Random river:
Trade and rent extraction in imperial China

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Abstract

This paper exploits changes in the course of the Yellow River in China to isolate exogenous variation in the natural distribution of economic centers across space and over 2,000 years. Using original data on population and taxation from dynastic histories and local gazetteers, I assess the effect of market access on population density and resource extraction. I find that the changes in connectedness have two opposite effects. First, they induce a very large increase in the level and concentration of economic activity in the short run. Second, they trigger a large increase in taxation per capita and an elite flight, which reverse the concentration effect in the longer run.

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1 Introduction

As the economy grows, economic activity becomes increasingly concentrated in few cities. This process can be thought of as a consequence of economies of scale and agglomeration economies, and thus as conducive to economic development (Kim, 1995; Henderson et al., 2001). However, our understanding of agglomeration economies may be limited by the literature's focus on short-term economic effects, keeping political structures constant. This paper uses data covering 2,000 years to study the very long run, as political structures react.

In this paper, I investigate whether the spatial concentration of wealth allows the government to extract resources more efficiently, and the effect of higher tax rates on economic activity and its geographic concentration in the long run. If extracted resources primarily benefit other places or are not invested productively, the local economy suffers a negative externality that may limit the gains from agglomeration. Answering this research question poses two main challenges: we need exogenous variation in the spatial concentration of wealth, and we need data on the spatial distribution of economic activity and extracted resources.

I exploit major changes in geography to isolate exogenous variation in the natural distribution of economic centers across space. I use changes in the course of the Yellow River between 305 B.C.E. and today that constitute large, durable shocks to transportation costs and thus alter the spatial distribution of economic activity. Over this period, the Yellow River shifted its mouth by a maximum of 900 km—see Figure 1. This phenomenon may have both direct—on places that lost or gained access to the Yellow River—and indirect effects—through connections between river basins. The changes in the course of the Yellow River generate exogenous variation in trade costs and in connectedness, which I use to study the causal effect of market access on economic concentration and resource extraction.

I find evidence of two opposite effects of market access on economic activity and its spatial concentration over time. First, over the shorter run I find evidence of the expected positive relationship: improved market access generates large increases in both the level and concentration of economic activity. Second, the spatial concentration of wealth is associated with an increase in the rate of taxation and a decline in the share of elites in total population that announce a reversal of fortune. In the longer run, I indeed show that increases in market access *reduce* economic activity, while its effects on tax rates and the share of elites partially dissipate. This long-run reversal suggests a negative effect of market access due to resource extraction. I confirm this interpretation using data on innovation and on social unrest, and explore heterogeneous effects due to distance to imperial and provincial capitals, which I hypothesize to be inversely related to observability of economic transactions, and thus with taxation capability.

To best exploit 2,000 years of changes in trade routes, I collect original data on population and taxation, and nest these data at the level of prefectures as of 2000.[1] These data are extracted from historical sources—dynastic histories, geographic treatises, and local gazetteers—covering 2,000 years, which allows me to follow the evolution of economic activity and its concentration over the long run. They contain detailed information on taxation to the central government, which provides a rare picture of extracted resources across space and over a long time period.[2] To identify mechanisms and confirm my interpretation of the main variables of interest, I complement the population and taxation data with four additional datasets: (i) I leverage historical data on the urbanization rate to better characterize spatial concentration of economic activity. (ii) I use social unrest data to confirm that rents are increasingly contested over time in places that enjoy better market access. (iii) I use the geolocated birthplaces of imperial examination graduates to capture the elites' location decision. The resulting measure of elite share can be interpreted as a proxy for human capital and potential for innovation. (iv) I confirm this interpretation using data on inventions and their locations within China, as well as information on other types of innovation (commercial, literary, artistic, etc.) from dynastic histories. The output is a unique panel on economic concentration, taxation, and a range of economic and non-economic outcomes.

This paper makes several contributions to the literature. The main contribution of this paper is to document cyclical patterns in the distribution of spatial activity through the long-run adjustment of rent extraction by political elites. This is made possible by exogenous shocks and long-run data.

I put forward and test the hypothesis that economic concentration facilitates taxation, and show that the increase in taxation is associated with economic decline and lower innovation in the long run. The paper thus contributes to a large literature—within and outside of economics—on rent-seeking (North and Weingast, 1989; Bernhardt, 1992; De Long and Shleifer, 1993; Murphy et al., 1993; Behrens and Pholo Bala, 2013). Because of its focus on imperial China and rent extraction,

[1] Prefectures are today the third level of administration, below provinces and the central government. I recast all data to consistent units, using the map of prefectures in 2000. There were 348 prefectures in 2000. The procedure followed to combine data corresponding to different administrative divisions is described in detail in Appendix B.1.

[2] The taxation data additionally offer information on production and structural transformation, as for most of the period taxes were collected in kind.

which has been proposed as an explanation by historians, this paper relates to the debate on the causes of the Great Divergence (Elvin, 1972, 1973; Pomeranz, 2000; Acemoglu et al., 2002; Galor and Mountford, 2006; Brandt et al., 2014) and the related issue of the prevalence of "parasite cities" in China relative to Europe (Weber, 1921; Needham, 1969; Bairoch, 1988). The paper shows indeed that the effect of improved market access on rent extraction is larger where administrative capacity is higher, which suggests that the general mechanism may have been particularly important in China, with its long-lasting and stable administrative system. The closest paper to this one in this respect is Bai and Jia (2019), who show the positive but non-persistent effect of provincial capitals in imperial China. By studying the role of taxation, especially through human capital, this paper further relates to recent contributions on the effect of taxation on mobility and innovation (Kleven et al., 2014; Akcigit et al., 2016; Moretti and Wilson, 2017).

A second contribution of the paper is the use of exogenous variation in the natural distribution of economic centers. A large literature documents the role of geographic fundamentals in explaining the persistence of the spatial distribution of economic activity in the long run (e.g., Bleakley and Lin, 2012; Barjamovic et al., 2019) and in shaping institutions (Acemoglu et al., 2001; Alesina et al., 2013), in particular—and most relevant to this study—through state formation (Mayshar et al., 2020). This literature relies on cross-sectional differences in geography. One issue with this approach is that such differences may affect outcomes through other channels (other geographical features, amenities, culture, etc.). In order to study the effect of the spatial concentration of wealth on rent extraction, we need variation in this concentration that (i) affects existing economic activity, (ii) has sufficiently large effects to bring about a change in the spatial equilibrium, and (iii) is orthogonal to human activity. In other words, the ideal experiment would resemble *changes in geography*. My paper approaches this ideal experiment by isolating exogenous shocks to trade costs. Through its use of time-varying shocks over two millennia, this paper is thus closer to Bai and Kung (2011) than to papers using cross-sectional instruments. Contrary to the droughts and floods that Bai and Kung (2011) exploit for identification, changes in the course of the Yellow River were however likely to be interpreted by economic agents at the time as long-term rather than short-term shocks.

A third contribution of the paper comes from its broad time coverage. This allows me to bring empirical insights to two different strands of literature—the trade literature on the impact of market access on economic activity (Hanson, 2005; Redding and Venables, 2004; Redding and Sturm, 2007; Redding, 2010; Head and Mayer, 2011; Shiue, 2002) in the long run (Fogel, 1964; Banerjee et al., 2012; Donaldson and Hornbeck, 2016; Donaldson, 2018; Barjamovic et al., 2019), and the literature on the long-run effects of an initial economic head start (Chinitz, 1961; Falck et al., 2013; Glaeser et al., 2015; Franck and Galor, 2017; Heblich et al., 2019). Additionally, the information on production available from taxation data means that this paper relates to contributions on specialization and co-agglomeration (Glaeser et al., 1992; Kim, 1995; Duranton and Puga, 2001; Faggio et al., 2017).

The remainder of this paper is organized as follows. Section 2 provides some background information on the Yellow River. Section 3 presents the data and construction of the market access measures. Section 3.3 explains the empirical strategy. Section 4 describes the results. Section 5 concludes.

2 The random river

The identification strategy in this paper relies on changes in the course of the Yellow River. The Yellow River has followed a variety of different routes in history, as shown in Figure 1. This section (i) briefly explain the root of this phenomenon, (ii) describe the magnitude of the changes, and (iii) discuss its predictability.

2.1 Cause of the changing course

The root cause of changes in the course of the Yellow River is the uniquely high sediment load of its water in its lower basin and the fineness of the sediment particles, which makes changes extremely difficult to predict. As it flows across the Loess plateau, the Yellow River accumulates the sediments that give it its distinctive color. This phenomenon makes it the "most hyperconcentrated sediment-laden river in the world" (Kong et al., 2017): its sediment concentration is approximately 14 times the concentration in the Mississippi and 48 times that of the Yangzi River (Lu et al., 2011; Xu et al., 2019). Huge amounts of sediments are carried by the high volume of water and can swiftly form low, invisible sand shoals, much below the opaque surface, that can suddenly raise the bottom of the river and force it out of its bed.

2.2 Unpredictable courses

Both the timing and route of the course changes are difficult to model and predict. In imperial times, the lack of a clear understanding of the dynamics of the Yellow River led to heated policy debates, for instance between Li Chui and Ding Wei at the Song court (Lamouroux, 1998), and in the Republican era the government commissioned a Sino-German team of scientists to investigate the process, which led to the construction of a large outdoor model of the Yellow River in Obernach, Bavaria (Pietz, 2015). Even today, an active literature studies the Yellow River. Until recently, models could not explain how the Yellow River carries so much sediment over such distances. According to Ma et al. (2017), previous models are inadequate because they assume that the sediments coalesce into dense clusters of tall dunes that slow down the river. Ma et al. (2017) show instead that the fine sediment particles form low, dispersed dunes that preserve the energy of the flow and allows the river to move more sediment.

