed operated on the same day or days, in 1970. As evident from panel (a) of Figure 4, the new markets predominantly emerged in the northeast of the study region, where as Wood (1973b) notes, widespread plantation agriculture historically obliviated the *raison-d'-être* for small-scale producer markets, which changed with the liberalization of the land market after the colonial period.

[13]Note that I call this measure 'urban access' to differentiate between 'marketplaces' and 'towns'. I construct the measure analogous to their measure of 'market access' though

[14]I follow Aggarwal et al. (2022) and set $\theta = 5$.

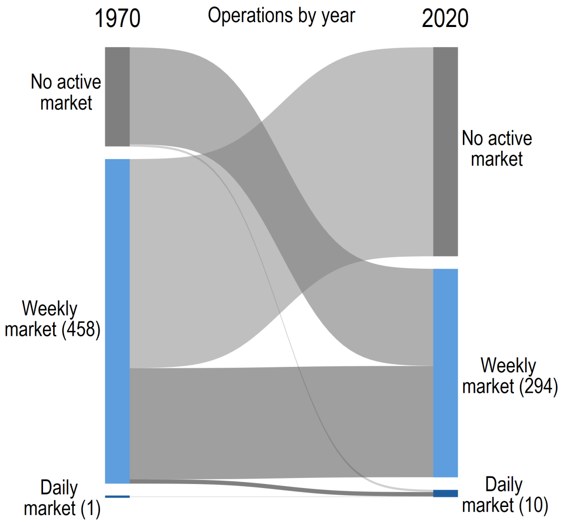
Figure 4: Gridded maps of key variables



Maps constructed from 2.5km-gridcells across Western Kenya for three key variables. Across columns, darker pixels indicate higher values. Top (bottom) row shows values for 1970 (2020). Unfilled areas indicate lakes, forest reserves or neighboring countries that are excluded from the analysis. Column (a) displays the negative of the log of a gridcell's centroid's distance to the nearest existing marketplace with colors scaled equally across the two rows. Column (b) shows the density of detected houses within each gridcell with colors scaled between the highest and lowest value per row. Column (c) shows the log of urban access (equally scaled across rows), following Donaldson and Hornbeck (2016), using roads data from Jedwab and Storeygard (2022) and considering all urban centers as defined by the censuses of 1969 and 2009, respectively.

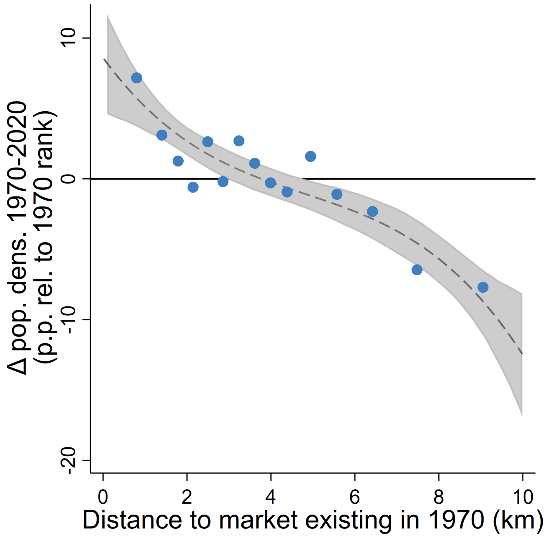
Population concentration: While this first finding may suggest that markets have been losing importance, locations with markets in 1970 saw their population increase on average relative to adjacent areas (Figure 6). This population concentration occurred both at the market location itself – through the emergence and growth of rural towns – and in the vicinity of markets – through higher rural population density. An obvious question here is whether markets are drivers of development or symptoms of it – perhaps markets exist in places featuring geographical advantages that let population grow for other reasons than the markets themselves.

Figure 5: Market concentration 1970 - 2020; locations with a market in at least one year (n=614)



Segments correspond to the number of market locations by frequency of operation in 1970 and 2020. Places without an active market in 2020 had a weekly market in 1970 according to Wood (1973b) but no discernible market activity in 2020 based on a remote-sensing algorithm. Correspondingly, places without an active market in 1970 had discernible activity in 2020 but were not listed in Wood (1973b). Shaded areas indicate flows between categories.

Figure 6: Population concentration around markets 1970 - 2020



Binned scatter plot of 2.5km × 2.5km grid cells by population density change between 1970 and 2020 and distance to market in 1970, constructed including fixed effects for 1970 population density and urban access measure percentiles. Dashed line represents the estimate from a quadratic regression, with the shaded area indicating the bootstrapped 90%-confidence interval based on 3,000 iterations.

While markets surely benefit from local growth, two additional observations suggest that they indeed contribute to local development. First, population concentrated around markets even within groups of locations that had similar population density and access to large cities in 1970. The line in Figure 6 is a quadratic fit to the data including fixed effects for the 1970 percentiles of population density and urban access across gridcells. Here, any location fundamentals existing prior to 1970 should already be reflected in higher population density then.

Second and focusing on areas without larger population agglomerations in 1970, market locations tended to grow in population if their market persisted, but saw relative decreases in population if their market declined. This is shown in Table 1, where I separate results by whether the market persisted or declined, and whether the gridcells falls into relatively sparsely or densely populated regions. More specifically, I estimate the following regression at level of gridcell i:

$$\Delta P_i = \beta_1 M_i^S + \mu_i + \lambda_i + \epsilon_i$$

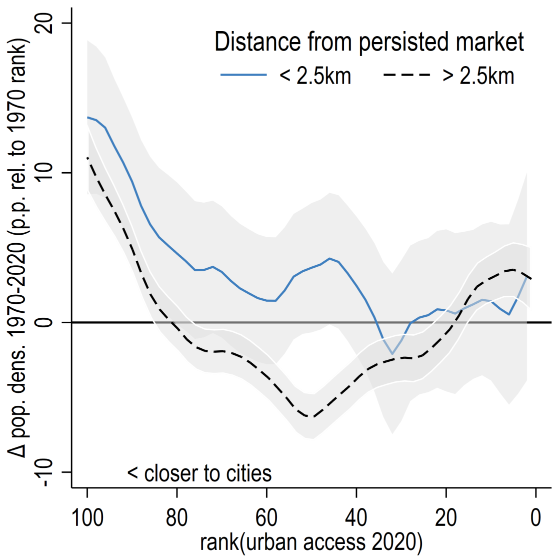
ΔP_i measures the within-district rank change in population density in percentage points of the number of gridcells in a given district. M_i^S is a dummy equalling one for gridcells within 2.5 kilometers of a market from a given set. μ_i and λ_i are fixed-effects for percentiles of 1970 population density and 1970 urban access, respectively. β_1 can then be interpreted as the average difference within locations with similar population density and connectivity in 1970 between places close to a market from a given set versus

Table 1: Population concentration at markets

Dependent variable:	% change in population density rank		
	(1)	(2)	(3)
Panel A: Gridcell distance to market in 1970			
<2.5km vs. >2.5km	3.962***	-1.622	7.832***
	(0.878)	(1.765)	(1.351)
Panel B: Gridcell distance to declined market			
<2.5km vs. >2.5km	-0.127	-4.413**	3.743**
	(0.991)	(1.948)	(1.494)
Panel C: Gridcell distance to persisting market			
<2.5km vs. >2.5km	9.817***	8.388***	9.306***
	(1.259)	(3.206)	(1.758)
Sample	All gridcells	Least populated 1970	Most populated 1970
Fixed effects			
1970 Urb. Acc.	Yes	Yes	Yes
1970 Pop. Dens.	Yes	Yes	Yes
N	5,221	1,723	1,722

Results from nine regressions using different sets of gridcells. The dependent variable in all cases is the change in the within-district ranking of gridcells according to population density between 1970 and 2020. Each regression in columns (1)-(3) compares gridcells directly adjacent to a market to gridcells further away. Panels A-C vary the set of markets that is considered. Robust standard errors in parentheses; * p<0.10, ** p<0.05, *** p<0.010.

Figure 7: Urban shadow



Binned scatter plot of access to urban centers and changes in 2.5km gridcell-level population density. The blue line indicates gridcells within 2.5km of markets that persisted since 1970 until 2020. The dashed line indicates gridcells further away than that. The lines are constructed using a local polynomial smoother. The shaded areas indicate 90% confidence intervals.

places far from a market. A positive estimate suggests that locations close to markets have seen relatively larger population increases since 1970 compared to those further away from markets.

Table 1 shows the results. Gridcells within 2.5 kilometers of an existing market in 1970 on average moved up four percentage points in the within-district ranking according to population density compared to gridcells away from markets. This suggests that places with markets saw higher population density increases than other, comparable places. This effect is entirely driven by places where markets persisted, whereas places where markets declined saw no disproportionate population increase (column 1).

In column (2), I look exclusively at gridcells that fell into the bottom tercile in terms of 1970 population density. Here, market locations do not have higher population density than their surrounding areas. Strikingly, locations where market persisted saw stronger population increases (panel C) than the average gridcell, but the reverse is true for the declined markets in panel B. This suggests that in places where markets are located away from population centers, local population trends are tied to their existence or disappearance.

Column (3) confirms that market locations also grew faster when their initial population was relatively high already, especially so if the market persisted. Here, however, locations that initially had markets and then lost it may have grown for other reasons. Also, since I do not have information on the precise date when a market declined, it may well be the case that they contributed to town growth until their disappearance.

