Malthus Goes to China: The Effect of "Positive Checks" on Grain Market Development, 1736–1910

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After peaking around the mid-eighteenth century, grain market integration in China declined by a colossal 80 percent amid a twofold increase in population and remained at low levels for well over a century. Markets only resumed their growth momentum after the largest peasant revolt—the Taiping Rebellion—wiped out roughly one-sixth of the Chinese population starting 1851. This U-shaped pattern of grain market integration distinguished China from Europe in their trajectories of market development. Using grain prices to divide China into grain-deficit and grain-surplus regions, we find that the negative relationship between population growth and market integration originated from the grain-surplus-cum-exporting regions.

The development of markets is often seen as a harbinger of modern economic growth or specifically the Industrial Revolution (Chilosi and Federico 2015; Christopoulos and Tsionas 2004; Epstein 2000; Jacks 2005; Keller and Shiue 2007; Persson 2010; Rodrik, Subramanian, and Trebbi 2004; among others). China diverges from Europe in this regard, which presents a puzzle. By the early-to-mid-eighteenth century, while market performance in China appeared to be at least comparable to that in Western Europe, English markets outperformed even the most advanced areas of China (Pomeranz 2000a; Shiue and Keller 2007). But by extending the panel of data observations beyond 1800 to cover a period of 175 years (c. 1736–1910), there is evidence for a robust U-shaped pattern of market integration in China.[1] We use the speed at which markets adjusted to shocks, estimated with a Band Threshold Autoregressive (Band-TAR) model, as our main measure of integration, finding that, after peaking

The Journal of Economic History, Vol. 81, No. 4 (December 2021). doi: 10.1017/S0022050721000437

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We thank the editor Dan Bogart and two anonymous referees for helpful comments and suggestions on earlier drafts. The remaining errors are our own responsibility. James Kung would like to thank Sein and Isaac Souede for their generous financial support.

[1] By extending Shiue and Keller's (2007) analysis for the period 1742–1795 and covering 10 provinces only, we study the longest period of market integration in the history of China. Our data set contains nearly 400,000 monthly observations on grain price in 17 provinces or 226 prefectures.

around the mid-to-late eighteenth century, China's grain market began to disintegrate, and it remained so for well over a century until around the mid-to-late nineteenth century, when markets trended toward greater integration. This helps resolve, to a certain extent, the puzzle of why Europe experienced an overall trend toward a more integrated market in its march toward the Industrial Revolution (e.g., Chilosi et al. 2013), whereas China simply ran out of steam.[2]

While conventional studies of market integration have seldom considered population dynamics to be an important determinant, the fact that China's grain markets began to resume their integration only after the largest demographic catastrophe (viz. the Taiping Rebellion of 1851–1864)[3] left 73 million people dead suggests that the relationship between population growth and market integration deserves closer examination. Using a fixed-effects model, we find that the relationship between population growth and market integration as covered in our period (1736–1910), is on the whole *negative*. Specifically, a 100 percent increase in population density for a prefecture will lead to a 0.025–0.027 reduction in the distance-weighted average speed of adjustment for that prefecture, which then is translated into 39.7–40.2 percent when evaluated at the mean of market integration in late imperial China. Given that the population actually increased by approximately 200 percent during 1741–1851, this would mean that market integration fell by a colossal 80 percent. Our result is robust to the alternative regression using gaps in grain price between pairs of trading prefectures as the dependent variable for market integration and their differences in average population growth as the independent variable.[4] Our regressions also include controls for alternative drivers of market integration, including transport and communications changes, weather shocks, war, and the introduction of transit taxes.

We explain that under a Malthusian regime, unchecked population growth would likely reduce the grain surplus available for trade, thereby retarding the development of markets. To look into this mechanism, we divide late imperial China into three distinct regions according to whether they were deficient in grain, self-sufficient, or able to produce a surplus based on grain prices and other historical considerations. Doing so reveals that the negative relationship is significant only for the grain-surplus

[2] Except during the French and Napoleonic Wars, which caused market disintegration, grain markets in Europe—be they local or continental—became increasingly integrated over time (Bateman 2011; Bochove 2007; Chilosi et al. 2013; Dobado-Gonzãlez, Garciã-Hiernaux, and Guerrero 2012; Jacks 2004; O'Rourke and Williamson 2002; Özmucur and Pamuk 2007; Persson 1999; Rönnbäck 2009).

[3] The Taiping Rebellion was the largest peasant revolt in late imperial China. A recent estimate puts the death toll in excess of 70 million (Cao), far exceeding a previous estimate of 50 million (Perkins 1969).