Anecdotal evidence illustrates the unpredictability of the changes in the course of the Yellow River. Chen et al. (2012) put forward a quote from the Ming-dynasty hydraulic engineer Wan Gong ("Floods are rapid and large. Flood stage fluctuates unpredictably.") to show that the runoff of the lower river was highly variable and known to be unpredictable. In the *Veritable Records of the Ming Dynasty*, a record illustrates that sudden course shifts would take even river traders by surprise: "The water level of the Yellow River at Shangqiu County rose and the water broke through the levee at the village of Xiajiakou. The whole flow was diverted southward. The trunk channel changed into a flat sandy land, and merchant boats were stuck in the sands."[3]

Because of its economic and cultural significance (water management is a major imperial prerogative in China), central and local governments tried to control the Yellow River. This took mostly the form of levee construction, maintenance, and repair, and the construction and regular consolidation of banks.[4] The effect of such actions was mixed, as repairing banks prevents the channel from scouring naturally, increasing the likelihood of breaches and therefore the need for repairs (Chen et al., 2012). Importantly, once a levee is breached, the new course of the river is extremely difficult to predict.

Finally, some course shifts were man-made—in 1128 and 1938. Both artificial course shifts served a military purpose: they aimed at stopping the advance of the enemy (the Jurchen and the Japanese, respectively) by drowning its troops. In both cases, deviating the river proved very difficult, and the new course followed by the river failed to fulfill its military purpose, as the river flowed south, while the enemy was advancing from the north. In both cases, the enemy eventually took control of the entire country. I argue that these artificial course changes do not threaten

[3]The possibility of a sudden shift inhibited water transport along the Yellow River, which was therefore more expensive than along the Yangzi (e.g., Evans, 1984). This is accounted for empirically through river-specific trade costs. Note that because large course changes are rare, the Yellow River however remained a major trade route.

[4]I digitize and geolocalize detailed historical data on the management of the Yellow River from Shen et al. (1935). These data are used to control for human intervention in robustness checks.

identification: even if the timing is not random, the course followed by the river after a man-made breach could not be predicted.[5]

2.3 Magnitude of the shocks

Because of the flat terrain of the Lower Yellow River basin and of the mountainous Shandong peninsula that stands in the middle, this feature of the Yellow River makes it one of the most fickle rivers on earth. Between 602 B.C.E. and today, the Lower Yellow River experienced several major course changes, shifting its mouth over about 900 km, from present-day Tianjin in the north to the Yangzi River delta in the south. The magnitude of the shocks and the fact that they happened in the cradle of the Chinese civilization mean that they had large effects on human activity.

Geography amplifies these shocks, as changes in the course of the Yellow River may mean that northern and southern China become connected or disconnected. A major source of variation in the magnitude of the changes is indeed whether the River flows north or south of the Shandong peninsula. The Yellow River changed its course completely to the other side of the Shandong peninsula four times in recorded history. Such changes are particularly important because most major rivers in China flow west to east, and they may link China's two longest rivers, the Yellow River and the Yangzi, as well as their large drainage basins. The course shifts may thus affect connectedness and trade costs far away from the Lower Yellow River basin.

3 Data and empirical strategy

This section describes the data sources and empirical strategy. First, I present my main data: on population and taxation. Second, I explain how I measure market access and construct an instrument based on exogenous changes in geography. Third, I finally describe my main estimation strategy.

3.1 Population and taxation data

My main outcomes of interest are population density and taxation intensity. I collect original data on population and taxation at the prefecture level from dynastic histories and geographical treatises, and geolocate them using a combination of place lists (from the CHGIS and SongGIS databases, which contain precise geocoordinates) and textual information on location from various historical sources. This yields a unique geolocalized data set spanning more than 200 prefectures and 2,000

[5] I however drop in robustness checks periods in which the course of the Yellow River resulted from a man-made breach.

years, starting with the earliest extant population census in the world in 2 C.E.[6] I now describe the data and the challenges they raise.

Description I extract population and taxation data from original sources in classical Chinese.[7] The texts usually follow a similar structure: For each province, prefectures are listed and described along different dimensions—population and taxation for each prefecture, subdivisions of each prefecture, administrative changes, customs, biographies of notable people, etc. Population is typically recorded in two ways: as the total numbers of households (*hu*) and individuals (*kou*). Some sources distinguish between "master" (*zhu*) and "guest" (*ke*) households, a distinction mostly determined by asset ownership.

Taxation is provided alongside population figures from the beginning of the 8th century. For most of Chinese imperial history, taxation was predominantly in kind. In early waves, lists of goods are available. Starting with the Northern Song dynasty (960–1127), the sources specify amounts in great detail. A wide variety of goods were involved, which allows me to create a large set of taxation variables: number of goods used for taxation, number of goods exiting or entering the list, share of manufactured goods, degree of alignment between production and comparative advantage, etc. In later periods, taxes were increasingly collected in money or in a standard metal such as silver. This allows me to study the monetization of the local economy as an additional outcome. Finally, in some years the taxation data allow me to distinguish between taxes levied in urban and rural areas. It is important to note that the data contain information on tax remittances to the *central* government. Such taxes fueled the Imperial Treasury and were typically spent on maintaining the palace, defending borders, and remunerating officials; some redistribution could take place, for instance as Treasury relief in case of famine, but they were not specifically meant to benefit the prefectures where they had been collected.

Challenges In total, I use 25 waves of population data and 13 waves of taxation data for imperial China,[8] to which I add 8 post-1911 censuses in some specifications. Over such a long period (and across such a wide territory as China's), population and taxation data may not be consistently recorded. Appendix B.2 provides details about data characteristics and harmonization, and describes the challenges that the

[6] The main analysis focuses on imperial China, which ended with the Revolution of 1911. In additional results, I expand the study of the effect of trade costs on economic activity to 2010.

[7] Sources are listed in Appendix Table B.2.

[8] Population censuses were often used to evaluate tax revenues, so the waves usually coincide. In some rare instances, population and taxation data are slightly asynchronous; I then assume that the taxation data correspond to the closest year with population figures.

population and taxation data raise. I present here the main challenges briefly.

First, the data are organized by prefectures, but prefecture boundaries change over time. I recast all the data to the level of prefectures as of 2000. Second, data for some prefectures are missing in some periods. The changes in administrative divisions and reweighting of the data subsequently needed make this issue more complicated than in most empirical settings. I develop a simple spatial interpolation methodology to deal with missing observations and assess the robustness of the results.[9] Third, population and taxation data coverage may vary according to state capacity and administration quality (Ho, 1959; Cartier and Will, 1971; Bielenstein, 1987). In some regressions, I control for the dynastic cycle, distance to the imperial capital, and distance to the border to capture the effect of state capacity on data quality.

Other data I use additional data sources to (i) establish my intepretation of the main findings, (ii) identify mechanisms, and (iii) check the robustness of the results. I summarize these sources briefly here; a detailed description is provided in Appendix B.3. (i) I leverage historical data on the urbanization rate to better characterize spatial concentration of economic activity, and I use social unrest data to confirm that higher taxation rates do not simply reflect higher productivity.[10] (ii) I use the geolocated birthplaces of the highest rank of imperial examination graduates (*jinshi*) from the China Biographical Database to capture the elites' location decisions.[11] I also digitize data on inventions from a dictionary of inventors (Li and Cha, 2002) and collect new information on other types of innovation (industrial, literary, artistic, etc.) from the dynastic histories. (iii) I digitize and geolocate detailed data on floods and river management activities from Shen et al. (1935); I use maps of administrative seats and boundaries from CHGIS and Hartwell, respectively, to define consistent prefectures over time; and I create time-varying controls by interacted with various GIS measures with time dummies to capture local dynamics that may confound the results.

3.2 Market access

To construct historical market access measures between 350 B.C.E. and the present, I need to (i) determine travel costs across all of China at different points in time

[9] This methodology is described in Appendix B.2.

[10] These data come from dynastic histories and are similar to the data used by Kung and Ma (2014).

[11] These data are widely used in the economic history literature on China (e.g. Chen et al., forthcoming).

based on historical geography, (ii) calculate minimum travel cost between any two origin/destination, and (iii) combine trade costs and population (as a proxy for economic activity) into market access measures.

Cost surface For identification, I use two measures of market access: one based on trade costs calculated *as they were*, which accounts for all rivers, roads, railroads, and canals, and the other where I isolate the exogenous component in the cost surface, keeping artificial transport infrastructure, which is likely endogenous to economic activity, fixed. More concretely, consider the transport structure at period t: I construct a measure of market access based on (i) all transportation infrastructure and all rivers but the Yellow River at period $t-1$ and (ii) the Yellow River at period t.

These two measures rely on different specifications of the cost surface.[12] In both cases, I distinguish between overland (with and without roads), sea, and inland waterway transport. Inland waterway trade costs are allowed to differ by waterway type (natural rivers vs. canals) and by river (e.g., Yellow River vs. Wei River) to reflect differences in navigability and transportation costs. Most rivers experience only minor, very local changes in their courses (e.g., due to the natural evolution of meanders, or to floods) and are considered time-invariant. Since rivers are cheap and therefore major trade routes, I further allow trade costs to differ for up- and downstream journeys. I rely on historical accounts to parameterize relative trade costs at different points in time. I normalize the cost of sea transport to 1.

To calculate the *actual* trade costs, I use all the variation in the cost surface; to construct the *exogenous* component, I isolate exogenous changes, such as shifts in the course of the Lower Yellow River, and keep man-made infrastructures—canals, roads, and later railways—constant. For the Lower Yellow River, I use Chen et al.'s (2012) maps of its historical courses since 350 B.C.E.[13] For the courses of other rivers and for transport infrastructures, I digitize maps from Tan (1989) and Cheng and Hsu (1983) based on dynastic histories and geographical treatises.

The cost surface is obtained by overlaying a 20×20-km grid on China and assigning a cost to crossing each cell, depending on the geography that characterizes that cell. I assume that a cell has a uniform trade cost determined by the lowest-cost geographical feature (land, road, railroad, river, or canal) intersecting it.

[12] Appendix B.4 presents in detail the sources that allow me to measure relative transport costs over time, the sources that I use to map river courses and transport infrastructures, and the procedure followed.

[13] Accounts of earlier courses of the Yellow River are available, but they do not allow me to date course changes with precision. I am grateful to Chen et al. (2012) for sharing their maps with me.

Finally, I use the time-varying cost surfaces to calculate trade costs as the minimum cost distances τ_{ijt} between all prefecture centroid pairs i, j at time t.[14] Figure 2 shows the resulting measures for Kaifeng, Henan Province, before and after the 1855 change in the course of the Yellow River.