Finally, column (4) provides some suggestive evidence that larger markets are associated with faster town growth. I here restrict the sample to gridcells adjacent to markets that persisted since 1970 and proxy for market size with the number of days at which markets were held in 1970 per week. The positive point estimate suggests that among two markets with similar initial population size, the one with more frequent operations saw a larger population increase.

The main estimate in column (1) is defined in terms of percentage point differences over a ranking across gridcells. To ease quantitative interpretation, I convert this estimate from the panel into differences in the density of detected houses in both the 1970 and 2020 cross-sections. Assuming a constant number of occupants per house, these figures are then comparable to population density. Specifically, I calculate for each district the median house density across all locations within $2.5km$ of an existing market in 2020 and then consider the range of house densities within $\pm\frac{\beta_1 \hat{M}_i^{2020}}{2}$ times the rank of the median location. In the median district, house densities increase by 6.4% (4.2%) within this range in 2020 (1970).

Taken together, these first two observations suggest that some marketplaces may have formed the nuclei of small-scale urbanization where population was initially scattered, or contributed to the growth of towns that already existed. Interestingly, however, there appears to exist a heterogeneity as to which markets grow into towns and which decline.

Urban shadow: The last stylized fact characterizes the heterogeneity evident in the first two facts in terms of markets' distance to larger cities. Figure 7 shows changes in population density ranks between areas adjacent and away from markets depending on their distance to larger cities in 2020. Specifically, I rank gridcells by their access to urban places as mentioned in the census.

The figure shows that market locations always saw higher increases in population density than locations away from markets at comparable distance, but especially so for markets located at an intermediate distance from larger cities. This suggests the existence of an 'urban shadow' (Cuberes et al., 2021), where places are held back in their development by their proximity to a nearby large city with established, productive industries.

5 A spatial model with rural marketplaces

The previous section presented evidence that while a large number of markets in Western Kenya declined since 1970, places with markets grew more than otherwise comparable ones, especially so away from larger cities. What may rationalize this heterogeneity and what forces make markets potential nuclei ' of urbanization? To answer these questions, I now introduce a model of rural-urban trade which includes marketplaces as explicit, population-independent locations of trade. Building on the New Economic Geography tradition (Fujita et al., 2001), the latter is a key conceptual novelty, where existing spatial models typically have trade flowing directly from producers to consumers. This assumption of direct trade flows may be a good approximation of industrialized economies with formal value chains, but is far removed from the reality of informal value chains. Therefore, existing models limit our ability to understand patterns of population agglomeration in particular and development more generally in non-urbanized, informal economies. In this section, I describe the basic functions and extensions of the model and link them to the observed empirical patterns. I provide ' formal derivations in Appendix C.

5.1 Model

Geography The economy consists of a continuum of locations $r \in (-\infty, \infty)$ along a line. I parameterize the model such that it initially has a unique, monocentric equilibrium where the economy's only city is located at $r = 0$. The economy's total population consists of N agents, $L < N$ of which produce tradable and non-tradable goods in the central city, while the remainder produces food at $r \neq 0$ wherever this is profitable to do. Specifically, each populated unit of land at $r \neq 0$ has c^A workers to farm that land. I inherit from the original model the assumption that the agricultural workforce is spread evenly throughout the city's hinterland, with agricultural nominal wages and land rents of absentee landlords adjusting such that real wages are identical everywhere. The economy is symmetric, i.e. for every farmer at r there exists an identical farmer at $-r$. For simplicity, I will focus on the 'right' side of the economy with $r > 0$.

The geography is furthermore characterized by $M > 1$ potential market locations placed exogenously at $m_1 = 0, m_2, m_3, ..., m_M$. Market locations, as I detail below, affect at what cost goods and food are shipped throughout the economy and where non-tradable goods may be produced and consumed. Not all potential market locations necessarily offer these advantages, as some may not have actually operating markets.

Preferences Agents – non-agricultural workers and farmers – have Cobb-Douglas preferences over food A, a tradable good M and a non-tradable good S with associated utility weights $\mu^{i\in\{A,M,S\}}$.

$$U = A^{\mu^A} M^{\mu^M} S^{\mu^S} = A^{\mu^A} \left(\int_0^{n^M} m(i)^{\rho^M} di \right)^{\frac{\mu^M}{\rho^M}} \left(\int_0^{n^S} s(i)^{\rho^S} di \right)^{\frac{\mu^S}{\rho^S}} \quad \text{with} \sum_{i\in\{A,M,S\}} \mu^i = 1 \qquad (1)$$

As Equation 1 shows, both tradable and non-tradable goods consist of composites of different varieties of the same. There are $n^{i\in\{M,S\}}$ varieties of either good, with each variety produced by an individual firm. Consumers substitute between varieties with substitution elasticity $\sigma^{i\in\{M,S\}} \equiv \frac{1}{1-\rho^{i\in\{M,S\}}} > 0$. If $\sigma^{i\in\{M,S\}}$ is large, individual varieties are substitutes from the perspective of consumers, whereas if $\sigma^{i\in\{M,S\}}$ is small, they demand all available varieties as complements.

As shown in Appendix C, utility maximization implies that the minimal cost of attaining a unit of either the tradable composite M or the non-tradable composite S at location r depends on the cost of shipping each variety from where it is produced to its place of consumption. The price indices for either good are given by

$$G^j(r) = \left[\int_0^{n^j} p^j(i,r)^{1-\sigma^j} di\right]^{\frac{1}{1-\sigma^j}} \text{ for } j \in \{M, S\},$$

with $p(i,r)$ the price at r for a variety produced at i. I will return below to the specific functional form for the transportation of tradables and non-tradables.

Transport I now specify how prices differ with transport costs across space, incorporating marketplaces. I follow the canonical framework in assuming that transport costs for food and the tradable good take the iceberg form. For non-tradables, however, I assume that these can only be consumed at their place of production or at marketplaces. Intuitively, a certain service may not be possible to provide economically to individual households, but crowds at markets may make it worthwhile for service providers based in the central city to offer their services also at marketplaces.

Assume for now that all non-agricultural production occurs at location s ($= 0$ in the initial monocentric equilibrium) and farmers live at locations $r > 0$. Then non-agricultural goods flow from s to r and food from r to s. I do not allow for intra-rural exchange: instead, the agricultural good is uniform and its flows directed towards the city. As an extension to the original model, I introduce marketplaces $m = 1, ..., M$ located at exogenous potential locations m_m. Whether a given market actually operates will be determined endogenously in the model. Fixing market locations, however, avoids having to deal with multiple equilibria.

Transport of food from r to s (or from location s to r for manufactures) may occur directly at rate $\tau^A |r - s|$ ($\tau^M |s - r|$) or through marketplaces at locations m_m at rate $\tau^A |r - m| + \tau^m |m - s|$ ($\tau^M |r - m| + \tau^m |m - s|$). The τ here represent canonical iceberg transport costs, where for every good that leaves origin o, only $e^{-\tau|o-d|}$ arrives at destination d. Note that for simplicity I assume symmetry in the cost of exporting from and importing to a marketplace. I further assume economies of scale in transportation – i.e.that the cost of transporting through a marketplace falls with the volume of food traded there (V_m) – and fixed costs to setting up a market – i.e. trade only takes place at a given market if a sufficiently large volume γ is traded there. Furthermore, trading food through a market can never be more expensive then trading with consumers directly.

$$1 + \tau^m = max\left(min\left(\left(1 + \tau^A\right)^{\frac{\gamma}{V_m}}, 1 + \tau^A\right), 1 + \tau^{min}\right)$$

The intuition here is that markets only address search frictions if sufficiently many buyers and sellers attend a given location. For tractability, I assume perfect competition in the transport sector between any given market and wherever goods are shipped to. While recent evidence suggests that transport markets may be uncompetitive in developing countries (Allen et al., 2020), this assumption appears necessary for tractability reasons.

All farmers simultaneously choose the marketplace to trade in based on the utility their income buys them at that location, be it a market in a town or not. The market that a farmer at r trades at is given by[15]

$$m^*(r) = \left\{ m \in [1, M] : \max_m \left(\frac{p^A e^{-\tau^m m_m} e^{-\tau^A |m_m - r|}}{G^M (r)^{\mu^M} G^S (r)^{\mu^S}} \right) \right\} \tag{2}$$

Note how for the farmer it matters both how far she is from a given market and what the transport costs from that market to final consumers in the city are. There exists for each pair of markets $[m, m+1]$ for $m < M$ a marginal farmer at s_m that is indifferent between visiting market $m-1$ or market m. Supply to each market is then given by

$$V^m = \left(1 - \mu^A\right) \begin{cases} 2 \int_0^{s_m} e^{-\tau^A i} di & \text{for } m = 1 \\ \int_{s_m}^{s_{m+1}} e^{-\tau^A |m_m - i|} di & \text{for } m \in (1, M) \\ \int_{s_m}^{f} e^{-\tau^A |m_m - i|} di & \text{for } m = M \end{cases}$$

Note that supply to the market in the central city is doubled due to symmetry of the geographic structure, and that for the market furthest from the central city, the catchment area is up to the boundary of cultivation f, an equilibrium object I specify further below. A market is only operational if volume traded at the market is sufficiently large, $V_m > \gamma$. Markets lead to discontinuities in the cost of accessing markets throughout space that make them attractive locations to sell through.