[4] A Chinese prefecture is an administrative unit immediately below that of a province.

region, which is consistent with Pomeranz's (2000b) conjecture that this kind of region may have experienced a higher rate of population growth and thus led to a notable decline in the grain trade. Pomeranz's conjecture is consistent with our finding that the bottleneck lay squarely on the supply side. Moreover, to ensure that regions previously producing a grain surplus would also export it accordingly, we use a panel data set to examine the role of population growth in grain trade between and within the provinces, using grain price to identify the importers and exporters. Consistently, we find that only population growth in the exporting prefectures has a significantly negative effect on market integration, regardless of whether it was long-distance trade between the provinces or short-distance trade within the same province. Our finding is supported by the conjecture made by Pomeranz (2000b) and others (e.g., Skinner 1977a, 1977b; von Glahn 2016) that the more developed lower Yangtze region and its middle and upper counterparts experienced a decline in grain trade between them from around the mid-eighteenth century onwards.

Our focus on the role of population growth in determining market integration does not imply that other factors are unimportant. In fact, we do find that both technological progress and the decline of political trade barriers had a positive effect on market integration, as many others have also found (e.g., Andrabi and Kuehlwein 2010; Findlay and O'Rourke 2003; Jacks 2006; Keller and Shiue 2014). In particular, the introduction of the steamboat, which was widely adopted in domestic trade (Yan 1955), had significantly improved market integration in the second half of the nineteenth century, whereas the *likin* tax—a political barrier of sorts, had wittingly led to a decrease in market integration after the Taiping rebellion.[5] Both of these factors are, however, secondary to the pivotal role played by population dynamics in affecting the way the grain markets in China developed.

Our study contributes to studies of market integration. First, the identification of a U-shaped pattern between population growth and market integration in late imperial China inspires us to incorporate the role played by population dynamics—rather than the costs of transportation and institutions—in market integration. By focusing on the relationship between population dynamics and market integration, our study provides fresh empirical evidence with which to contrast the European experience that markets continued to integrate into the march toward the Industrial Revolution, thereby shedding new light on the differing trajectories

[5] The *likin* tax was essentially a decentralized local tax adopted during the Taiping Rebellion, as provincial governments were allowed to tax goods both in storage and transit so that they could employ these tax revenues to recruit their own troops to suppress the Taiping rebels. More on this later.

between China and Europe from the perspective of market performance. While Europe also experienced population growth in the sixteenth and seventeenth centuries, it continued to develop along the Smithian path, whereby the population increase had the virtuous effect of deepening specialization instead of disintegrating markets. The difference between China and Europe in this regard might be due to the *varying* degrees of population growth, but this comparative analysis goes beyond our present scope. Second, the fresh empirical evidence presented by our study supports the theory that in a Malthusian world, "positive checks" (i.e., events that shortens the human life span) such as the Taiping Rebellion are an effective means to restrict population growth (see, e.g., Clark 2007; Galor 2011; Galor and Weil 2000).

The remainder of this paper is organized as follows. We begin in the second section by introducing the data on grain prices, followed by examining the patterns of market integration in late imperial China for the extended period 1736–1910 using the Band-TAR model. Additionally, we also calculate the coefficients of correlation to test for price co-movements and Weir's (1989) *R* index to test for price variance. In the third section, we analyze the association between population growth and market integration. In the fourth section, we examine the underlying mechanism through which population growth influenced market integration in late imperial China. The fifth section provides a brief conclusion.

MEASURING MARKET INTEGRATION IN HISTORICAL CHINA

Grain Price Data

Following other studies of market integration, we similarly use monthly grain price to estimate market integration in late imperial China, which we obtain from two sources. The first is based on a data set on grain prices in the Qing Dynasty, published by the Institute of Modern History in Taiwan (Wang 2009). This particular source contains monthly grain prices at the prefectural level—a level of administration between the province and the county—from 1736 to 1911. Our second data source comes from the Grain Price Series of 1821–1911 (*Qingdai Daoguang Zhi Xuantong Jian Liangjiabiao*) edited by the Chinese Academy of Social Science (2010). Both sources are based on the same grain price reporting system put in place by the Qing emperors, and so the two are compatible. These price data are based largely on the same high-quality sources as in Keller, Shiue, and Wang (2018), who showed diverging capital market integration over time. We then constructed a data series of monthly grain prices covering a total of 226 prefectures in 17 provinces from 1736 to 1910 (Table 1).[6] This is a highly representative sample, as it covers approximately 90 percent of the total population in China during the eighteenth and nineteenth centuries with broad geographic coverage (Figure 1). Merging the two data sets provides us with approximately 400,000 observations, with each prefecture consisting of an average of 1,652–1,959 observations.[7] A summary of China's grain price data for the period 1736–1911 is provided in Table 1. Wheat and rice (including indica rice) are the two main staple crops in China.[8] To ensure comparability, we use caloric content as the weight to calculate a weighted average of the grain price in each prefecture. For example, using the price of first-grade rice as numeraire, wheat has a caloric content of 317 kilocalories per 100 grams, rice 346, and indica rice 328. We then employ the average price of these various grain crops for calculating the grain price index.