Market access measures I measure the *actual* market access of prefecture i at time t as:

$$m_{it} = \sum_{j \neq i} \tau_{ijt}^{-1} N_{jt}, \tag{1}$$

where τ_{ijt} is the minimum cost distance at time t between i and j using the observed cost surface, and N_{jt} is the population of prefecture $j \neq i$ at time t.

I next construct an instrument capturing the *exogenous* component in market access, defined as:

$$z_{it} = \sum_{j \neq i} \tau_{ijt}^{*-1} N_{j0}, \tag{2}$$

where τ_{ijt}^{*} is the minimum cost distance at time t between i and j based on exogenous geographical features (i.e., time-invariant or due to changes in the course of the Yellow River) and keeping man-made infrastructures fixed at baseline. N_{j0} is the population of prefecture j at baseline.

The constructed measure z_{it} differs from the actual measure m_{it} in two respects. First, z_{it} keeps man-made changes in transportation infrastructures fixed, which implies that variation only comes from exogenous changes in the course of the Yellow River. Second, it uses population at baseline rather than at time t. This is meant to avoid the reflection bias (Manski, 1993) that might arise from regressing population on a (population-based) measure of market access.

To mitigate spatial autocorrelation issues, I further create an alternative measure identical to m_{it}, except that τ_{ijt} is replaced by the as-the-crow-flies distance. This alternative measure will enter some regressions as a control.

Figure 3 illustrates the variation in market access, conditional on the as-the-crow flies measure included in the preferred specification (see Section 3.3). Panel (a) displays the constructed measure of market access (z_{it}) in 1080 and Panel (b) in 1393. We can see that there is a large cross-sectional variation and that the southern shift of the Yellow River in 1128 led to a dramatic change in residual market access.

[14] A more detailed description of the procedure is available in Appendix B.4.

In the empirics, I average m_{it} and z_{it} over a time window s (100 years, in the baseline specification) to deal with the random timing of changes in geography and irregular intervals in the population and taxation data. More precisely, I use:

$$M_{it,t-s} \equiv \sum_{T=t-s}^{t} m_{iT}, \tag{3}$$

and similarly for $Z_{it,t-s}$.[15]

3.3 Strategy

I implement a 2SLS procedure to estimate the effect of market access on the concentration of economic activity and rent extraction. I instrument the actual market access instrumented by the constructed measure described in Section 3.

The baseline regression writes:

$$Y_{it} = \beta_0 + \beta_1 M_{it,t-s} + \mathbf{X}_{it}\beta_{\mathbf{x}} + \delta_t + \mu_i + \varepsilon_{it}, \tag{4}$$

where $M_{it,t-s}$ is instrumented by $Z_{it,t-s}$, t stands for time and i for a fixed-boundary (2000) prefecture (or an arbitrary grid cell, in alternative specifications), Y_{it} is the outcome of interest (population density, tax burden, elite share, etc.), $\mathbf{X}_{it}$ are time-varying characteristics of prefectures, i.e., the controls mentioned in Appendix B.2 and B.3, to deal with measurement and data quality issues; additional controls can be included to enhance the precision of the estimates, e.g., average cost of crossing prefecture i, sea access×year, etc. Finally, standard errors are clustered at the prefecture (2000) level.

I then introduce lags of $M_{it,t-s}$, instrumented by the corresponding lags of $Z_{it,t-s}$ in some specifications to compare shorter- and longer-run effects.

There are three main threats to the identification of Equation 4 as a causal effect of market access on Y_{it}. First, the exclusion restriction would be violated if agents anticipated river course changes or could affect the course of the Yellow River. The identifying assumption under which β_1 estimates the causal effect of market access is that changes in the constructed measure of market access, which are exclusively due to changes in the course of the Yellow River, are orthogonal to agents' location decisions and rent extraction. It is unlikely that the timing and course of the Yellow

[15] This further allows me to test the robustness of the results to (i) alternative time windows s and (ii) weighting the averages $M_{it,t-s}$ and $Z_{it,t-s}$ by the share of s corresponding to the exposure to each level of market access.

River after a change could be predicted, because the accumulation and movement of sediments at the bottom of the river is unobservable and challenging to model even for modern science. In some instances, a course change was artificially created for military purposes (in 1128 and 1938). Even if in such cases the timing was not random, the exact course the river would adopt was impossible to predict. In robustness checks, I however deal with man-made course changes by (i) excluding periods when the river course resulted from an artificial change, and (ii) considering artificial changes in market access but not the instrument—in other words, I treat artificial courses as canals. The exclusion restriction would also be violated if river management systematically targeted prefectures with a higher (economic or rent) potential. In robustness checks, I control for flood events and river conservation activities, which I geolocated.

Second, because of the nature of the research question, spatial auto-correlation is a potential issue. I control for a simple, "as-the-crow-flies" measure of market access, i.e., weighting populations by the straight line distance rather than taking the cost surface into account. This reduces spatial auto-correlation: if population is highly spatially auto-correlated, then population and market access will be naturally correlated; controlling for the as-the-crow-flies measure ensures that I only use variation from exogenous changes in geography for identification.

Third, the changes in geography brought about by shifts in the course of the Yellow River may have a variety of effects on the economy. The effect I attribute to market access may support other interpretations. (i) The Yellow River was at times utilized for military purposes, as a flood may drown enemy troops or its course act as a natural barrier. (ii) Rivers are not only used for trade; they are also used for irrigation. Other water resources are however available to peasants, as other rivers cross the North China Plain, so that irrigation did not critically rely on the Yellow River, contrary to the Nile, which constitutes Egypt's single most important water source. (iii) Losing access to the Yellow River also meant that its river bed could be cultivated, increasing agricultural output; the sediments deposited by the river during floods may also enrich the soil and alter agricultural suitability. Historical sources suggest that "the benefits from the fertility of the silt brought by floods could almost offset the losses caused by floods" (Chen et al., 2012).

4 Results [PRELIMINARY]

I first present the effects of market access on economic concentration, structural change, taxation intensity, and elite location choices in the shorter run. I next study the effects of market access in the longer run.

Shorter run I first find the—expected—result that market access leads to an increase in economic concentration, proxied by population density.

This short-run effect can be shown visually. Figure 4 shows population density by prefecture in 1102 (Panel a) and 1784 (Panel b). Several changes in the course of the Yellow River occurred between these two dates, but the most important one was the 1128 change, which led to a shift of the river from the north to the south of the Shandong Peninsula. The two maps show that population (and economic activity) concentrates along major waterways, the Yellow River and Yangzi River. They also show that concentration largely shifted from the old to the new course of the Yellow River.

More formally, I regress population density on market access $M_{it,t-s}$, instrumented by $Z_{it,t-s}$. The identification strategy relies on large, durable changes in geography. Table 1 shows the results of the first stage of the baseline 2SLS results. The dependent variable is market access, and the instrument is $Z_{it,t-s}$, which isolates exogenous changes in geography. We see that the two measures are strongly, positively associated, even controlling for the as-the-crow-flies market access measure to alleviate spatial auto-correlation.[16]

Table 2 then regresses population density (in log) on market access (standardized), with OLS—Panel (a)—and 2SLS—Panel (b). Panel (a) shows a large, positive correlation between market access and population density. In the preferred specification (controlling for the as-the-crow-flies market access, sea access interacted by year, and the average cost of crossing a grid cell, a 1-SD increase in market access corresponds to a 17% increase in population density. As shown in Panel (b), instrumenting confirms the positive relationship: a 1-SD increase in market access leads to a 28% increase in population density.

The increase in economic concentration translates into structural transformation, which I measure by the share of manufactured goods among the goods remitted as taxes to the central government. Table 3 shows the effect of market access on the share of manufactured goods. The effect is large: in Panel (b), we see that a 1-SD increase in market access doubles the share of manufactured goods. This effect is consistent with urbanization and economies of scale.

I next study taxation. An important caveat is that the measures used in this section may not only capture taxation intensity, but also economic differentiation and development (higher output per capita), as I generally do not observe output. The interpretation of taxation per capita as the tax rate will be supported by additional

[16] These preliminary results focus on the period 1080–1578, for which it is more straightforward to harmonize the taxation data. Results based on the whole period using population density as the dependent variable are displayed in Tables A1 and A2 for the first and second stages, respectively.

data available only in some periods and by data on social conflicts about taxation.

With this caveat in mind, I find that improved market access increases taxation intensity. Figure 4 shows this visually. Panel (c) maps taxes per capita in 1077 and Panel (d) in 1784.[17] Taxation intensity closely matches population concentration: taxes are higher on a per capita basis along major waterways, and the spatial distribution is dramatically affected by the change in the course of the Yellow River.

I then show this in regression format. Measuring the tax burden presents two main challenges: first, the time span covered by the taxation data and China's geographical variety mean that different taxation rules and practices underpin the data; second, as taxation was mostly in kind, I need to either find goods used for taxation that are common to a large number of prefectures and to most years or to construct aggregate measures of taxation. I adopt the latter approach, first using the number of goods remitted, which may also capture the diversification of the local economy, and second computing a monetary aggregate based on Peng's (1965) historical price indices, and normalized by total population.[18] Table 4 shows that a 1-SD increase in market access leads to a 29% increase in the number of goods remitted for taxation. Table 5 provides consistent results, showing that a 1-SD increase in market access leads to a 35% of a standard deviation increase in total taxes per capita.[19]

The sharp increase in taxation per capita may reflect a higher tax burden and rent extraction; it may however also reflect higher productivity. I provide suggestive evidence of the former by exploiting data on the birthplaces of the highest rank of imperial examination graduates (*jinshi*), which I interpret as capturing the location choices of the elite. Table 6 shows that an increase in market access leads to a sharp drop in the probability of being the birthplace of any *jinshi*.[20] If *jinshi* presence is to be interpreted as a proxy for human capital and innovation, the short-run evidence of an elite flight displayed in Table 6 announces a negative effect of market access on economic activity in the long run.

[17] Taxation data are not available in 1102. Note that I use taxes in strings of cash and in *dan* (a measure of volume) of wheat in Panels (c) and (d), respectively. Both maps show deciles of the prefecture distribution.

[18] Following the former approach, I can also provide robustness checks where I use goods remitted in a subset of prefectures$\times$years.