The transport cost for the agricultural good, the tradable good and the non-tradable good between any two places are then given by

$$\left. \begin{array}{rcr} T_{rs}^A & = & \tau^A |r - m^*| + \tau^{m^*} |m^* - s| \\ T_{rs}^M & = & \tau^M |r - m^*| + \tau^{m^*} |m^* - s| \\ T_{rs}^S & = & \tau^{m^*} |m^* - s| \end{array} \right\} \text{for } r \in (s_{m^*}, s_{m^*+1})$$

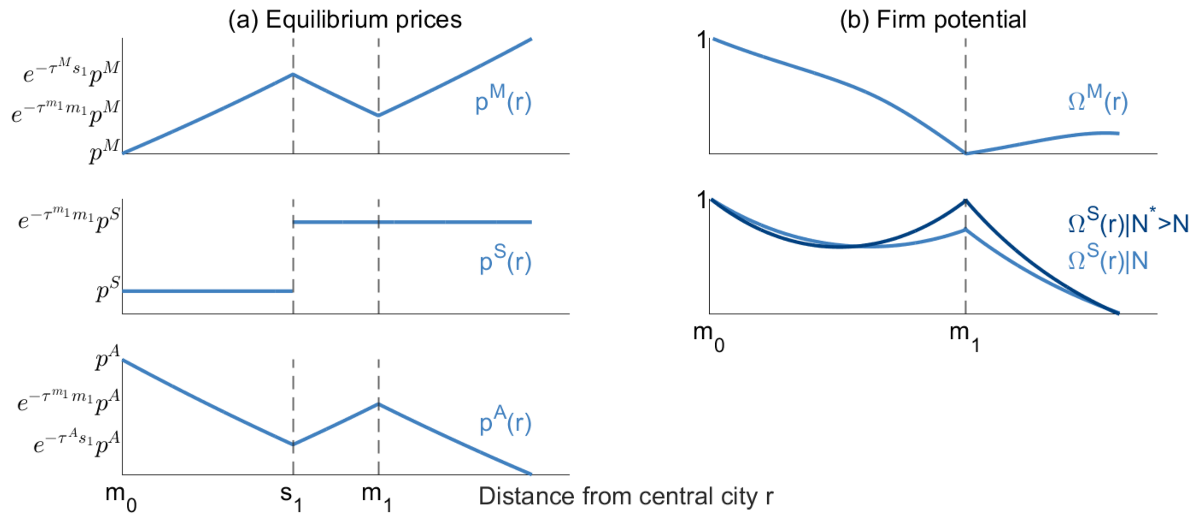
Figure 8(a) illustrates the resulting spatial structure. Farmers between s_1 and f can access the central town at the origin through the marketplace at m_1, where food prices are locally higher because of the lower transport costs through the market, and vice-versa for imported manufactures.

Production There are two types of production technologies in the economy. In rural areas, an agricultural sector produces food with constant returns to scale. Its productivity is embedded in c^A, denoting how many farmers are required two produce one unit of food from a unit of land.

The production of tradable and non-tradable goods is carried out by firms operating with increasing returns to scale and taking labor as their only input. Since consumers value variety and production exhibits increasing returns to scale, a new firm will never specialize in a variety that is already produced by an existing firm. Therefore, each variety is only produced in one location by one firm. Firms will operate wherever the wage they can pay workers and still break even matches farmers' reservation wage,

[15] Lanzara and Santacesaria (2021) show that under standard assumptions on utility and price functions, resulting equilibria with distinct market catchment areas are unique.

Figure 8: 3-good spatial model with marketplaces(tradables M; non-tradables S; food A)



The left column shows equilibrium prices for tradables M, non-tradables S and food A faced by farmers living at distance r from a central city in a model with a rural marketplace at m_1. Transportation is costly, so the price farmers receive for food (pay for tradables) decreases (increases) between 0 and s_1. At m_1, farmers receive a higher price for food (pay a lower price for tradables) than simple distance would suggest because they can trade with an intermediating sector transporting goods with scale economies between market and city. s_1 indicates the farmer indifferent between trading at market or city. Farmers to her left access the non-tradable good in the city, while farmers to her right obtain it at the market. The right column shows the ratio between the break-even wage a firm in $\{S, M\}$ could pay and farmers' reservation wages. Firms operate wherever this ratio reaches unity. The marketplace is a local minimum for M production because competing varieties can be cheaply imported from the central city. For S, however, marketplaces are local maxima since farmers can only access the goods there. As overall demand grows, for example with population growth, the curves will eventually reach unity, either away from the marketplace for M firms or at markets for S firms. The dark line in the lower panel illustrates this case. I list underlying parameter values in Table C.1.

i.e. their income from agriculture. As shown in Appendix C, for a firm producing tradable goods at location r, break-even wages are given by

$$\begin{aligned} w^M(r)^{\sigma^M} &= \underbrace{Y(0)\left(T_{r0}^M\right)^{1-\sigma^M} G^M(0)^{\sigma^M-1}}_{\text{urban consumers}} \\ &+ \underbrace{\int_{-f}^{f} Y(i)\left(T_{ri}^M\right)^{1-\sigma^M} G^M(i)^{\sigma^M-1}\, di}_{\text{rural consumers}} \end{aligned}$$

The wage a firm can pay increases with incomes of its urban customers $Y(0)$ and the prevailing price level in the central city $G^M(0)^{\sigma^M-1}$, and it decreases with the transport cost to reach them $\left(T_{r0}^M\right)^{1-\sigma^M}$. The same comparative statics hold for rural customers who pay for the transport of the tradable good through them either directly from the place of production or through a marketplace.

The wage equation for non-tradable goods incorporates that these goods can only be consumed at either their place of production or at marketplaces. Firms thus incorporate the transportation cost to each market $\left(T_{rm}^S\right)^{1-\sigma^S}$ and there access the demand from all market attendants V^M.

$$w^S(r)^{\sigma^S} = \underbrace{Y(0)\left(T^S_{r0}\right)^{1-\sigma^S} G^S(0)^{\sigma^S-1}}_{\text{urban consumers}} + \underbrace{\sum_{m=1}^{M}\left(T^S_{rm}\right)^{1-\sigma^S}\int_{V^m} Y(i)\, G^S(i)^{\sigma^S-1}\, di}_{\text{rural consumers}}$$

Equilibrium In equilibrium in the monocentric economy, the following conditions must hold for a given overall population size N and other parameters as introduced above. First, food prices in the central city must be such that supply equals demand there:

$$p^A = \frac{\mu^A L^M w^M}{V^1 + 2\sum_{m=2}^{M} V^m e^{-\tau^m m}} = \frac{\mu^A\left(N - 2c^A f\right) w^M}{V^1 + 2\sum_{m=2}^{M} V^m e^{-\tau^m m}}$$

Second, real wages must be equalized between rural and urban areas so no worker or farmer has an incentive to relocate.

$$\frac{p^A(r)}{p^A(r)^{\mu^A}\prod_{h=1}^{H} G^h(r)^{\mu^h}} = \frac{w^M(0)}{p^A(0)^{\mu^A}\prod_{h=1}^{H} G^h(0)^{\mu^h}}$$

Third, wages paid in each sector must be equal within production locations, ensuring zero profits for firms.

$$\left[w^{Mh}(0)\right] = 1 \forall h \in 1, ..., H$$

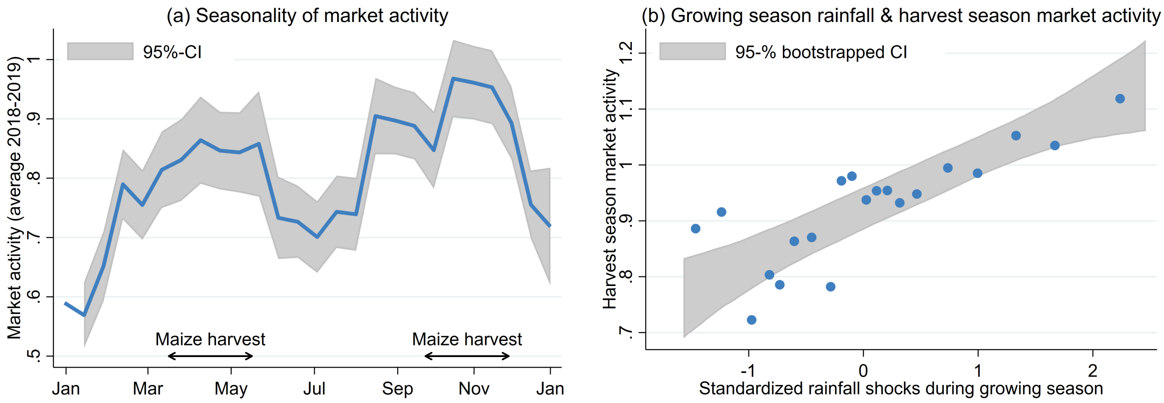
With the manufacturing wage in the central city normalized to one, this is a system of three equations in three unknows (p^A: the price of food in the central city; f: the cultivation frontier, until where agriculture is profitable; L^S labor employed in the non-tradable sector). A nested problem is to find the market catchment areas defined by s_m and associated volumes at each market.[16] Finally, we have to verify that with given parameters, the resulting equilibrium is indeed monocentric, that is, firms cannot operate and break even at any location other than the central city. This condition corresponds to the real value of the potential wage paid in firms from either the tradable or non-tradable sector nowhere exceeding the local real wage in agriculture.

$$\Omega^{i\in M,S}(r) = \frac{\omega^{i\in M,S}}{\omega^A} < 1 \;\forall\; r \text{ with } \omega^{i\in M,S} = \frac{w^i(r)^{\sigma^i}}{p^A(r)^{\mu^A} G^M(r)^{\mu^M} G^S(r)^{\mu^S}}$$

Figure 8(b) illustrates urban potential for firms producing tradable or non-tradable goods at and around the marketplace. With $\lambda^h = 0$ (left panel), the market location is a local minimum in urban potential, since food prices are higher and imported manufactures cheaper at the marketplace than in the surrounding areas. With concentrated spending at the marketplace through $\lambda^h = 1$ (right panel), however, marketplaces become a local maximum since for good h, the market is now the location where local

[16] Lanzara and Santacesaria (2021) show that for CES preferences, these partitions always exist and are unique for general underlying geographies.