Empirical Results Based on the BAND-TAR Model

Economic historians study market integration from two perspectives. The first is price convergence, which assumes that prices must be equal everywhere in perfectly integrated markets. It is believed that the degree of price convergence depends on the decline in transaction costs resulting from improvements in transportation, such as the development of railroads and steamboats. The other is market efficiency, which captures the speed of adjustment to shocks. Efficiency is a function of the degree of market transparency, the state of information technology (such as telegraph), market structure, and so forth. In this paper, we focus on the second perspective, primarily because in China technological improvements such as those in transportation came rather late—either towards the end of the Qing dynasty in the case of steamboats (Xu 1992) or after its collapse in the case of railroads (Yan 1955).

According to Federico (2012), market efficiency can be measured by co-integration tests, co-movement tests, and variance tests. In particular, co-integration tests allow us to test whether arbitrage in the market can return the price differential between markets to its equilibrium level after

[6] These provinces include Zhili, Shanxi, Shaanxi, Henan, Shandong, Yunnan, Sichuan, Jiangsu, Zhejiang, Anhui, Jiangxi, Hubei, Hunan, Fujian, Guangdong, Guangxi, and Guizhou. The last ten of these provinces are also included in Shiue (2002) and Shiue and Keller (2007), respectively.

[7] Exceptions to this are Shaanxi, Sichuan, Yunnan, and Zhili provinces, where missing observations are more severe.

[8] Grain was the most important staple commodity in pre-modern countries; imperial China was no exception. By 1840 the annual volume of grain trade reached approximately 12.25 billion kilograms (or 24.5 billion Chinese catties), which made up 10.5 percent of China's total grain output at the time. While being a staple, grain trade was important for even the self-sufficient Chinese peasants as they depended heavily on selling grain for cash income, which they then used to purchase a variety of life essentials such as cotton, cloth, and salt. The exchange between grain and industrial products accounted for roughly 80 percent of the trade-in domestic market in the first half of the nineteenth century (Fang et al. 2000).

TABLE 1
SUMMARY OF CHINA'S GRAIN PRICE DATASET, 1736–1911

Province	No. of Prefectures	Obs.	Average Observation per Prefecture
South China			
Anhui	12	20,566	1886
Fujian	11	20,744	1900
Guangdong	12	22,794	1959
Guangxi	12	23,505	1712
Guizhou	13	22,261	1695
Hubei	10	16,951	1949
Hunan	13	25,341	1824
Jiangsu	10	18,237	1916
Jiangxi	14	26,830	1727
Sichuan	17	29,353	1430
Yunan[1]	18	25,741	1862
Zhejiang	11	20,482	1886
North China			
Henan	13	24,187	1861
Shandong	12	21,853	1821
Shanxi	19	36,383	1915
Shaanxi[2]	12	16,057	1338
Zhili[3]	17	28,085	1652
Total	226	399,370	1767

Notes: [1]Grain prices for Yunnan during 1858–1878 are missing. [2]Grain prices in Shaanxi during 1836–1909 are missing. [3]Only five prefectures in Zhili province, namely Chengde, Hejian, Yizhou, Xuanhuan, and Zhunhua, have observations before 1764.
Sources: Wang (2009); the Chinese Academy of Social Science (2010).

a shock hits. A common approach employed in co-integration tests is an error-correction-mechanism (ECM) specification, which provides valuable information about the process of price adjustment. However, the ECM specification fails to satisfy the condition that transaction costs are positive. Hence, to the extent that price differentials are lower than transaction costs, prices will move freely within the bands without any arbitrage between markets. The ECM specification will thus cause a negative bias in estimating the speed of adjustment, with the size of the bias increasing with the size of the commodity price band. The Band-TAR model can more realistically measure the speed of price adjustment as well as yielding an estimate of transaction costs.[9] Given this advantage, the Band-TAR model has become a popular method for examining market efficiency in co-integration tests—a method we will employ in our

[9] Except for the estimates of transaction costs will be biased upwards if the market is inefficient or downwards if the market is efficient (Federico 2012).