[19] Table A3 provides the results from the same regression, but controlling for the type of good remitted as tax (e.g., silver, wheat, silk) interacted with a year fixed effect to account for residual price differences that the aggregate measure does not capture.

[20] I show in Appendix Table A4 that using a continuous measure of elite presence, the share of *jinshi* in the total population, produces qualitatively similar results.

Longer run Table 7 studies the longer-run effect of market access on population density (column 1), total taxes per capita (column 2), and elite presence (column 3), using a one-period lag in the market access variable on the right-hand side.[21] I find that, in stark contrast to Table 2, a 1-SD decrease in past market access is associated with a 39% *decline* in population density (Panel (b), column 1). The effect on taxation intensity and on the probability of being the birthplace of any *jinshi* is not statistically significant at conventional levels, but the coefficient is—if anything—negative. These results are robust to controlling for market access in period t and thus do not reflect later fluctuations in the course of the Yellow River itself. This suggests that (i) the surge in taxation per capita observed in the short run virtually disappears, as population and economic activity shifted elsewhere, and (ii) the short-run elite flight becomes less severe in the long run.

4.1 Robustness checks

I run a wide range of robustness checks. They deal with potential concerns about (i) the exclusion restriction and (ii) data quality.

I implement seven robustness checks to establish the identifying assumption. These checks can be organized into two main categories: (a) checks of potential direct effects of course changes and (b) checks of potential human intervention in the course of the Yellow River. As far as direct effects are concerned, I first control for flood events, flood intensity and destruction, and Imperial Treasury relief interventions. Second, I exclude the whole Lower Yellow River basin to avoid any effect (e.g., disruption due to floods) of course changes on the outcomes of interest that does not go through market access. Third, I allow for a broader understanding of direct effects and control for access to negatively affected areas.

The role of human intervention is investigated through four checks. First, I control for levee maintenance and construction work, as well as for other river conservancy measures. Second, I exclude periods when the course of the Yellow River resulted from an artificial breach in its banks. Third, I keep man-made course changes but treat them as endogenous changes in the cost surface, i.e., I maintain the Yellow River on its pre-change course in the constructed market access measure. Fourth, I implement a series of placebo tests using proposed (but rejected or failed) artificial course changes.

Data quality raises several concerns. First, as put forward by Cartier and Will (1971), censuses and tax registries were carried more effectively in border prefectures; laws were also applied to the letter and corruption was less of an issue in those

[21] A one-period lag corresponds to 166 years on average.

regions. I deal with this issue by controlling for a dummy equal to 1 if a prefecture lies on the border, and 0 otherwise. Second, population and taxation data are available at irregular intervals. In robustness checks, I select periods at various, approximately equal intervals.

5 Conclusion

What is the effect of market access on economic activity in the long run? This paper attempts to provide an answer by exploiting two millennia of data from China and leveraging changes in geography for identification. It thus contributes to expanding a literature on agglomeration economies that focuses on the short run.

I first look at the effect of market access in the shorter run. As expected, I find that improved market access yields a large increase in economic activity and its spatial concentration. Using data on taxation and elites' location choices, I however show that market access also leads to a sharp increase in taxes per capita and to an elite flight.

I then explore longer-run effects of market access. In stark contrast to the short-run results, better (lagged) market access is associated with a marked *decline* in economic activity, while the tax burden and elite flight partially disappear. This suggests that rent extraction follows productivity, largely reversing the positive short-run effects of market access in the long run.

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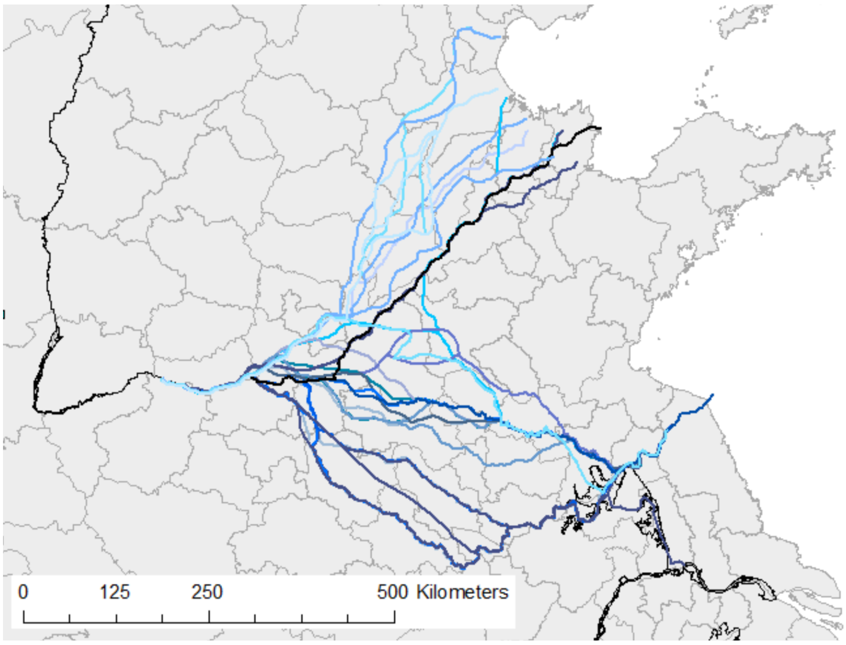
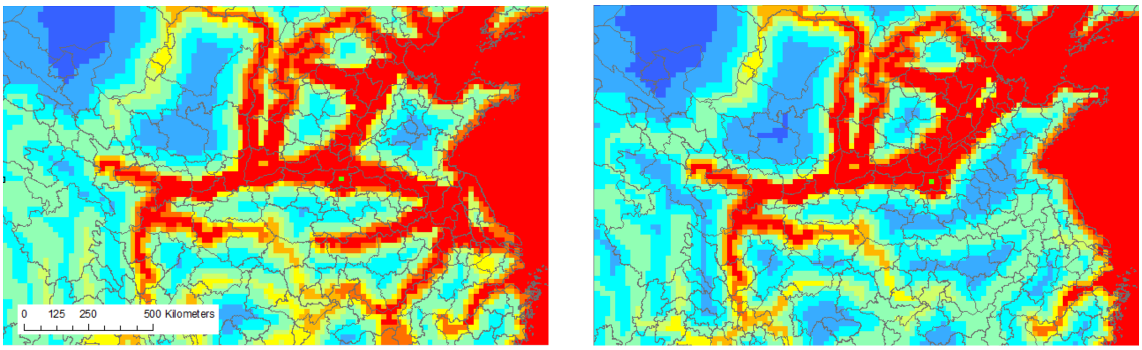
Figures and tables

Figure 1. Courses of the Yellow River since 350 B.C.E.



Notes: This map represents major changes in the course of the Yellow River between 305 B.C.E. and the present. It focuses on the North China Plain, between Tianjin and the Yangzi River delta. The black line corresponds to the current courses of the Yellow River and Yangzi River. Blue lines correspond to major past courses of the Yellow River (the lighter the color, the older the course). Grey lines materialize prefecture boundaries (as of 2000).

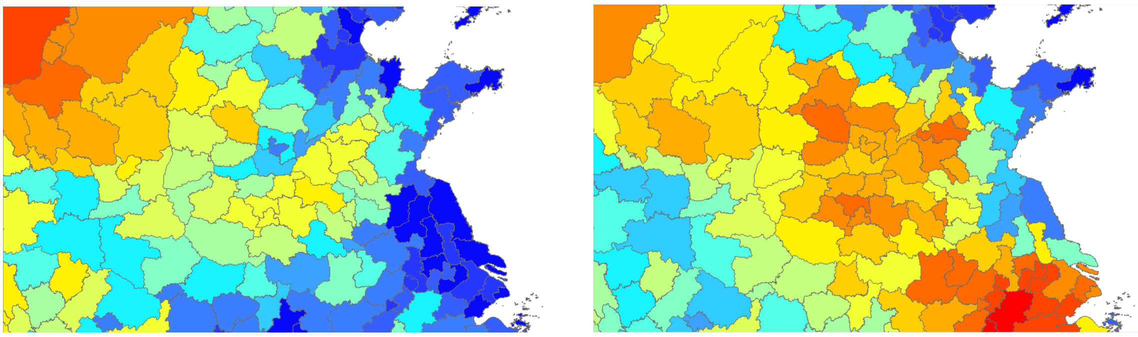
Figure 2. Least cost distances from Kaifeng, before and after the 1855 Yellow River diversion.



(a) Travel costs from Kaifeng, 1644–1855 (b) Travel costs from Kaifeng, 1855–1938

Notes: This map represents the minimum cost distances from Kaifeng (d_{ijt}), before (a) and after (b) the 1855 change in the course of the Yellow River. It focuses on the North China Plain, between Tianjin and the Yangzi River delta. The baseline scenario is used to define relative trade costs—see Section 3 for details. A darker (lighter) color indicates a lower (higher) travel cost. Grey lines materialize prefecture boundaries (as of 2000). Kaifeng is materialized by a green square.

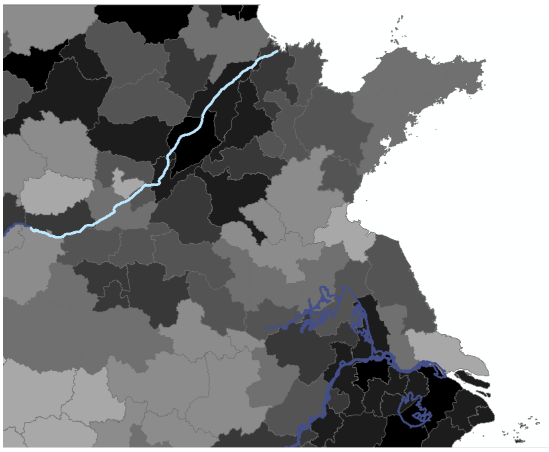
Figure 3. Variation in market access.