Figure 9: Rainfall, agriculture and market activity



Panel (a) shows mean values of remotely-sensed market activity across markets in Western Kenya in 2018-2019 for each fourteen-day period within the year. The confidence interval tracks differences between mean activity in the first fourteen days of the year and subsequent weeks. Panel (b) plots bin means of local deviations from 2000-2019 seasonal rainfall means against market activity during the subsequent harvest period. The confidence band is constructed from fitting 1,000 quadratic models.

demand for this good can be accessed. Intuitively, goods which are consumed in-situ, such as services benefit most from being produced where demand is the most concentrated.

5.2 Validation

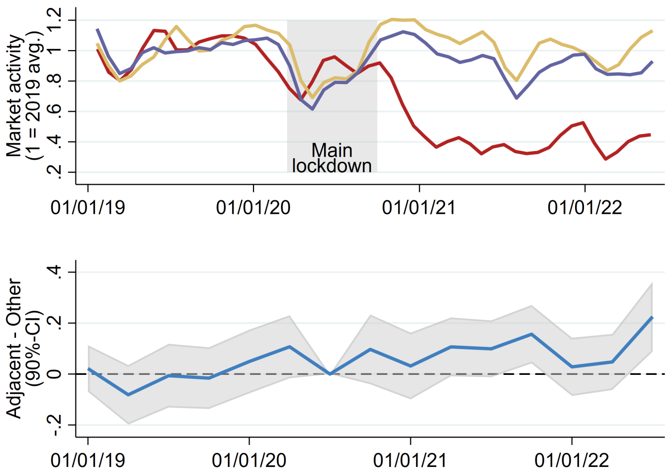
One central assumption in the spatial model with marketplaces is that trading within them is linked to the agricultural economy, and does not just reflect exchange and consumption between urban populations. While it is well known that rural economies more broadly are tight to agriculture, this assumption is directly testable with the remotely-sensed market activity data. Figure 9 shows that activity within markets is indeed closely linked to both intra- and inter-annual weather variation, suggesting that activity correlates with and possibly even directly tracks agricultural incomes.

Another key assumption is that farmers indeed choose between visiting different markets and not just trade off visiting their nearest market with being in autarky. The COVID-19 pandemic provides a context where a set of markets ceased to operate in Western Kenya, allowing me to test this prediction. Specifically, I test whether remotely-sensed market activity gets replaced from the declined markets to adjacent ones.

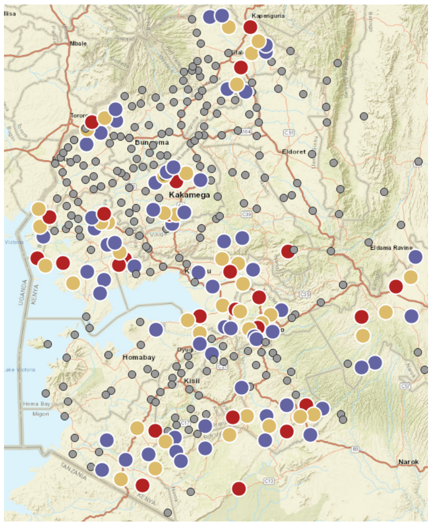
Figure 10a shows how for a set of markets, activity never recovered after the initial lockdowns. I match these markets (marked in red in Figure 10b) to the two nearest adjacent markets (marked in yellow), and in turn the latter to their two closest neighbors (marked in blue). Figure 10a then highlights how activity recovered faster in those markets adjacent to a declined one, relative to their non-declined neighbors. This suggests that at least some of the market attendants from the declined markets relocated to other markets in their vicinity.

Figure 10: Substitution in activity across markets

(a) Market activity decline & recovery around COVID-19



(b) Affected markets



The upper part of panel (a) shows remotely-sensed market activity in a set of markets that did not resume operations after the COVID-19 lockdowns (red), markets that were among the two closest adjacent ones to a declined market (yellow) and markets that were in turn the latters' two closest adjacent neighbors. The lower part shows the quarterly difference between activity in the second and third group, normalized to mean activity in the first quarter of 2020. Panel (b) locates these sets of markets in Western Kenya. Grey dots indicate other active markets not considered in this analysis.

5.3 Linking model to empirical findings

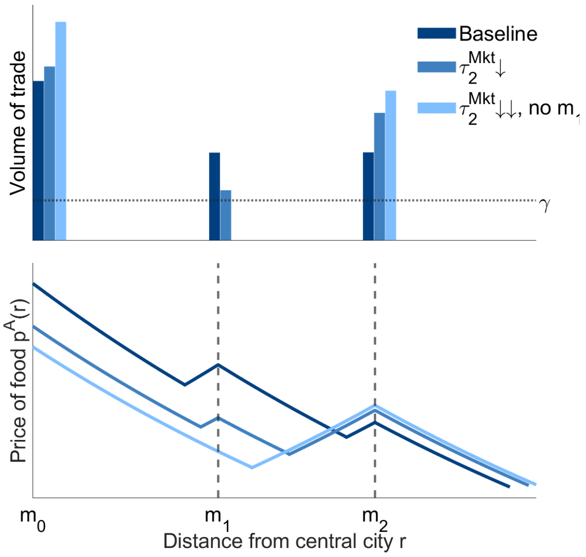
Having introduced the model and validated some of its core assumptions, I now describe how the novel features – economies of scale in transportation to and from marketplaces and concentrated demand there – provide an explanation for the observed empirical patterns.

Market concentration Economies of scale in transportation and substitution across marketplaces imply that farmers do not necessarily choose the marketplace closest to them. Rather, they weigh costs of reaching a given market from their home location against the price level a given market offers. As a result, they may prefer going to a distant, larger market over visiting a closer, smaller one, leading to the eventual concentration of trading at a smaller set of markets.

The model provides a structured way to think about what factors may determine which markets survive and disappear. Such an exercise is illustrated in Figure 11. Starting from an initial equilibrium spatial distribution of markets, some markets may become more attractive than others, for example due to improved transport connections to the central city (decreasing τ^m for some m) or newly established local production of certain goods (decreasing $G^{i \in M,S}(m)$ more for some m than others). Beyond the scope of the model, one may also imagine other technologies involving fixed costs that are only provided at specific locations. Figure 12 supports this story empirically, showing that markets were more likely to disappear around towns that grew relatively strongly.

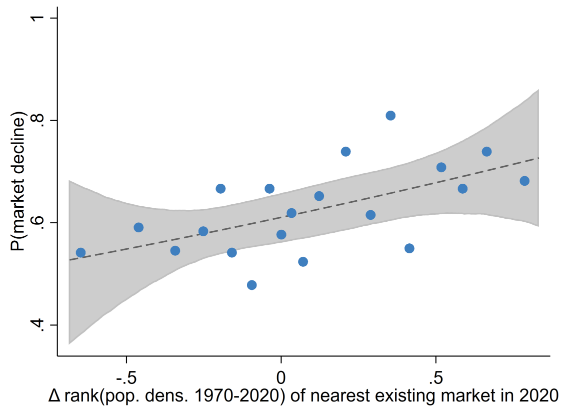
Population concentration Cheaper transport to and from markets reduces the cost of accessing urban goods and increases revenues from agriculture. This implies that living standards around markets

Figure 11: Market concentration at advantaged markets (model)



Results from three model runs, distinguished by color. Bar heights at three marketplaces indicate volume traded there. Lines show price of food by location. In the second scenario, m_2' access to the city improves relative to baseline. Traded volumes at m_1 fall close to market existence threshold γ as some farmers relocate. In the third scenario, m_2' access improves further and m_1's ceases to operate.

Figure 12: Market concentration around growing towns (data)



Bins of marketplaces operating in 1970, grouped according to population density growth at the closest existing market in 2020. Y-axis indicates the within-bin share of markets that declined. Dashed line indicates a quadratic fit with its 90% confidence interval from 3,000 bootstrap repetitions.

are higher than at comparable locations without. In line with the data, the model thus suggests higher levels of development around markets. These same effects imply, however, that markets are relatively unattractive locations for firms producing tradable goods to establish themselves, since they have to compete with cheap imports and pay farmers higher wages to induce them to leave agriculture. As a result and as Figure 8(b) shows, marketplaces are less likely to see firm establishment in this sector. In contrast, establishing at a market to produce non-tradables is particularly attractive, given that access to consumers is the most direct here. The finding from Table A2 in the appendix, that places with more frequent markets grew faster, may serve as further evidence of this.