FIGURE 1
SAMPLE SELECTION

Note: Map of China in 1820.
Data Source: CHGIS, Version 4 Cambridge: Harvard Yenching Institute, January 2007.

analysis that follows.[10] To briefly summarize, the Band-TAR model estimates a set of coefficients capturing the speed of adjustment to a market shock. The absolute value of their sum will equal zero in the case of no integration and one (or less) in the case of perfect integration. A higher value suggests a more rapid adjustment of prices and a higher degree of integration between the two markets.

Additionally, we will also employ both price co-movement and variance tests to check robustness. To test for price co-movements, we use the first difference of grain prices to calculate the coefficients of correlation. This "detrending" exercise is important for reducing the upward bias in the estimate of market efficiency because, even for perfectly disjoint grain markets, shared monetary trends (be it inflation or deflation) will create positive correlations among them (Weir 1989). We thus use Weir's (1989) R index, which is formulated for exactly that purpose:

$$R = \frac{\dfrac{Var(national)}{\sum_i Var(p_i)/n^2} - 1}{(n-1)}, \tag{1}$$

where $Var(national)$ is the variance of the detrended series of national prices, which we obtained by taking the simple average of all (prefectural-level) grain prices, $Var(p_i)$ represents the variance of the i-th detrended

[10] Details of the Band-TAR model are provided in Online Appendix A.

https://doi.org/10.1017/S0022050721000437 Published online by Cambridge University Press

series of prices, and n is the number of markets. Weir (1989) argues that, under conditions of perfect market integration, prices will synchronize across markets, which means that the variance in price across markets would converge to the variance of a single national price. In short, the R index would be equal to one. In contrast, where the market is not integrated, the R index would be equal to zero. Thus, the higher the R index is, the higher the degree of market integration would be.

We begin by employing the Band-TAR model to estimate the speed of grain price adjustment between pairs of Chinese prefectures in the 23 subperiods each of a 15-year duration (e.g., 1736–1750, 1751–1765, and so on) for the entire 1736–1910 period. Figure 2 reports the average half-life by distance, which can be interpreted as the average time taken for grain price to get adjusted toward the equilibrium price after experiencing a shock. The higher the half-life, the slower the speed of price adjustment. We include distance because the longer distance would not only decrease arbitrage opportunities due to higher transport costs, it also increases the time to transport grain from the exporters to importers, thereby decreasing the speed of price adjustment. As Figure 2 indeed shows, China's grain market became less integrated from the eighteenth century onwards (as indicated along the vertical axis), a trend that continued into the early nineteenth century. Having reached its nadir around the 1820s–1840s, grain markets in China rebounded and resumed their forces of integration, so much so that by the second half of the nineteenth century, market integration climbed back to the level it attained around 1736. In other words, China experienced a robust U-shaped pattern of market integration during 1736–1910.

To check the robustness of this finding, we also examine the average speed of price adjustment from the middle to the lower Yangtze region—a region most active in the grain trade. By one estimate, the middle Yangtze region (represented by the provinces of Anhui, Jiangxi, and Hunan) exported around 0.9–1.5 billion kilograms of rice to the lower Yangtze region (represented by the provinces of Fujian, Jiangsu, and Zhejiang), which accounted for 80 percent of the total grain imports in this latter region (Chuan and Kraus 1975). Given that half-lives are a decreasing function of the *rho* parameter estimated from the BAND-TAR model, from now on, we will only report *rho*. Figure 3 shows both the TAR-Band estimates and the LOWESS smoothed curve of the average speed of price adjustment between the two regions. Consistent with the historical narrative of a sharp decline in the volumes of grain shipped from the middle to the lower Yangtze region since 1780 (Cheung 2008; Deng 1994; Jiang 1992; Rowe 1984), Figure 3 shows that the average speed of price adjustments decreased rapidly to a nadir around the 1780s, but bounced back in the 1840s. This finding is in line with Figure 2.