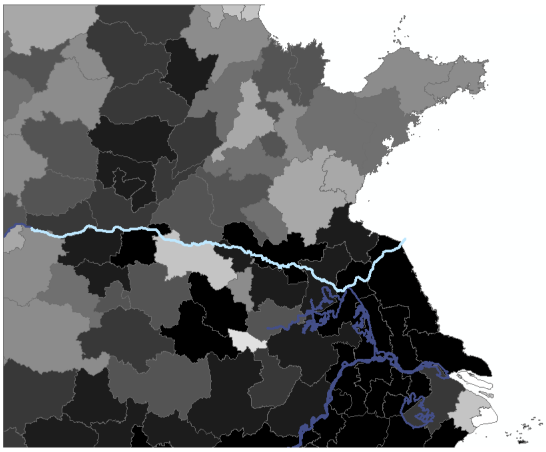
(a) Constructed market access, 1080 (b) Constructed market access, 1393

Notes: This map represents the residual of the constructed measure of market access (Z_{it}), in 1080 (a) and in 1393 (b) by quantiles (20), from a regression on the as-the-crow-flies market access. It focuses on the North China Plain, between Tianjin and the Yangzi River delta. The baseline scenario is used to define relative trade costs—see Section 3 for details. A warmer (colder) color indicates a higher (lower) residual. Grey lines materialize prefecture boundaries (as of 2000).

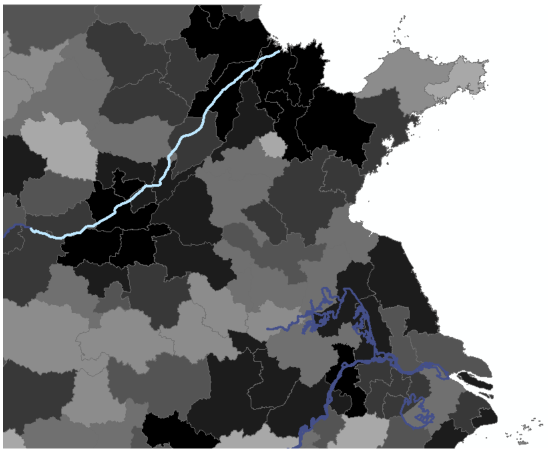
Figure 4. Variation in economic activity and taxation.



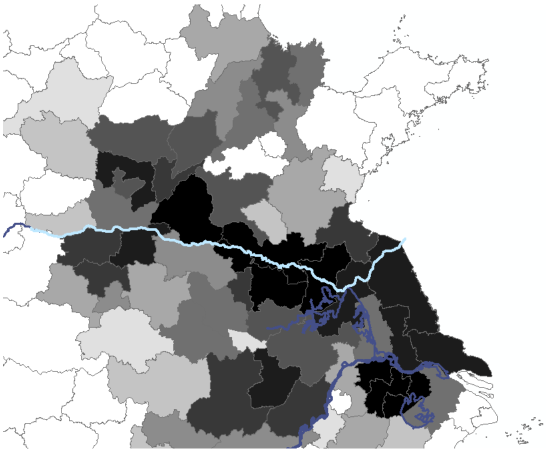
(a) Population density, 1102



(b) Population density, 1784



(c) Tax per capita (strings of cash), 1077



(d) Tax per capita (*dan* of wheat), 1784

Notes: This map represents population density in 1102 (a) and 1784 (b), and the amount of tax per capita in 1077 (c) and in 1784 (d), by deciles. It focuses on the North China Plain, between Tianjin and the Yangzi River delta. Taxes are measured in strings of cash (*guan*) in 1077 and in *dan* (a measure of volume) of wheat in 1784. The lower Yellow River is shown in light blue. The Yangzi river system is shown in navy blue. A darker (lighter) shade indicates a higher (lower) value. Grey lines materialize prefecture boundaries (as of 2000).

Table 1. First stage.

	Actual market access (M_{it})			
	(1)	(2)	(3)	(4)
Constructed market access (Z_{it})	0.993***	0.982***	0.725***	0.801***
	(0.275)	(0.241)	(0.167)	(0.172)
Observations	2,620	2,620	2,620	2,620
Cell fixed effects	Yes	Yes	Yes	Yes
Year fixed effects	Yes	Yes	Yes	Yes
As-the-crow-flies market access	No	Yes	Yes	Yes
Sea access×year	No	No	Yes	Yes
Cost surface	No	No	No	Yes

Notes: This table shows the first stage of the main specification. The sample is restricted to observations with non-missing population density in 1080, 1393, 1491, and 1578. An observation is a grid cell×year. Both the left- and right-hand side variables are standardized; they follow the baseline specification of the cost surface—see Section 3 for details. All regressions include year and cell fixed effects. Column 2 controls for as-the-crow-flies market access. Column 3 introduces a dummy equal to 1 if the cell has access to the sea, interacted with the year fixed effects. Column 4 additionally controls for the cost of crossing the cell (cost surface used to compute M_{it}). Standard errors are clustered at the prefecture (2000) level.

Table 2. Effect of market access on economic concentration.

	Population density (log)			
	(1)	(2)	(3)	(4)
Panel A: OLS specification				
Market access	0.340***	0.148*	0.169**	0.167**
	(0.088)	(0.085)	(0.082)	(0.082)
Observations	2,620	2,620	2,620	2,620
Panel B: IV specification				
Market access	0.246*	0.238*	0.332**	0.284*
	(0.134)	(0.137)	(0.158)	(0.159)
Observations	2,620	2,620	2,620	2,620
Cell fixed effects	Yes	Yes	Yes	Yes
Year fixed effects	Yes	Yes	Yes	Yes
As-the-crow-flies market access	No	Yes	Yes	Yes
Sea access×year	No	No	Yes	Yes
Cost surface	No	No	No	Yes
F-Stat. (first stage)	13.02	16.67	18.77	21.69

Notes: This table shows OLS (Panel A) and IV (Panel B) regressions of (log) population density on market access (standardized). The sample covers the following years: 1080, 1393, 1491, and 1578. An observation is a grid cell×year. In the IV specification, the actual market access (M_{it}) is instrumented by the exogenous market access (Z_{it}). Both follow the baseline specification of the cost surface—see Section 3 for details. All regressions include year and cell fixed effects. Column 2 controls for as-the-crow-flies market access. Column 3 introduces a dummy equal to 1 if the cell has access to the sea, interacted with the year fixed effects. Column 4 additionally controls for the cost of crossing the cell (cost surface used to compute M_{it}). Standard errors are clustered at the prefecture (2000) level.

Table 3. Effect of market access on share of manufacturing goods in taxes.

	Share manufacturing			
	(1)	(2)	(3)	(4)
Panel A: OLS specification				
Market access	0.378***	0.311***	0.346***	0.346***
	(0.076)	(0.085)	(0.099)	(0.100)
Observations	1,919	1,919	1,919	1,919
Panel B: IV specification				
Market access	0.759***	0.769***	1.002***	1.092***
	(0.192)	(0.209)	(0.239)	(0.252)
Observations	1,919	1,919	1,919	1,919
Cell fixed effects	Yes	Yes	Yes	Yes
Year fixed effects	Yes	Yes	Yes	Yes
As-the-crow-flies market access	No	Yes	Yes	Yes
Sea access×year	No	No	Yes	Yes
Cost surface	No	No	No	Yes
F-Stat. (first stage)	17.26	20.10	25.11	30.20

Notes: This table shows OLS (Panel A) and IV (Panel B) regressions of the share of manufactured goods or handicrafts (among the goods remitted as taxes by the prefecture) on market access. The sample covers the following years: 1080, 1393, 1502, and 1578. An observation is a grid cell×year. In the IV specification, the actual market access (M_{it}) is instrumented by the exogenous market access (Z_{it}). Both the dependent variable and market access measures are standardized. Market access measures follow the baseline specification of the cost surface—see Section 3 for details. All regressions include year and cell fixed effects. Column 2 controls for as-the-crow-flies market access. Column 3 introduces a dummy equal to 1 if the cell has access to the sea, interacted with the year fixed effects. Column 4 additionally controls for the cost of crossing the cell (cost surface used to compute M_{it}). Standard errors are clustered at the prefecture (2000) level.

Table 4. Effect of market access on number of goods taxed.

	Number of goods taxed			
	(1)	(2)	(3)	(4)
Panel A: OLS specification				
Market access	0.477***	0.237***	0.274***	0.275***
	(0.079)	(0.071)	(0.081)	(0.080)
Observations	1,919	1,919	1,919	1,919
Panel B: IV specification				
Market access	0.297*	0.242*	0.267	0.293*
	(0.166)	(0.135)	(0.173)	(0.173)
Observations	1,919	1,919	1,919	
Cell fixed effects	Yes	Yes	Yes	Yes
Year fixed effects	Yes	Yes	Yes	Yes
As-the-crow-flies market access	No	Yes	Yes	Yes
Sea access×year	No	No	Yes	Yes
Cost surface	No	No	No	Yes
F-Stat. (first stage)	17.26	20.10	25.11	30.20

Notes: This table shows OLS (Panel A) and IV (Panel B) regressions of the number of goods remitted as taxes by the prefecture on market access. The sample covers the following years: 1080, 1393, 1502, and 1578. An observation is a grid cell×year. In the IV specification, the actual market access (M_{it}) is instrumented by the exogenous market access (Z_{it}). Both the dependent variable and market access measures are standardized. Market access measures follow the baseline specification of the cost surface—see Section 3 for details. All regressions include year and cell fixed effects. Column 2 controls for as-the-crow-flies market access. Column 3 introduces a dummy equal to 1 if the cell has access to the sea, interacted with the year fixed effects. Column 4 additionally controls for the cost of crossing the cell (cost surface used to compute M_{it}). Standard errors are clustered at the prefecture (2000) level.

Table 5. Effect of market access on total taxes per capita.