Urban shadow Finally, the patterns shaping town emergence at markets are also relevant for explaining the urban shadow observed in the data. Marketplaces close to larger cities face stronger import competition, and hence are less likely to develop into towns.

6 Policy

Beyond providing an explanation for the empirical findings, the model also allows me to think about policy questions surrounding markets. In particular, I now use the model to describe the conditions under which markets provide the largest benefits, and what complementary investments can catalyze markets for local developemt.

6.1 Where can markets prosper?

The previous section has shown that a dense market network may not be sustainable if individual markets become more attractive than others. It also showed that larger markets provide advantages in terms of fostering the emergence of local towns. What then characterizes the locations where markets bring the highest benefits? This exercise mimics a policymaker having to decide where to place a new market. It also highlights where we may expect marketplaces to emerge and function.

I start from the same setup as in Figure 8 and vary the location of market m_1 throughout the hinterland of the city. For each location, I record the equilibrium real wage in the economy as a measure of the welfare gain induced by the market. As shown in Figure 13, the gains are highest away from the central city, where relatively disadvantaged farmers benefit from better prices for their products and present a market themselves for the established production in the central city.

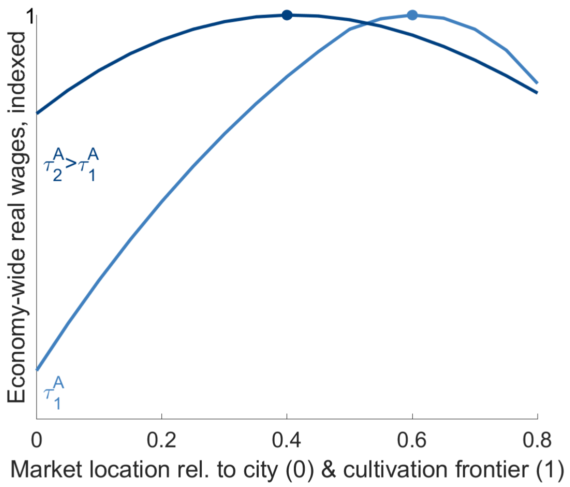
Figure 13 also shows that with higher overall transport costs, the optimal location for a marketplace is closer to the central city relative to the cultivation frontier. When transport costs are high, farmers already at intermediate distances benefit little from demand and supply in the central city, and hence welfare gains are high when a market operates there. This effect gets weaker the better alternative transport options are, explaining the outward shift in optimal market locations as roads improve.

6.2 How to catalyze markets for local development?

Given the advantages marketplaces provide their surrounding economies with, how can policymakers catalyze markets and the linkages they create for local development? One obvious policy tool to create such linkages are improved road connections. Empirical research on the topic has frequently found, however, that instead of catalyzing local structural transformation, roads foster the concentration of industrial activity in existing centers and a specialization in agriculture in rural areas (Michaels et al., 2012; Faber, 2014; Baum-Snow et al., 2020; Asher et al., 2020). These findings are directly in line with predictions from simple spatial models, where lower transport costs work in favor of increased concentration and spatial specialization.

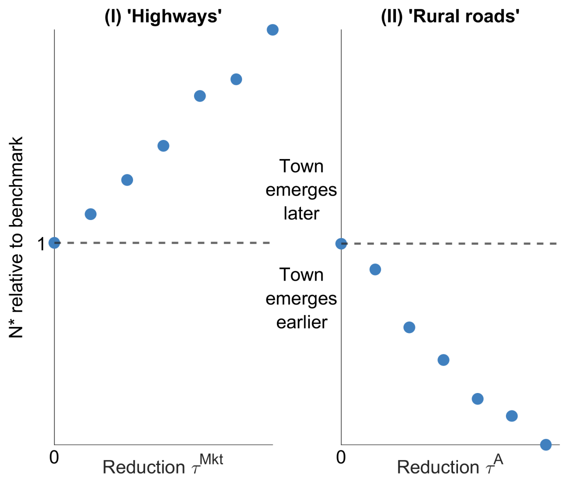
In the context of marketplaces, a policymaker may consider two types of roads. On the one hand, she may build 'highways' to improve markets' access to central cities. On the other hand, she may improve 'rural roads' to ease access of farmers to marketplaces. Abstracting from their construction costs, both policies would increase welfare, since transport becomes cheaper. Beyond transport costs, the model architecture allows me to examine the effects of these policies towards the emergence of rural towns. This exercise is illustrated in Figure 14 where I compare the critical population size ('demand') at which a market develops into a town. The figure shows that while better access to the central city delays town emergence as is standard in trade models, better access from rural areas to markets accelerates town emergence. This heterogeneity is due to highways exposing firms wanting to operate at marketplaces to higher import competition, while rural roads broaden the customer base they can access at marketplaces.

Figure 13: Optimal market locations relative to central city with varying transport costs



Simulation results for the economy-wide equilibrium real wage for an economy with one marketplace located at a given share of the distance between the central city and the cultivation frontier. The lighter color indicates higher transport costs. Dots indicate the market location giving the highest real wage given transport costs.

Figure 14: Town emergence at marketplaces with connections to central city (I) or hinterland (II)



Simulation results for critical population size N^* at which firm potential as in Figure 8(b) reaches unity for non-tradable sector. Panel I varies the effective market distance from the central city which imported and exported goods have to be transported over. Panel II varies the cost of transport τ^A between the marketplace and its hinterland.

The insights from the previous modelling exercise can also be applied to examine further changes in production locations once a town has established itself. While Section 5 showed that marketplaces without production are local minima for the potential production of tradable goods due to their exposure to import competition, the workforce employed in a nascent non-tradable sector provides an additional pool of potential customers. Hence, in contrast to standard macroeconomic theories of development – where services grow on the back of manufacturing –, local economies in an integrated system with larger cities may instead grow on the back of services.

As Section 5.2 showed, growth in the volume traded at one market may drive concentration of activity there at the cost of surrounding markets. Town emergence and its associated cheaper local production works in the same direction. While beyond the scope of the current modelling setup, nascent towns would further be supported by concentration of trading there and, once large enough for economies of scale to have developed, also become competitive with central city products.

7 Discussion & conclusion

This paper presents new evidence on the way rural marketplaces shape local development and proposes a spatial model including marketplaces that explains the empirical findings and provides a sandbox for policy experiments.

Marketplaces are a way to realize economies of scale even in agricultural economies which in many low-income countries appear to be characterized by low and stagnant productivity. The empirical patterns suggest that some marketplaces have contributed to small-scale urbanization and economic diversification of their surroundings: marketplaces appear as catalysts for the local emergence of a market economy with market-oriented production. It appears reasonable to think that the importance of marketplaces is especially high for a given place at times where the economy is otherwise not diversified yet, but markets – in an abstract sense – exist for both locally produced and imported goods. As local economies develop, more formal forms of trade may take over and the importance of marketplaces shrinks.

The paper also showed that the fortunes of individual marketplaces are linked to their neighbors' and depend on the available surrounding infrastructure. Policymakers may thus wish to take into account existing marketplaces and other transport infrastructure when designing rural transport and trade policies.

Finally, it is worth highlighting that both historical topographical maps and modern satellite imagery contain a wealth of detail that development and spatial economists have only begun to tap. These data sources can shed light on important past and ongoing transformational processes in contexts where data is otherwise scarce.

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A Figures

Figure A.1: Study area with main cities and roads

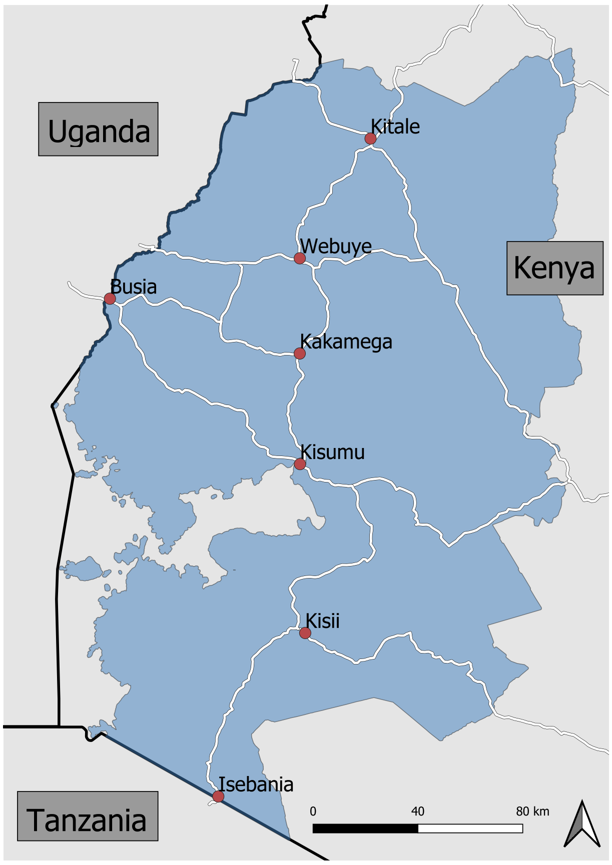
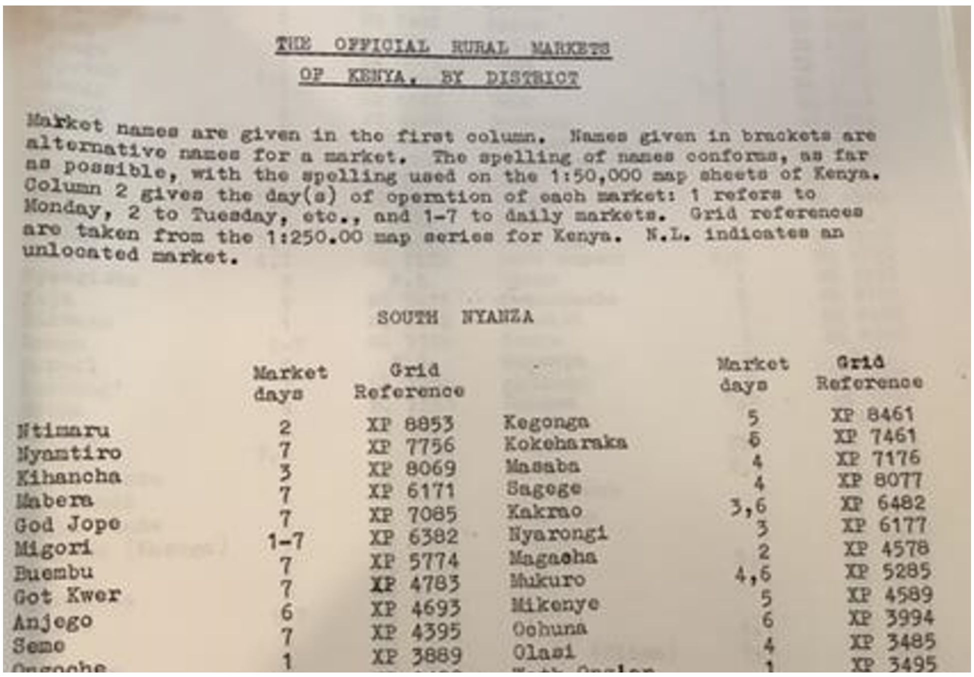