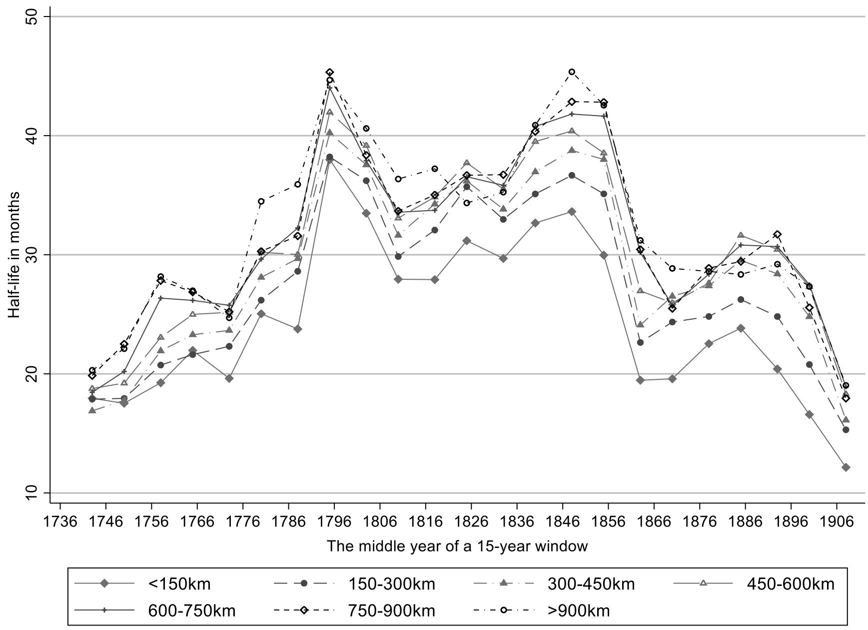

FIGURE 2

AVERAGE SPEED OF PRICE ADJUSTMENT IN CHINA'S GRAIN MARKET, BY DISTANCE, 1736–1910

Notes: The half-life of a shock is calculated based on the following formula: $\lambda = \ln(0.5)/\ln(1+\rho)$, where ρ is the coefficient of the Band-TAR model shown in Online Appendix A, and $\rho \in (-1,0)$. If prices are not cointegrated between prefectures, ρ would be 0, with half-life tend towards infinity. We therefore report the half-life of only those prefecture-pairs whose prices are cointegrated. The larger the half-life, the slower the speed of grain price adjustment, and vice versa.
Sources: Authors' own construction based on grain price data collected by Wang (2009) and the Chinese Academy of Social Science (2010).

We then use the coefficient of correlation of the first-differenced grain prices to test the price co-movement and Weir's *R* index to examine the price variance. Together, Figures 4 and 5 show the coefficient of correlation (a co-movement test) and Weir's *R* index (a variance test), respectively. In line with the finding from using the Band-TAR model, both the coefficient of correlation and Weir's *R* index declined from the eighteenth century to the first half of the nineteenth century, before rising again in the second half of the nineteenth century. Summing up, regardless of the method used, China's grain market exhibited a U-shaped pattern during the entire period of 1736–1910.

THE ASSOCIATION BETWEEN POPULATION GROWTH AND MARKET INTEGRATION

Save for a few case studies (e.g., Jacks 2004), population dynamics or specifically the Malthusian model has not figured importantly in studies

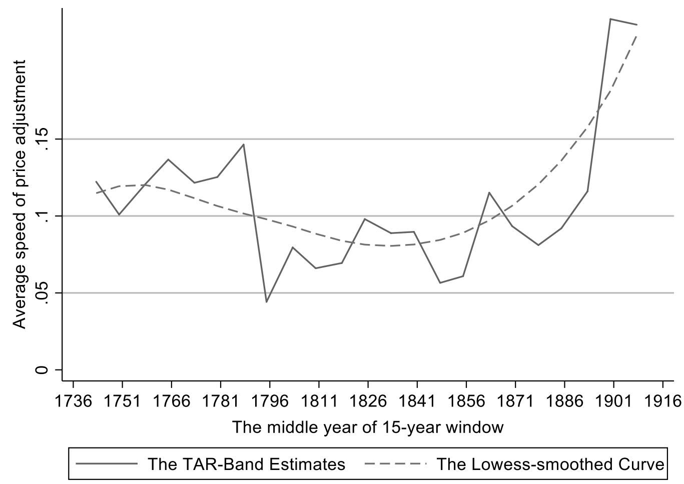

FIGURE 3
AVERAGE SPEED OF PRICE ADJUSTMENT FROM THE MIDDLE TO THE LOWER YANGZI REGION, 1736–1910

Notes: The average speed of the price adjustment is measured by the mean of the absolute value of ρ, where ρ is the coefficient of the Band-TAR model as shown in Online Appendix A.
Sources: Authors' own construction based on grain price data collected by Wang (2009) and the Chinese Academy of Social Science (2010).