	Total taxes (standardized)			
	(1)	(2)	(3)	(4)
Panel A: OLS specification				
Market access	0.061**	0.124***	0.081***	0.080***
	(0.027)	(0.028)	(0.030)	(0.030)
Observations	2,620	2,620	2,620	2,620
Panel B: IV specification				
Market access	0.306***	0.311***	0.338***	0.348***
	(0.082)	(0.075)	(0.091)	(0.110)
Observations	2,620	2,620	2,620	
Cell fixed effects	Yes	Yes	Yes	Yes
Year fixed effects	Yes	Yes	Yes	Yes
As-the-crow-flies market access	No	Yes	Yes	Yes
Sea access×year	No	No	Yes	Yes
Cost surface	No	No	No	Yes
F-Stat. (first stage)	13.02	16.67	18.77	21.69

Notes: This table shows OLS (Panel A) and IV (Panel B) regressions of the total amount remitted as taxes (standardized) by the prefecture on market access. The sample covers the following years: 1080, 1393, 1502, and 1578. An observation is a grid cell×year. In the IV specification, the actual market access (M_{it}) is instrumented by the exogenous market access (Z_{it}). Both the dependent variable and market access measures are standardized. Market access measures follow the baseline specification of the cost surface—see Section 3 for details. All regressions include year and cell fixed effects. Column 2 controls for as-the-crow-flies market access. Column 3 introduces a dummy equal to 1 if the cell has access to the sea, interacted with the year fixed effects. Column 4 additionally controls for the cost of crossing the cell (cost surface used to compute M_{it}). Standard errors are clustered at the prefecture (2000) level.

Table 6. Effect of market access on probability of top imperial graduates (*jinshi*).

	Any top imperial graduate (*jinshi*)			
	(1)	(2)	(3)	(4)
Panel A: OLS specification				
Market access	-0.053***	-0.032*	-0.047**	-0.045**
	(0.019)	(0.019)	(0.023)	(0.024)
Observations	2,620	2,620	2,620	2,620
Panel B: IV specification				
Market access	-0.181**	-0.182***	-0.242**	-0.268**
	(0.084)	(0.085)	(0.097)	(0.107)
Observations	2,620	2,620	2,620	
Cell fixed effects	Yes	Yes	Yes	Yes
Year fixed effects	Yes	Yes	Yes	Yes
As-the-crow-flies market access	No	Yes	Yes	Yes
Sea access×year	No	No	Yes	Yes
Cost surface	No	No	No	Yes
F-Stat. (first stage)	13.02	16.67	18.77	21.69

Notes: This table shows OLS (Panel A) and IV (Panel B) regressions of the probability of having any top imperial graduate—defined as the probability of having any person graduating from imperial examinations with the top (*jinshi*) rank—born the prefecture on market access. The sample covers the following years: 1080, 1393, 1502, and 1578. An observation is a grid cell×year. In the IV specification, the actual market access (M_{it}) is instrumented by the exogenous market access (Z_{it}). Both the dependent variable and market access measures are standardized. Market access measures follow the baseline specification of the cost surface—see Section 3 for details. All regressions include year and cell fixed effects. Column 2 controls for as-the-crow-flies market access. Column 3 introduces a dummy equal to 1 if the cell has access to the sea, interacted with the year fixed effects. Column 4 additionally controls for the cost of crossing the cell (cost surface used to compute M_{it}). Standard errors are clustered at the prefecture (2000) level.

Table 7. Effect of past market access on population density, taxes, and the elite.

	Density	Taxes	Elite
	(1)	(2)	(3)
Panel A: OLS specification			
Market access	-0.129***	0.178	-0.077***
	(0.035)	(0.133)	(0.019)
Observations	1,390	1,390	1,390
Panel B: IV specification			
Market access	-0.297***	-0.067	-0.059
	(0.074)	(0.222)	(0.062)
Observations	1,390	1,390	1,390
Cell fixed effects	Yes	Yes	Yes
Year fixed effects	Yes	Yes	Yes
As-the-crow-flies market access	Yes	Yes	Yes
Sea access×year	Yes	Yes	Yes
Cost surface	Yes	Yes	Yes
F-Stat. (first stage)	7.36	7.36	7.36

Notes: This table shows OLS (Panel A) and IV (Panel B) regressions of population density (log), the total amount remitted as taxes (standardized) by the prefecture, and the probability of having any top imperial graduate—defined as the probability of having any person graduating from imperial examinations with the top (*jinshi*) rank—born the prefecture on market access. The sample covers the following years: 1080, 1393, 1502, and 1578. An observation is a grid cell×year. In the IV specification, the actual market access (M_{it}) is instrumented by the exogenous market access (Z_{it}). Both the dependent variable and market access measures are standardized. Market access measures follow the baseline specification of the cost surface—see Section 3 for details. All regressions include year and cell fixed effects. Column 2 controls for as-the-crow-flies market access. Standard errors are clustered at the prefecture (2000) level.

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A Additional results

Table A1. First stage – whole period.

	Actual market access (M_{it})			
	(1)	(2)	(3)	(4)
Constructed market access (Z_{it})	1.158***	1.109***	0.738***	0.817***
	(0.317)	(0.272)	(0.170)	(0.173)
Observations	3,025	3,025	3,025	3,025
Cell fixed effects	Yes	Yes	Yes	Yes
Year fixed effects	Yes	Yes	Yes	Yes
As-the-crow-flies market access	No	Yes	Yes	Yes
Sea access×year	No	No	Yes	Yes
Cost surface	No	No	No	Yes

Notes: This table shows the first stage of the main specification. The sample is restricted to observations with non-missing population density in all waves. An observation is a grid cell×year. Both the left- and right-hand side variables are standardized; they follow the baseline specification of the cost surface—see Section 3 for details. All regressions include year and cell fixed effects. Column 2 controls for as-the-crow-flies market access. Column 3 introduces a dummy equal to 1 if the cell has access to the sea, interacted with the year fixed effects. Column 4 additionally controls for the cost of crossing the cell (cost surface used to compute M_{it}). Standard errors are clustered at the prefecture (2000) level.

Table A2. Effect of market access on economic concentration — whole period.

	Population density (log)			
	(1)	(2)	(3)	(4)
Panel A: OLS specification				
Market access	0.514***	0.339***	0.282***	0.280***
	(0.099)	(0.106)	(0.094)	(0.094)
Observations	3,025	3,025	3,025	3,025
Panel B: IV specification				
Market access	0.390***	0.358***	0.418**	0.381**
	(0.137)	(0.135)	(0.173)	(0.180)
Observations	3,025	3,025	3,025	3,025
Cell fixed effects	Yes	Yes	Yes	Yes
Year fixed effects	Yes	Yes	Yes	Yes
As-the-crow-flies market access	No	Yes	Yes	Yes
Sea access×year	No	No	Yes	Yes
Cost surface	No	No	No	Yes
F-Stat. (first stage)	13.40	16.67	18.79	22.40

Notes: This table shows OLS (Panel A) and IV (Panel B) regressions of (log) population density on market access (standardized). The sample covers the whole period. An observation is a grid cell×year. In the IV specification, the actual market access (M_{it}) is instrumented by the exogenous market access (Z_{it}). Both follow the baseline specification of the cost surface—see Section 3 for details. All regressions include year and cell fixed effects. Column 2 controls for as-the-crow-flies market access. Column 3 introduces a dummy equal to 1 if the cell has access to the sea, interacted with the year fixed effects. Column 4 additionally controls for the cost of crossing the cell (cost surface used to compute M_{it}). Standard errors are clustered at the prefecture (2000) level.

Table A3. Effect of market access on total taxes — additional controls.

	Total taxes (standardized)			
	(1)	(2)	(3)	(4)
Panel A: OLS specification				
Market access	0.082***	0.127***	0.112***	0.111***
	(0.023)	(0.025)	(0.029)	(0.029)
Observations	2,620	2,620	2,620	2,620
Panel B: IV specification				
Market access	0.464***	0.435***	0.532***	0.570***
	(0.116)	(0.101)	(0.118)	(0.151)
Observations	2,620	2,620	2,620	
Cell fixed effects	Yes	Yes	Yes	Yes
Year fixed effects	Yes	Yes	Yes	Yes
As-the-crow-flies market access	No	Yes	Yes	Yes
Sea access×year	No	No	Yes	Yes
Cost surface	No	No	No	Yes
Additional controls	Yes	Yes	Yes	Yes
F-Stat. (first stage)	11.42	15.40	16.39	18.32

Notes: This table shows OLS (Panel A) and IV (Panel B) regressions of the total amount remitted as taxes (standardized) by the prefecture on market access. The sample covers the following years: 1080, 1393, 1502, and 1578. An observation is a grid cell×year. In the IV specification, the actual market access (M_{it}) is instrumented by the exogenous market access (Z_{it}). Both the dependent variable and market access measures are standardized. Market access measures follow the baseline specification of the cost surface—see Section 3 for details. All regressions include year and cell fixed effects, and control for indicator variables for each commodity remitted as tax interacted with year fixed effects. Column 2 controls for as-the-crow-flies market access. Column 3 introduces a dummy equal to 1 if the cell has access to the sea, interacted with the year fixed effects. Column 4 additionally controls for the cost of crossing the cell (cost surface used to compute M_{it}). Standard errors are clustered at the prefecture (2000) level.

Table A4. Effect of market access on share of top imperial graduates (*jinshi*).

	Share of top imperial graduate (*jinshi*)			
	(1)	(2)	(3)	(4)
Panel A: OLS specification				
Market access	-0.064***	-0.038	-0.038	-0.035
	(0.023)	(0.030)	(0.030)	(0.030)
Observations	2,620	2,620	2,620	2,620
Panel B: IV specification				
Market access	-0.115*	-0.114	-0.161	-0.109
	(0.069)	(0.070)	(0.098)	(0.090)
Observations	2,620	2,620	2,620	2,620
Cell fixed effects	Yes	Yes	Yes	Yes
Year fixed effects	Yes	Yes	Yes	Yes
As-the-crow-flies market access	No	Yes	Yes	Yes
Sea access×year	No	No	Yes	Yes
Cost surface	No	No	No	Yes
F-Stat. (first stage)	13.02	16.67	18.77	21.69

Notes: This table shows OLS (Panel A) and IV (Panel B) regressions of the share (in the population) of top imperial graduate—defined as people who graduated from imperial examinations with the top (*jinshi*) rank—born the prefecture on market access. The sample covers the following years: 1080, 1393, 1502, and 1578. An observation is a grid cell×year. In the IV specification, the actual market access (M_{it}) is instrumented by the exogenous market access (Z_{it}). Both the dependent variable and market access measures are standardized. Market access measures follow the baseline specification of the cost surface—see Section 3 for details. All regressions include year and cell fixed effects. Column 2 controls for as-the-crow-flies market access. Column 3 introduces a dummy equal to 1 if the cell has access to the sea, interacted with the year fixed effects. Column 4 additionally controls for the cost of crossing the cell (cost surface used to compute M_{it}). Standard errors are clustered at the prefecture (2000) level.