Figure A.2: Example of a market list as published in Wood (1973b)



THE OFFICIAL RURAL MARKETS
OF KENYA, BY DISTRICT

Market names are given in the first column. Names given in brackets are alternative names for a market. The spelling of names conforms, as far as possible, with the spelling used on the 1:50,000 map sheets of Kenya. Column 2 gives the day(s) of operation of each market: 1 refers to Monday, 2 to Tuesday, etc., and 1-7 to daily markets. Grid references are taken from the 1:250.00 map series for Kenya. N.L. indicates an unlocated market.

SOUTH NYANZA

	Market days	Grid Reference		Market days	Grid Reference
Ntimaru	2	XP 8853	Kegonga	5	XP 8461
Nyamtiro	7	XP 7756	Kokeharaka	6	XP 7461
Kihancha	3	XP 8069	Masaba	4	XP 7176
Mabera	7	XP 6171	Sagege	4	XP 8077
God Jope	7	XP 7085	Kakrao	3,6	XP 6482
Migori	1-7	XP 6382	Nyarongi	3	XP 6177
Buembu	7	XP 5774	Magaoha	2	XP 4578
Got Kwer	7	XP 4783	Mukuro	4,6	XP 5285
Anjego	6	XP 4693	Mikenye	5	XP 4589
Seme	7	XP 4395	Oohuna	6	XP 3994
[illegible]	1	XP 3889	Olasi	4	XP 3485
		[illegible]	[illegible]	1	XP 3495