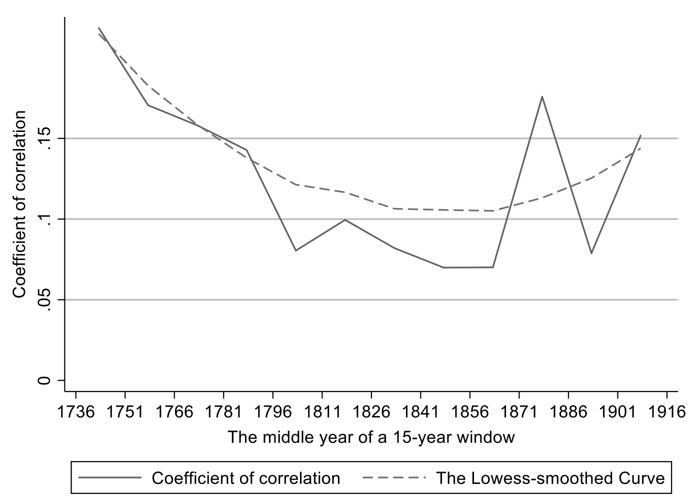

FIGURE 4
COEFFICIENT OF CORRELATION OF THE FIRST-DIFFERENCED GRAIN PRICES, 1736–1910

Notes: The coefficient of correlation of the first-differenced grain prices is calculated according to the formula $\mathrm{CV} = \frac{cov(p_i, p_j)}{\sqrt{var(p_i)var(p_j)}}$, where p is the first-differenced grain price, i indicates prefecture i, and j indicates prefecture j.
Sources: Authors' own construction based on grain price data collected by Wang (2009) and the Chinese Academy of Social Science (2010).

FIGURE 5
WEIR'S *R* INDEX, 1736–1910

Notes: Weir's *R* index is calculated according to Equation (1). The figure reports the average of Weir's *R* index by year.
Sources: Authors' own construction based on grain price data collected by Wang (2009) and the Chinese Academy of Social Science (2010).

of market integration, which conventionally depend on broadly defined costs of transportation and institutions. However, our estimates imply that market integration went into a gradual decline amid sustained population growth surged after a Malthusian positive check, the Taiping Rebellion, significantly reduced the population. This data pattern suggests that there might be an "equilibrium" point beyond which unchecked population growth would prevent the grain market from further developing. From this particular vantage point, our primary task is to examine the overall relationship between population growth and market integration for the entire period of 1736–1910. We will also identify the conventional determinants of market integration such as railroads and steamships as they are potentially confounding factors. In order to pin down the mechanism of this relationship more specifically, we divide China into regions characterized by the varying degrees of grain self-sufficiency, and as a corollary, their corresponding role in the grain trade. Our classification is based on Wang and Huang (1989), who divide Qing China into three regions depending on whether they were able to produce a surplus (which enabled them to export), just self-sufficient, or were deficient (and hence needed import from regions with a surplus) (Figure 6). By using grain price as a check, we will demonstrate later that this classification is not endogenous to population growth (see the fourth section).

FIGURE 6
MAP OF THE DEMAND AND SUPPLY OF GRAIN IN EIGHTEENTH-CENTURY CHINA

Data Source: Wang and Huang (1989).

Data Sources and Variables Definition

KEY VARIABLES OF INTEREST

Degree of market integration. Given that our key independent variable, population density, has only five data points, we construct a balanced panel of 226 prefectures and estimate market integration for the periods of 1769–1783, 1813–1827, 1844–1858, 1873–1887, and 1886–1910, respectively.

Given that transport costs are likely an increasing function of distance, it can significantly bear upon market integration (Keller and Shiue 2007; Shiue 2002). For this reason, we use the distance between two prefectures to calculate the mean adjustment speed of each prefecture as our dependent variable using the following equation,

$$MI_{it} = \sum_{j=1, j \neq i}^{226} d_{ij} * speed_{ijt} \Big/ \sum_{j=1, j \neq i}^{226} d_{ij}, \quad (2)$$

where MI_{it} is the distance weighted mean of the price adjustments between prefecture i and all other prefectures in period t; d_{ij} is the distance between prefecture i and j; $speed_{ijt}$ is the price adjustment between prefecture i and prefecture j in period t, and is seen as the measure of market integration between prefecture i and prefecture j ranging from 0, which indicates no market at all, to 1, indicating a perfectly functioning market. The mean

TABLE 2
SUMMARY STATISTICS OF VARIABLES OF INTEREST

Variable	Unit	Data Source	Obs.	Mean	S.D.
Market integration		A	1112	0.063	0.038
Population density	1 people/Km^2	B	1112	136.877	126.150
Duration of maize adoption	Year	C	1112	73.570	86.476
Temperature	Centigrade	D	1112	–0.199	0.282
Drought		E	1112	0.317	0.236
Flood		E	1112	0.459	0.266
War		F	1112	0.015	0.053
Telegraph		C	1112	0.133	0.340
Steamboats (no.)	10,000	G	1112	2.976	4.953
Railway (duration)	Year	H	1112	0.146	1.003
Multiple levy of likin tax		I	867	0.328	0.470
Taiping population loss[a]	1 people/Km^2	B	1112	45.287	98.044
Taiping population loss[b]	1 people/Km^2	B	1112	55.886	114.636