B Data sources and descriptive statistics

In this section, I explain how I deal with changing administrative divisions, describe the population and taxation data, other data used for robustness checks and mechanisms, and the sources and methodology used to compute trade costs.

B.1 Changes in administrative divisions

The data used in this paper cover two millennia and are nested at the level of historical administrative units. As the size and boundaries of administrative entities changed markedly over the period, I need to recast all data to spatial units that are fixed in time. In this paper, I use two types of spatial units: I use a grid of 20×20 km cells or I use Chinese prefectures as of 2000.

I recast the data to fixed spatial units based on the following reweighting procedure. First, I intersect historical administrative maps with the chosen map of fixed units. Second, I distribute the data into each intersection and sum across intersections within fixed spatial units. For count variables, e.g., population totals, I divide the count by the share of the intersection in the total land area of the historical unit, and then sum across intersections within fixed spatial units. For other variables, e.g., population density, I assume in the baseline that they are homogeneous within units, and then sum across intersections within fixed spatial units weighting by the share of the intersection in the total land area of the fixed spatial unit.

B.2 Population and taxation data

I present here in greater detail the population and taxation data. I first summarize the main characteristics of the data. I then discuss some possible issues and how I tackle them.

Characteristics The population and taxation data used in the main results of this paper, as well as additional data exploited to highlight mechanisms and in robustness checks, come from dynastic histories and geographical treatises in classical Chinese. These sources usually provide similar information: For each province, prefectures are listed and described along different dimensions—population and taxation for each prefecture, subdivisions of each prefecture (counties), administrative changes, customs, etc. Population is typically recorded in two ways: as the total numbers of households (*hu*) and individuals (*kou*). Some, especially Song, sources distinguish between "master" (*zhu*) and "guest" (*ke*) households, a distinction mostly determined by asset ownership. Table B.2 summarizes population data sources and characteristics for the imperial period.

Taxation data cover two broad tax types: *fu* taxes, which involve goods such as grain and silk, and *gong* taxes or tribute, which consist of luxury goods, often specific to a region. Over the imperial period, *fu* taxes become increasingly common, while the importance of tributes recedes. For most of the period, taxes were remitted in kind, and the historical sources that I draw upon record the amounts remitted for each good type in great detail. In later dynasties, monetary amounts (amounts of quasi-currencies, such as silver, gold, or even silk) are increasingly available.

Challenges Given the length of the series created, the data used in this paper raise several challenges. They belong to three main categories: (i) data mapping, (ii) data quality, and (iii) definitions and measurement.

The first challenge pertains to the spatial nature of the data and changes in administrative divisions. The population and taxation data correspond to an entire prefecture (polygon) rather than the prefecture capital (point). Because of frequent changes in administrative boundaries over time, I thus need to remap all geolocated historical data to consistent administrative divisions. I proceed in the following way: First, I geolocalize the data from the original sources with (point) data on administrative divisions over time.[22] If coordinates are not available, I use textual information on the history of administrative changes to geolocate the data using Google Maps. Next, I use Hartwell's maps of historical administrative divisions (polygons) to determine the spatial area covered by each figure.[23] When administrative maps are not available, I infer the size of prefectures from the location of historical prefecture seats, based on a Thiessen interpolation. Finally, I superimpose maps of prefectures in the original year and in 2000 (or I superimpose historical maps with a fixed grid), and reweight the data in the original year to obtain consistent measures, which are used as fixed geographical units throughout the analysis, and assign the resulting values to their centroids.[24] This remapping procedure is

[22] I mostly use CHGIS, Version: 6. © Fairbank Center for Chinese Studies of Harvard University and the Center for Historical Geographical Studies at Fudan University, 2016. These data are available at https://sites.fas.harvard.edu/~chgis/. For the Song dynasty, I further rely on Ruth Mostern's work to accurately geolocate prefectures. Her data, the "Digital Gazetteer of Song Dynasty China," are available at http://songgis.ucmerced.edu.

[23] I explain the procedure and assumptions in Appendix B.1, where I also test the robustness of the results to alternative assumptions. Robert Hartwell's maps are available at https://sites.fas.harvard.edu/~chgis/data/hartwell/.

[24] The minimum cost distances used in the market access measures are also calculated between centroids. I can also use administrative divisions in the earliest year of population data (2 C.E.), as today's administrative divisions could be endogenously determined by (past) market access, and all the results go through.

explained in greater detail in Appendix B.1.

A related issue is that data are missing for some prefectures in some periods. While this is not unique to these data, this issue is more serious than in most empirical applications because of changes in administrative divisions and the remapping subsequently needed. In this paper, I develop a simple methodology to deal with missing values in spatial data. The methodology, which consists of imputing values using the average within some radius around the point with missing data and conditional on having a minimum of data points, allows for clear parameters and robustness checks, i.e., I can change the parameters to vary the restrictiveness of the imputation rules, from the assumption that missing values are zeroes[25] to imputing all missing values regardless of the distance between points. I can further check the robustness of the results to dropping all the prefectures (as of 2000) or grid cells for which data are based, even partly, on imputed values.

Data quality varies across prefectures and over time, which poses a second challenge. A first cause of variation in quality is state capacity and administration quality (Ho, 1959; Cartier and Will, 1971; Bielenstein, 1987). Some officials were lazy, incompetent, or corrupt. State capacity varied over time, and the central government exerted unequal power over its nominal territory. For example, areas surrounding the imperial capital were probably under tight control, as were border prefectures, which were well administered (Cartier and Will, 1971). In the empirical part of this paper, I control for the dynastic cycle (time since the dynasty was founded or time to its downfall), distance to the imperial capital, and proximity to the border.

A second cause is that population and taxation figures reflect changes in the legal environment and institutional context. The earliest censuses were motivated by war effort and aimed at determining how many able-bodied men could be drafted, and how many women, children, and elderly would be left without support. Later on, censuses were mostly used to determine the tax base, reducing officials' incentives to count non-taxable individuals. Following the Ming and Qing reforms of the taxation system, population is often recorded as *ding*, a word with an elusive definition, sometimes just an abstract "taxation unit" far removed from demographics (Ho, 1959). Changes in the legal environment may also lead to endogenous responses in behavior; this is of particular concern when only household totals are available (this happens in 10 out of 25 population waves), as the tax system oscillated between taxing individuals and households, thus affecting the incentives to form (or report) large

[25] This assumption may be justified by the fact that missing population data, for instance, is highly correlated with low population, late incorporation into the kingdom, and low economic development.

households. Finally, emperors were reluctant to increase tax quotas—lest they came across as tyrants—and increased additional fees (e.g., "transportation fees") instead, which means that taxation figures may respond less to economic development as a dynasty ages. In the empirics, I systematically include period fixed effects; in some specifications, I further control for the type of data (e.g., individual vs. household counts, and *ding* vs. "mouths" or "households") interacted with time fixed effects.

A third source of data degradation comes from how the data were passed down across centuries. As argued by Cartier and Will (1971), it is crucial to work with the most disaggregated data, because of (i) copying mistakes that accumulated at each level of the administrative hierarchy, (ii) the fact that the data we have were compiled by historians rather than statisticians, (iii) deliberate falsification, and (iv) historiographic clichés.[26] The use of prefecture-level data in this paper should deal with most of these concerns; I however provide a robustness check on a subsample of prefectures using county-level data from local gazetteers.[27]

Finally, the data present several measurement issues—about precisely dating the information available in the texts, the definition of the population covered, and harmonizing taxation data. First, determining the year to which the data correspond is usually straightforward, as it is precisely recorded in the original text. A less precise reign period is however sometimes provided. In some rare cases, no date is given, and triangulation—based on other sources and the known dates of changes in administrative divisions—is necessary. Furthermore, in the Ming dynasty, the dates stated in the sources usually correspond to the last revision of the figures; I systematically replace them with the correct census year.

Second, the nature of the data and population covered is usually not known. In some periods, the whole population is counted.[28] In others, only taxable individuals were listed. I follow Bielenstein (1987) to classify the population data as censuses vs. tax registries, as well as to determine their level of disaggregation (individuals vs. households), in cases where the original source is not specific. To combine different data, in particular individual- and household-level data, the literature on Chinese demographic history usually uses a constant multiplier. Cartier and Will (1971)

[26] A larger population was seen as a sign of good government, and demographic decline as a sign that the Emperor lost the Mandate of Heaven. Dynastic histories, which were compiled by the next rulers, thus typically justify their accession to the throne by "population halving" in the later years of the previous dynasty. Such tampering with population data is however limited to national totals.

[27] Counties (*xian*) are the lowest level of government at which historical population figures are available.

[28] Slaves, monks and nuns, and soldiers were sometimes excluded or counted separately, and the registers were lost. I ignore these cases, which were probably marginal.

however show that this practice is highly questionable in the Chinese context. In the empirics, I will use logarithms, which make such a constant multiplier redundant, along with a rich set of period, dynasty, and prefecture fixed effects to alleviate concerns about changes in population units. Additionally, I offer an alternative population series, using exact household sizes measured in the nearest period where both household and individual totals are available. I finally show that the results hold in the subsets of periods where only individual or only household figures are available, and that the estimates are similar in periods where both are available.

Third, some issues are more specific to the taxation data: (i) There are two broad types of taxation data: *fu* taxes, which involve goods such as grain and silk, and *gong* taxes or tribute, which consist of luxury goods, often specific to a region. (ii) Different goods are used for taxation in different regions and at different times: For example, silk was the most common commodity used for taxation and was almost used as a currency in some periods in the North, while it was yet to be introduced in the South. Money or standards such as silver played an increasing role in taxation in later periods. (iii) When amounts are recorded, they use different units, which are often non-decimal and must be converted. Conversion rates varied across space and over time. I use the correct conversion rate from historical studies whenever possible. (iv) Even if a good is commonly cited, such as *juan*, a narrowly defined silk tabby, it need not be homogeneous. Goods may differ in quality, which may be due to tax evasion. Attested tax evasion practices include purposely remitting lower quality goods, e.g., moldy rice, or replacing dearer commodities (such as silk) with cheaper ones (hemp). In the empirical part of this paper, I deal with issues (i)–(iii) in two ways: I focus on the number of goods remitted for taxation to the central government, and I aggregate all taxes using historical price indices (Peng, 1965). This allows for comparisons across periods and across goods.