Figure A.3: Map of markets in validation dataset

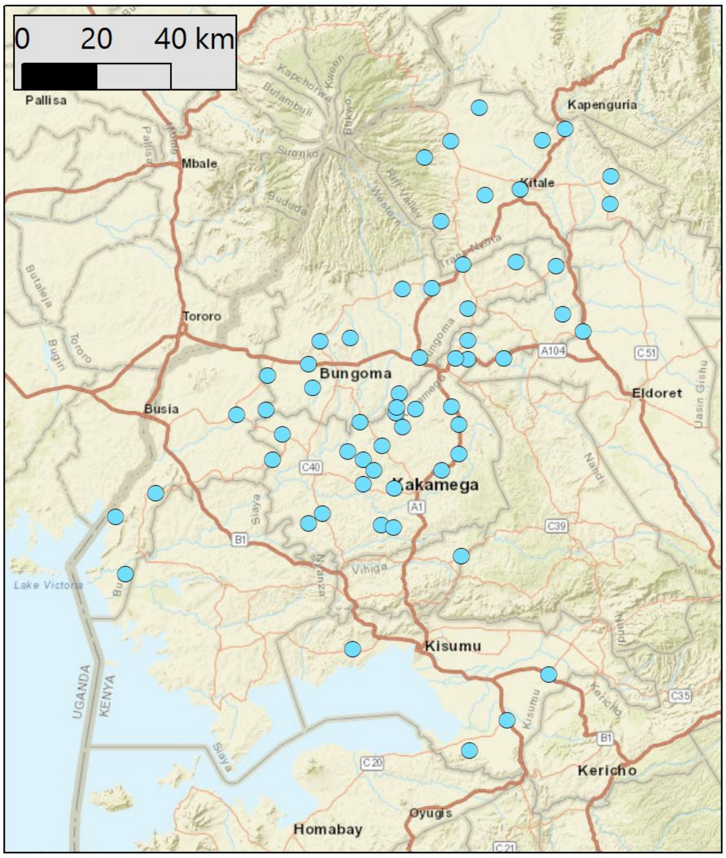


Figure A.4: Summary of calibration and validation exercise for market mapping

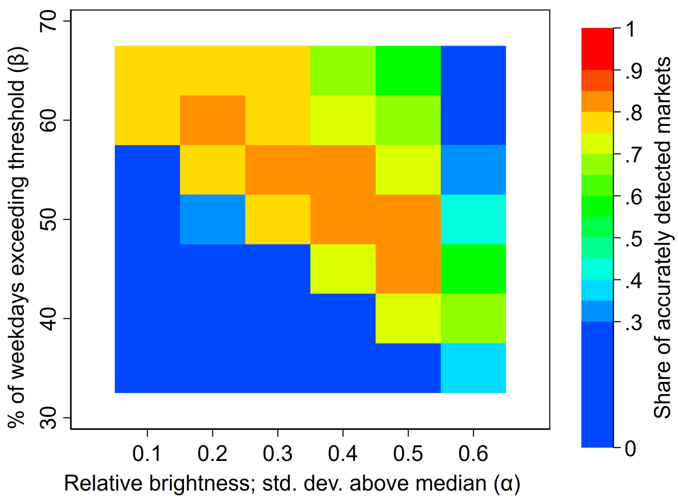


Figure A.5: Towns and cities mentioned in census, by market existence

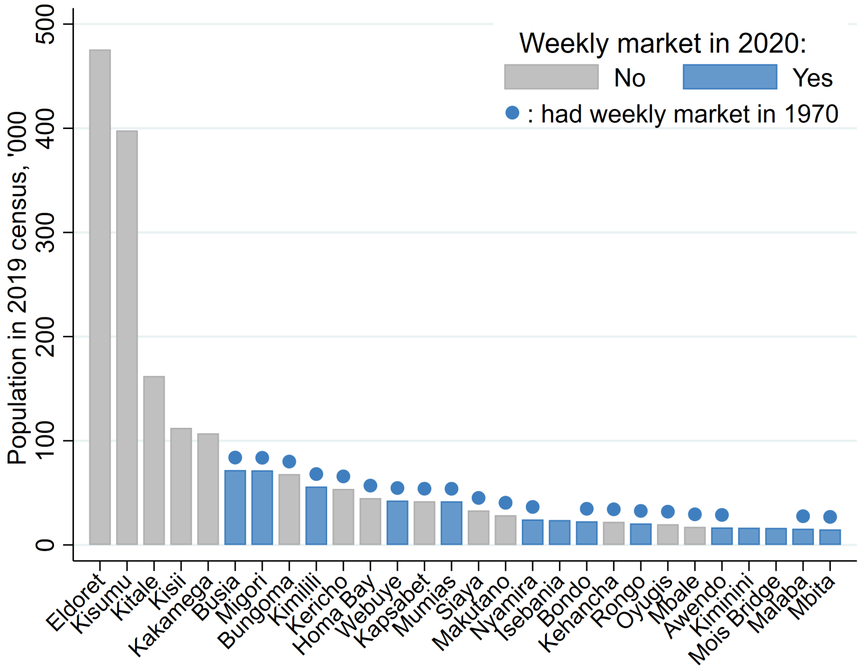


Figure A.6: Remotely-sensed market activity in Kenya, 2017-2022

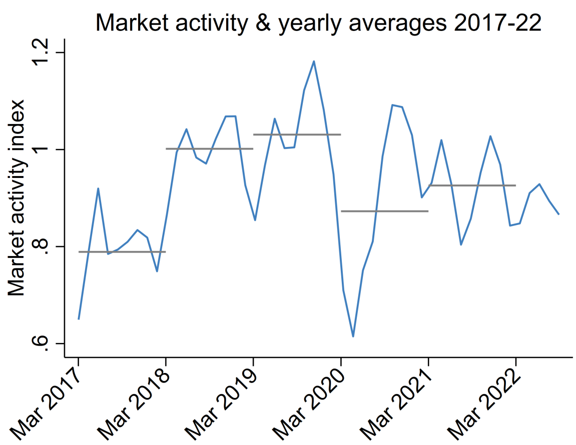
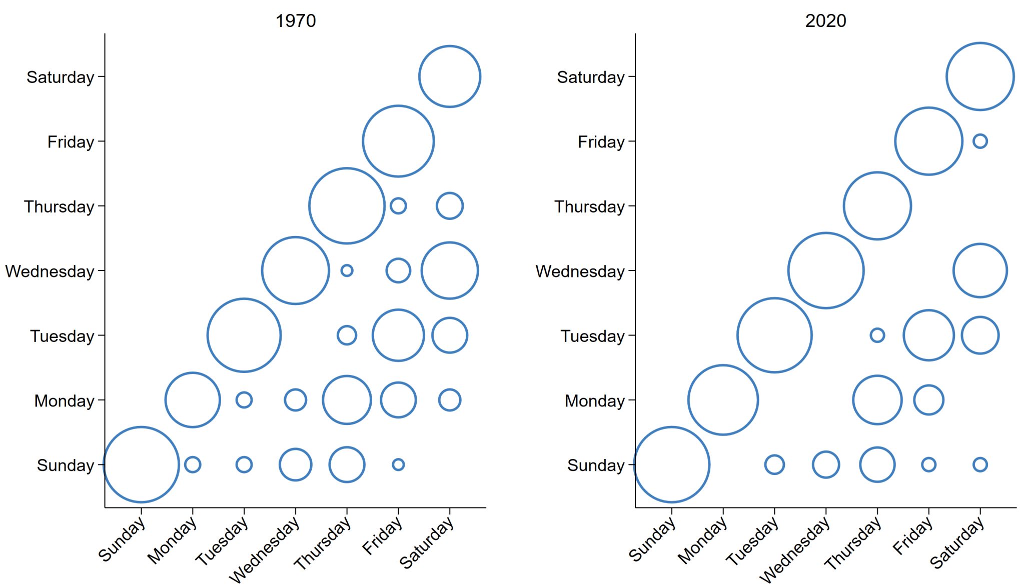


Figure A.7: Market days and their combinations in historical and contemporary market maps



B Description of house extraction from historical maps

I accessed digital copies of the maps of the Department of Overseas Surveys covering Kenya around 1970 via the National Library of Scotland (see Figure B.1 for an example). I then contracted a provider to create georeferenced versions. Consequently, I performed a sequence of processing steps to extract the black outlines of buildings.

Since the maps come from different editions and their scan quality varies, I first align colors between the maps by subtracting from each map the average color of the map collar. I then apply an unsupervised clustering mechanism to create up to 100 pixel clusters based on their color. This procedure does well at identifying colored areas such as forests and wetlands (shades of green), lakes and rivers (shades of blue) or roads and boundaries. I assign colors to categories by manually identifying a set of example patches for each category in the map and finding the cluster that most frequently overlaps with each category.

Patches indicating these categories may contain different dark symbols indicating e.g. types of vegetation or marking borders. Since these symbols share the color with buildings, I exclude them based on them being surrounded by other colors. I never observe cases where buildings are drawn within forests or wetlands which this procedure would also exclude.

I then all extract all remaining pixels that are darker than a specified threshold and identify all connected components within these images. This data contains both buildings as well as other dark features such as letters, grid lines or trails. I distinguish between the dots indicating towns and the other features by imposing threshold values on the ratio between circumference and the bounding box of the shape (less than 1.3 to exclude round shapes), as well as size (between $100m^2$ and $2500m^2$ to exclude noise from wrongly-classified small pixels as well as large structures such as letters). I visually assess the accuracy of the extraction procedure. Future improvements will include the creation of dedicated training data including both buildings and other black features to set threshold values maximizing accuracy.

Figure B.1: Example of a topographical map, including map collar

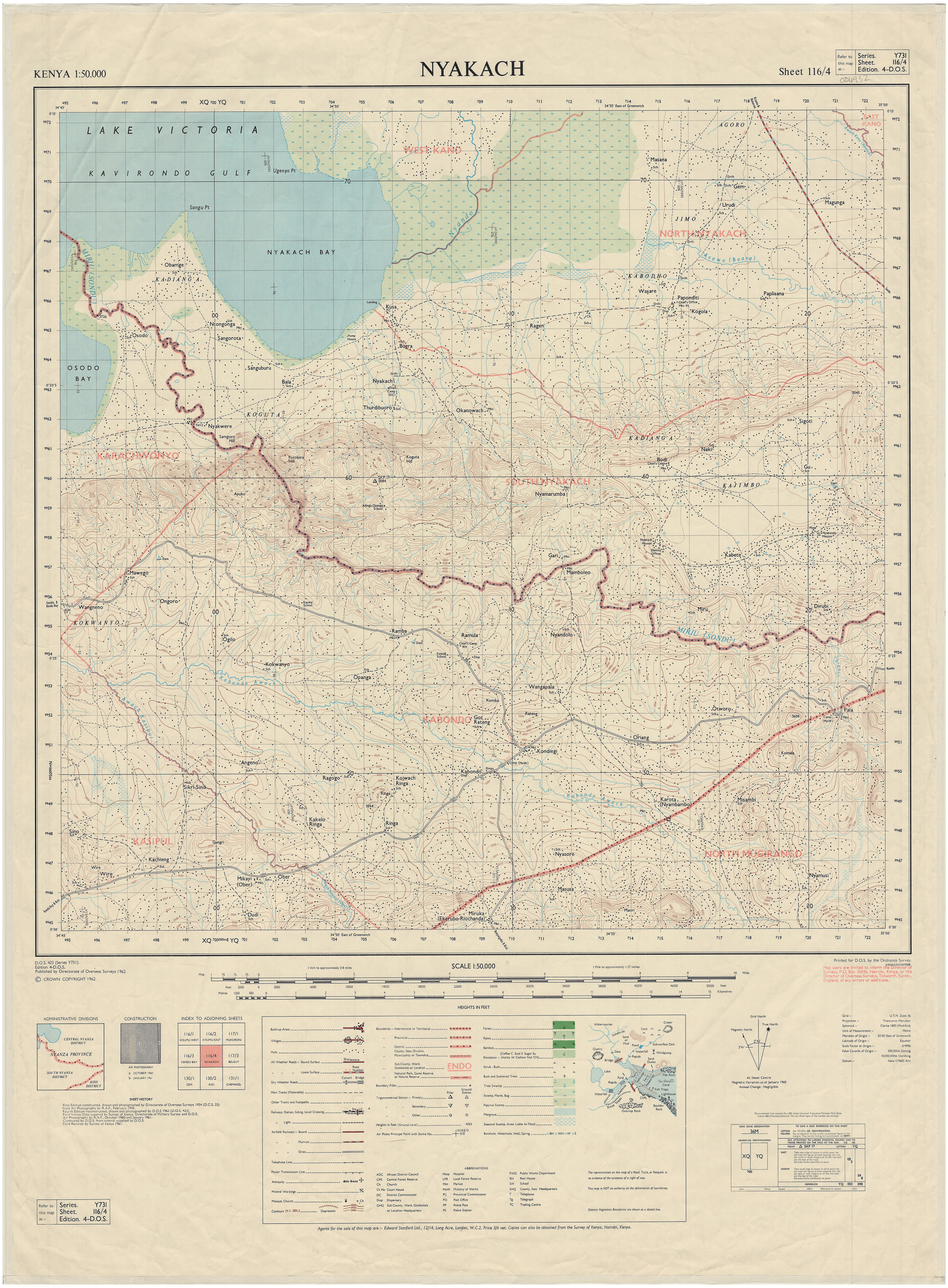
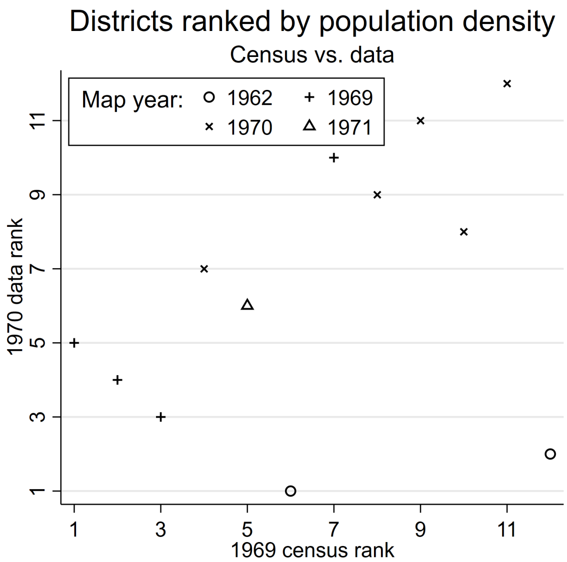


Figure B.2: Rank correlation between historical population measure and 1969 census



C Model derivation

Derivation of the tradable goods' price index Consumers at r maximize utility according to (1) given prices and their income subject to the budget constraint

$$p^A(r)A + \int_0^{n^M} p^M(i,r)\,m(i,r)\,di + \int_0^{n^S} p^S(i,r)\,s(i,r)\,di = Y(r)$$

To solve this, each tradable variety's quantity $m(i)$ has to be chosen such that it minimizes the cost of attaining M (The problem is analogous for the non-tradable composite S.

$$min \int_0^{n^M} p^M(i,r)\,m(i,r)\,di \text{ s.t. } \left[\int_0^{n^M} m(i,r)^{\rho^M}\,di\right]^{\frac{1}{\rho^M}} = M(r)$$