Notes: [a]Calculated as the differences in population density between 1851 and 1880; [b]Calculated as the differences between the predicted and actual population density in 1880.
Data Sources: A: Authors' estimation based on Wang (2009) and the Institute of Economics, Chinese Academy of Social Science (2010); B: Cao (2000); C: Various local gazetteers; D: Wang et al. (2007); E: CAMS (1981); F: Chen (1986); G: Nie (1983); Nie and Zhu (2002); H: Huenemann (1984); I: Luo (1936).

and standard deviations of the speed of adjustment, alongside other variables of interest, are reported in Table 2.

Population density. Constructed by Cao (2000) at the prefectural level and available for only five data points (1776, 1820, 1851, 1880, and 1910), the key independent variable is population density for the Qing dynasty. According to Cao, the average population density for China as a whole exhibited an increasing trend prior to the Taiping Rebellion and other natural calamities that occurred during the late nineteenth century but declined thereafter, before it gradually recovered during 1880–1910.

CONTROL VARIABLES

Steamboats and Waterways. Inland water networks and trade routes expanded considerably (by more than 50,000 km) during the eighteenth century, leading to a significant reduction in the cost of water transport and, accordingly, an unprecedented expansion of China's grain trade, especially large-scale and long-distance grain trade.[11]

To measure the effect of technological progress in water transport on China's grain trade, we employ the number of steamboats introduced during the second half of the nineteenth century as a proxy. Records on

[11] According to one estimate, long-distance grain trade more than tripled between the Ming and the mid-Qing eras (Fang et al. 2000; Xu and Wu 2000).

the number of steamboats used in domestic and foreign trade in China by country of origin during 1864–1910 are provided by the Chinese customs and documented in the *Historical Materials of Ship Transport in Modern China, Volume 1 & 2* (Nie 1983; Nie and Zhu 2002). Data on steamboat usage at the prefectural level are not available, but the available data reveal that on average 41,893 steamboats were deployed a year for the period of 1872–1911. Due to this limitation, we assign the value of 1 to prefectures with waterways and zero to those without one and interact steamboat with this dummy variable to measure it. The geography of waterways in China is shown in Figure A1 in Online Appendix A.

Duration of railway. While in China grain was mostly shipped by boats, we do not rule out the effect that improvements over railway may have on grain trade. To capture that effect, we employ the specific year in which a rail network was constructed in a prefecture relative to the five-time points of data on population density to proxy for its duration. The data on the railway are obtained from Huenemann (1984).

Telegraph. By speeding up the transmission of information, the telegraph could effectively improve market efficiency by leaps and bounds (Ejrnæs and Persson 2010; Federico 2007; Hoag 2006). As a Qing government-controlled corporation, the Imperial Chinese Telegraph Administration was established in 1881, but its diffusion was lackluster. For example, even by 1912, only 700 telegraph stations were available for use in China, which paled in comparison with Japan (4,657) and even Brazil (2,114), let alone Germany (46,444) and the United States (32,000) (Gu 2009). Moreover, government officials had priority in using the equipment; only when they did not need it were ordinary citizens and private businesses granted access, and at a high cost. We employ the dummy variable of whether a prefecture had ever adopted the telegraph—even though it was still a long way from becoming a popular means of communications in late Qing China—to proxy for its possible effect on market integration (Yoon 2015). The data on telegraph adoption are collected from various local gazetteers.[12]

Multiple Levies of Likin Tax. The early Qing dynasty adopted a highly centralized fiscal system, whereby nearly all revenues had to be submitted to the central coffers. But the Taiping Rebellion changed this. To suppress the rebels, the central government relied heavily on the initiatives of provincial governments to recruit their own armies, which in turn required a thorough decentralization of fiscal powers to the province chiefs to collect their own revenues. Specifically, since 1853 provinces were given the authority to collect a commodity circulation

[12] We thank Chicheng Ma for sharing the data on the telegraph.

tax, known in Chinese as *likin* tax, of which they were allowed to retain up to 80 percent and the discretion to deploy them in ways as they saw fit (Fairbank and Liu 1980; Luo 1936). Unsurprisingly, this measure became the most important source of revenue for the provincial governments, thereby providing unprecedentedly strong incentives for them to levy taxes (Shen 2011). Imposed on both shop inventories (the *in situ likin* or *zuoli*) and transported commodities (the *transit likin* or *xingli*), *likin* increased the costs of doing business; we thus expect it to be negatively associated with trade and as a corollary market integration.[13] While the effective tax rates of *likin* would be an ideal measure of this local tax, such data are not available. Thankfully, we are still able to differentiate the *intensity* of this tax based on whether it was collected just once (as in the case of Hunan Province) or multiple times (as in the case of Jiangsu Province). Given that commodity trade was more vulnerable in provinces employing multiple levies, we assign the value of 1 to provinces using a multiple-levy approach and zero to those using a single-levy tax.[14]