B.3 Other data

I use additional data sources to (i) establish my intepretation of the main findings, (ii) identify mechanisms, and (iii) check the robustness of the results.

First, I use two additional data sets to strengthen my interpretation of the effect of market access on economic activity and taxation. (a) The hypothesis that improved market access facilitates taxation presupposes that economic activity becomes more spatially concentrated. To better capture the concentration of economic activity, I leverage historical data on the urbanization rate to better characterize spatial concentration of economic activity. (b) Taxes could be productively employed and need not be synonymous with rent extraction. The taxation data leveraged in this paper however record remittances to the central government and not taxes financing financing local public goods. I use social unrest data to confirm that taxes and rents—as taxes were typically collected through landlords (Bernhardt, 1992)—are increasingly contested over time in places that enjoy better market access.

Second, I use two additional data sources to highlight the mechanism behind the negative long-run effect of market access on economic activity. (a) I use the geolocated birthplaces of the highest rank of imperial examination graduates (*jinshi*) from all extant rosters between 618 and 1905, from the China Biographical Database. This allows me to capture the elites' location decisions. The resulting measure of elite share can be interpreted as a proxy for human capital and potential for innovation. (b) I confirm this interpretation using data on inventions and their locations within China from a dictionary of inventors (Li and Cha, 2002), as well as newly collected information on other types of innovation (industrial, literary, artistic, etc.) from the dynastic histories already used for the population and taxation data.

Third, I gathered further data that I use in robustness checks. (a) Local populations and imperial governments actively tried to control the Yellow River. I use and geolocate detailed data on floods and river management activities from Shen et al. (1935), based on gazetteers and histories. These data are precisely dated; I further geolocate them and nest them at the prefecture level. They contain information on flood events and intensity, levee construction, maintenance and repair activities, flood prevention measures such as damming, diversion, spillway, soil and water conservation, the establishment of river bureaus, and imperial Treasury relief interventions. (b) In baseline results, I assume for simplicity that population is homogeneously distributed within prefectures. In robustness checks, I use maps of administrative seats (at the county level, below the prefecture) and boundaries (at the prefecture) from CHGIS and Hartwell, respectively, and distribute prefecture-level population totals to geolocalized population centers. Boundaries are available from the Tang dynasty; administrative seats have been geolocated from 221 B.C.E. (c) Finally, the cost surface maps that I construct ignore other features of the topography (e.g., elevation and slope) than rivers and the coastline. In robustness, I create time-varying controls by interacted GIS measures of topography, physiographic macroregions (Skinner, 1977), and other geographical fundamentals (latitude and longitude, access to the sea, etc.) with time dummies to capture local dynamics that may confound the results.

B.4 Trade costs

I compute trade costs as minimum cost distances using historical accounts of total trade costs.

Cost distance I use the time-varying cost surface to calculate the minimum cost distance d_{ijt} between all prefecture centroid pairs i, j at time t.[29] For each period t, I apply an algorithm (the Cost Distance tool in ArcGIS) that iterates over the grid to assign each cell the minimum accumulative cost to the specified source cell. Using the node and link representation from graph theory, this algorithm treats each center of a cell as a node and translates the cost surface into an impedance attached to each link between any two nodes. Figure 2 shows the output of the algorithm for Kaifeng, Henan Province, before and after the 1855 change in the course of the Yellow River.

Relative trade costs The historical accounts that trade costs are based on correspond to different points in time and compare different means of transportation, which allows me to create time-varying cost surfaces reflecting changes in geography and infrastructures, but also changes in technology and prices.

For the Tang and Song dynasties, I rely on Kiyokoba (1991, 1996), which provides detailed figures for overland and river transport, further distinguishing between the Yellow River, Yangzi, and other rivers, between upstream and downstream journeys, and between different types of overland transportation (e.g., porters vs. carts). For the Ming dynasty, I rely on Perkins (1969) and Evans (1984), as well as Ayao (1969) for the Grand Canal. For the Qing dynasty, I use data on rice prices from Suzhou along the Yangzi and to Beijing, from Chuan and Kraus (1975). For the Republican period, I rely on Buck (1937) and Worcester (1966). Worcester (1966)'s estimates differ from the others, as they are based on travel time, not total trade costs. When I do not have trade cost data for a given year, I use the nearest available data. When some information is not available, e.g., up- vs. downstream costs, I apply the same ratio as in the nearest data, and rely on contemporaneous figures for the rest (e.g., on Yellow River vs. Yangzi River trade costs).

Random river and other rivers This paper relies on two measures of market access, an observed, endogenous measure and a constructed measure used as instrument. These two measures rely on different specifications of the cost surface.

[29] An alternative is to compute d_{ijt} for all cells in an arbitrary grid, and attribute the average d_{ijt} to a 2000 prefecture. This is done in robustness checks.

In both cases, I distinguish between overland (with and without roads), sea, and inland waterway transport. I assume overland (without roads) and sea trade costs to be uniform.[30] Inland waterway trade costs are allowed to differ by waterway type (natural rivers vs. canals) and by river (e.g., Yellow River vs. Wei River) to reflect differences in navigability and transportation costs. Most rivers experience only minor, very local changes in their courses (e.g., due to the natural evolution of meanders, or to floods) and are considered time-invariant. Time-invariant rivers are extracted from a map of the contemporary waterway network, from which I remove all time-varying waterways and replace them with historical courses to create time-varying waterway networks. Since rivers are cheap and therefore major trade routes, I further allow trade costs to differ for up- and downstream journeys. I rely on historical accounts to parameterize relative trade costs at different points in time.[31] I normalize the cost of sea transport to 1. For all river types, I distinguish between three scenarios—low, midpoint, and high river costs,—based on the range of costs provided by historians. I use the midpoint scenario and allow costs to differ by river in the baseline.[32]

To calculate the *actual* trade costs, I use all the variation in the cost surface; to construct the *exogenous* component, I isolate exogenous changes, such as shifts in the course of the Lower Yellow River, and keep man-made infrastructures—canals, roads, and later railways—constant. For the Lower Yellow River, I use the maps of its historical courses since 350 B.C.E. created by Chen et al. (2012) combining geographical accounts in historical writings with NASA/JAXA Shuttle Radar Topography Mission (SRTM) data.[33] As the courses of other rivers, such as the Huai, were at times noticeably affected by the evolution of the Lower Yellow River, I additionally digitize maps from Tan (1989) to create time-varying courses for such

[30] Alternatively, I can allow for different overland transportation costs by transforming Özak's (2010) human mobility index (HMI). Note, however, that the HMI does not account for inland waterways.

[31] Total trade costs include transportation costs and various barriers to trade. In the baseline strategy, I rely on historical accounts of the total costs of bringing goods from a given origin to a given destination. These accounts include transportation costs proper, the cost of labor, bribes, etc., but some barriers to trade such as time spent in transit and the cost of damages or loss might not be adequately captured. A more complete way of measuring total trade costs would be to use the difference in retail prices for goods from a known origin (Donaldson, 2018). For some periods, I use differences in retail prices to compute trade costs. In a robustness check (Appendix B), I rescale trade costs in other periods to obtain total trade costs.

[32] I provide robustness checks relying on alternative scenarios and assuming a uniform river cost in the Appendix. Shiue and Keller (2007) use uniform (and time-invariant) costs, taking the midpoint between historical accounts. Since the Yellow River was less navigable than other natural waterways (at least in more recent periods) and most of the variation in market access comes from the Yellow River, assuming a uniform river transportation cost may bias our results.

[33] Accounts of earlier courses of the Yellow River are available, but they do not allow me to date course changes with precision. I am grateful to Chen et al. (2012) for sharing their maps with me.

rivers. For roads, railways, and canals, I digitize high-resolution maps from Cheng and Hsu (1983), based on records of the evolution of the transportation network in local gazetteers compiled in dynastic histories and geographical treatises. These maps distinguish between major and secondary roads, and allow me to date infrastructures.[34]

[34] The large amounts of sediments carried by the Yellow River also mean that the coastline gradually moves out at its mouth. I rely on Cheng and Hsu's (1983) historical maps to create a time-varying map of the coastline. This map reflects both natural (due to the Yellow River) and artificial land expansions (polders).

Table B5. Population data

Source	Year presented	Year of data	Type	Level
Book of Han	111	2 C.E.	Census	households, individuals
Book of the Later Han	445	140	Census	households, individuals
Book of Jin	648	280	Tax registry	households
Book of Song	488	464	Census	households, individuals
Book of Wei	554	550	Tax registry	households, individuals
Book of Sui	636	607	Census	households
Comprehensive Statutes of Tang	801	634–640	Census	households, individuals
Old Book of Tang	945	634–640	Tax registry	households, individuals
		742	Census	households, individuals
Yuanhe Maps and Records	813	714	Census	households
		809	Census	households
Taiping Huanyu Ji	1007	714	Census	households
		988	Census	households (master, guest)
New Book of Tang	1060	742	Census	households, individuals
Song Government Manuscript Compendium	1408	1102	Tax registry	individuals
Yuanfeng Treatise	1085	1080	Census	rural (master, guest) households
History of Liao	1344	11^{th} c.	Tax registry	households
History of Song	1346	1102	Census	rural adults, households
History of Jin	1343	1208	Census	households
History of Yuan	1370	1281–1330	Census	households, individuals
Taizu Veritable Records	1399	1381	Census	rural master households
		1393	Census	rural master households, individuals
		1491	Census	rural master households, individuals
		1578	Census	rural master households, individuals
Collected Regulations	1509	1393	Census	rural master households, individuals
		1491	Census	rural master households, individuals
		1578	Census	rural master households, individuals
Records of the Unity	1842	1796–1820	Census	individuals

Note: This table lists the historical sources used in this paper to measure population at the prefecture level over time. *Year presented* indicates the year the book was presented to the emperor. *Year of data* indicates the year or era (an emperor's reign) in which the data were collected. *Type* provides us with the nature of the population data according to Bielenstein (1987). *Level* provides us with the level of disaggregation of the population data.