From the first-order conditions, we have that marginal rates of substitution between varieties equal their price ratio

$$\frac{m(i,r)^{\rho^M-1}}{m(j,r)^{\rho^M-1}} = \frac{p^M(i,r)}{p^M(j,r)} \Rightarrow m(i,r) = m(j,r)\left(\frac{p^M(j,r)}{p^M(i,r)}\right)^{\frac{1}{1-\rho^M}}$$

Substituting this back into the budget constraint gives the compensated demand function for the j^{th} variety of the tradable good.

$$m(j,r) = \frac{p^M(j,r)^{\frac{1}{\rho^M-1}}}{\left[\int_0^{n^M} p^M(i,r)^{\frac{\rho^M}{\rho^M-1}}\,di\right]} M(r)$$

The minimal cost of attaining $M(r)$ given expenditure for each variety $p^M(j,r)\,m(j,r)$ is

$$\int_0^{n^M} p^M(j,r)\,m(j,r)\,dj = \left[\int_0^{n^M} p^M(i,r)^{\frac{\rho^M}{\rho^M-1}}\,di\right]^{\frac{\rho^M-1}{\rho^M}} M(r)$$

The term multiplying M is naturally interpreted as a price index, multiplying total consumed quantity to get total expenditure. It measures the minimum cost of attaining a unit of the variety composite M at location r and is defined as

$$G^M(r) = \left[\int_0^{n^M} p^M(i,r)^{\frac{\rho^M}{\rho^M-1}}\,di\right]^{\frac{\rho^M-1}{\rho^M}} = \left[\int_0^{n^M} p^M(i,r)^{1-\sigma^M}\,di\right]^{\frac{1}{1-\sigma^M}}$$

Supply I can now rewrite the demand for a given variety $m(j,r)$ (and analogously for a given variety $s(j,r)$ as

$$\begin{aligned} m(j,r) &= \left(\tfrac{p^M(j,r)}{G^M(r)}\right)^{-\sigma^M} M(r) \\ s(j,r) &= \left(\tfrac{p^S(j,r)}{G^S(r)}\right)^{-\sigma^S} S(r) \end{aligned}$$

and use this to solve the original utility maximization problem for an agent at location r:

$$U(r) = A^{\mu^A} \left(M(r)\right)^{\mu^M} \left(S(r)\right)^{\mu^S} \text{ s.t. } G^M(r)\,M(r) + G^S(r)\,S(r) + p^A(r)\,A = Y(r)$$

The solution says that each good's expenditure share is equal to its utility weight.

$$\begin{aligned} m(j,r) &= \mu^M Y(r)\, \tfrac{p^M(j,r)^{-\sigma^M}}{G^M(r)^{-(\sigma^M-1)}} \text{ for } j \in \left[0, n^M\right] &\Rightarrow\quad M(r) &= \mu^M \tfrac{Y(r)}{G^M(r)} \\ s(j,r) &= \mu^S Y(r)\, \tfrac{p^S(j,r)^{-\sigma^S}}{G^S(r)^{-(\sigma^S-1)}} \text{ for } j \in \left[0, n^S\right] &\Rightarrow\quad S(r) &= \mu^S \tfrac{Y(r)}{G^S(r)} \\ & & A(r) &= \mu^A \tfrac{Y(r)}{p^A(r)} \end{aligned}$$

It then follows from the specification of the transport costs in Section 5 that demand in location r for a product produced in w is

$$\begin{aligned} m(j,r) &= \mu^M Y(r)\, \tfrac{p^M(j,r)^{-\sigma^M}}{G^M(r)^{-(\sigma^M-1)}} &= \mu^M Y(r)\, \tfrac{\left(p^M(j,w) T^M_{w,r}\right)^{-\sigma^M}}{G^M(r)^{-(\sigma^M-1)}} \\ s(j,r) &= \mu^S Y(r)\, \tfrac{p^S(j,r)^{-\sigma^S}}{G^S(r)^{-(\sigma^S-1)}} &= \mu^S Y(r)\, \tfrac{\left(p^S(j,w) T^S_{w,r}\right)^{-\sigma^S}}{G^S(r)^{-(\sigma^S-1)}} \end{aligned}$$

To supply this level of consumption to r, $T^{M,S}_{w,r}$ times this amount has to be shipped (due to iceberg losses along the route). The total sales for a variety produced in w thus are given by

$$\begin{aligned} q^M_w(j) &= \mu^M \int_{-f}^{f} T^M_{w,r} Y(r)\, \tfrac{\left(p^M(j,w) T^M_{w,r}\right)^{-\sigma^M}}{G^M(r)^{-(\sigma^M-1)}} dr &= \mu^M p^M(j,w)^{-\sigma^M} \int_{-f}^{f} Y(r)\, \tfrac{\left(T^M_{w,r}\right)^{1-\sigma^M}}{G^M(r)^{-(\sigma^M-1)}} dr \\ q^S_w(j) &= \mu^S \int_{-f}^{f} T^S_{w,r} Y(r)\, \tfrac{\left(p^S(j,w) T^S_{w,r}\right)^{-\sigma^S}}{G^S(r)^{-(\sigma^S-1)}} dr &= \mu^S p^S(j,w)^{-\sigma^S} \int_{-f}^{f} Y(r)\, \tfrac{\left(T^S_{w,r}\right)^{1-\sigma^S}}{G^S(r)^{-(\sigma^S-1)}} dr \end{aligned} \tag{3}$$

Production in the non-agricultural sectors only requires labor, but involves a fixed input F and a marginal input requirement c (both assumed to be constant across sectors, so that the labor required to produce $q^{M,S}$units is $l^{M,S} = F + c \times q^{M,S}$. Since consumers value variety and production exhibits increasing returns to scale, a new firm will never specialize in a variety that is already produced by an existing firm. Therefore, each variety is only produced in one location by one firm. I can thus infer the behavior of any firm from a representative firm producing any variety.

The profit of a firm producing a specific variety of the tradable good at location r is (analogous for production of the non-tradable good)

$$\pi^M_r = p^M_r q^M_r - w^M_r \left(F + c \times q^M_r\right)$$

where p^M_r is the price at the factory gate and w^M_r is a – for now – exogenously given wage rate common among manufacturing workers at location r. Firms compete in prices taking the overall price index as given. With the condition on total quantities produced (3), profit-maximizing prices at r are given by

$$p^M_r \left(1 - \frac{1}{\sigma^h}\right) = c \times w^M_r \tag{4}$$

With free entry and exit, profits must be zero and hence the equilibrium output and labor input of active firms are given by

$$q^{*} \equiv \frac{F\left(\sigma^{M}-1\right)}{c} \; ; \; l^{*}=F\sigma^{M}$$

Derivation of the wage equation What then pins down the wage that firms can pay at a given location and still break even? Turning around (3) and combining with (4) gives

$$w_{r}^{M}=\left(\frac{\sigma^{M}-1}{\sigma^{M} c}\right)\left(\frac{\mu^{M}}{q^{*}} \int_{-f}^{f} Y(s) \frac{\left(T_{r,s}^{M}\right)^{1-\sigma^{M}}}{G^{M}(s)^{-\left(\sigma^{m}-1\right)}}\right)^{\frac{1}{\sigma^{M}}}$$

The wage a firm can offer workers and still break even is thus higher if access to target markets is relatively cheap (low $T_{r,s}^{M}$) and if incomes in those markets are high (high $Y(s)$). Since active firms make zero profit, this equation gives the wage that any active firm pays. It is analogous to the wage equations in Section 5

With some normalizations choosing units $\left(c=\frac{\sigma^{M}-1}{\sigma^{M}} \; ; \; F=\frac{\mu^{M}}{\sigma^{M}}\right)$, we can write the price index more compactly (analogously for the non-tradable good)

$$G^{M}(r)=\left[\frac{1}{\mu^{M}} \sum_{k} L_{k}^{M}\left(w_{k}^{M} T_{kr}^{M}\right)^{1-\sigma^{M}}\right]^{\frac{1}{1-\sigma^{M}}}$$

where $k=1,...,K$ is the set of locations where manufactures are produced with K=1 initially. This also gives the real incomes from agriculture in any location and the real income from manufacturing if production in a given location was profitable.

$$\omega^{A}(r)=\frac{p^{A}(r)}{p^{A}(r)^{\mu^{A}} G^{M}(r)^{\mu^{M}} G^{S}(r)^{\mu^{S}}} \text{ and } \omega^{M}(r)=\frac{w^{M}(r)}{p^{A}(r)^{\mu^{A}} G^{M}(r)^{\mu^{M}} G^{S}(r)^{\mu^{S}}}$$

Table C.1: Parameter values underlying benchmark calibration

Group	Description	Parameter	Benchmark value
Technology	Transport cost agriculture	τ^{A}	0.9
	manufactures	τ^{M}	0.9
	Minimum transport cost	τ^{min}	0.3
	Minimum market size	γ	0.005
	Agricultural productivity	c^{A}	0.5
Preferences	Utility weight of food	μ^{A}	.5
	manufactures	μ^{M}	.25
	Substitution elasticity betw. varieties: manufactures	σ^{M}	10
	services	σ^{S}	20
Other	Population	N	1

The table lists the parameter values underlying the model's benchmark calibration in Figure 8. I inherit their orders of magnitude from Fujita et al. (2001) and choose their exact values for illustrative purposes.