New World crops. The introduction of New World crops in the eighteenth and nineteenth centuries had allegedly led to a substantial increase in population and total grain output (e.g., Ho 1959), and which may thus have increased the volume of tradable grain. It is, therefore, necessary to control for the effect of New World crops on market integration. Evidence suggests that maize was likely the most popular New World crop the Chinese had adopted (the other two were the potato and sweet potato)—a crop that had contributed to an increase of nearly 19 percent of the Chinese population during the period of the crop's diffusion (1776–1900) (Chen and Kung 2016). We thus control for the adoption of maize to proxy for the effect of New World crops on market integration in late imperial China. Moreover, given that maize adoption depended on the suitability of land and other characteristics, it is necessary to control also for the interaction of land suitability for growing maize and the time since maize was adopted in a prefecture to capture its time-varying effect.

The data on crop suitability for growing maize are obtained from the Global Agro Ecological Zones (GAEZ) 2002 database provided by the Food and Agriculture Organization (FAO) (Gaez 2002).[15] The duration

[13] To collect the transit *likin,* local governments set up tax stations along the major trade routes. Historians note that the transit *likin* was more detrimental to trade than the *in situ likin* because it delayed shipments, ruined ferry schedules, both of which led to a reduction in the volume of trade (Mann 1987). More generally, the consensual view is that the abolition of the *likin* had increased China's market integration in the 1930s (Feng 2011; Zhao, Zhao, and Dou 2011).

[14] While data on annual *likin* revenues collected by each province are available, it is not a good measure as it was directly determined by trade volumes, which are highly correlated with the dependent variable of market integration.

[15] We also ran the regressions using the Caloric Suitability Index (CSI) proposed by Galor and Ozak (2015), but the results remain the same, and so we do not report them separately.

of cultivation is measured by deducting the year of adoption from the years of the available population estimates, namely 1776, 1820, 1851, 1880, and 1910. The timing of adopting maize at the prefectural level is provided in Chen and Kung (2016).

War. It is also necessary to control for the possible effects of war, which typically are associated with a significant loss of lives, the destruction of cultivated land, and damage to transport and storage infrastructure, all of which are likely to affect market integration (Jacks 2006). The data on war is obtained from the *Chronology of Warfare and Natural Calamity in Dynastic China* (*zhongguo lidai tianzai renhuo biao*) (Chen 1986). Based on various historical records, Chen (1986) systematically collected information on wars (including their intensities) from 246 BC to 1911 AD. Based on this information, we first calculate the incidence of war in a prefecture during each of the five periods of market integration, namely 1769–1783, 1813–1827, 1844–1858, 1873–1887, and 1886–1910, and then divide this number by 15 (the interval) to obtain an average measure.

Weather extremities and temperature. We control for the effect of climate on market integration, given that climate could bear directly upon agricultural output and, therefore, grain supply. To proxy for the effect of climate, we use two measures—respectively, deviations from the average precipitation and temperature. The data on rainfall are obtained from the *Yearly Charts of Dryness/Wetness in China for the Last 500-years Period* (*zhongguo jin wubainian hanlao fenbu tuji*), compiled by the Chinese Academy of Meteorological Science (CAMS 1981) based on more than 2,200 issues of local annals. The CAMS data measures rainfall using an ordinal scale ranging from 1 (indicating extreme flood) to 5 (indicating extreme drought); we adopt the midpoint, 3, to indicate normal rainfall. We further construct two variables to proxy for the extremes in precipitation, namely flood and drought, based on rainfall records that deviate from the midpoint or normal rainfall. We then calculate the average extent of flood and drought during each of the five periods and use these figures to construct the proxy for precipitation extremes for each prefecture that correspond to the sub-periods of market integration.

In the case of temperature, the extreme temperature is constructed using *Temperature Reconstruction in China for the Past 1000 Years* (Wang et al. 2007), where, as with precipitation, the extreme temperature is measured based on deviations from the average temperature of the previous one thousand years. Given that extreme temperature is calculated at the (larger) regional level and on a decadal basis, to match with our data on market integration, which is based on prefecture and 15 years, we reconstruct the pertinent data ourselves (details of the reconstruction are provided in Online Appendix B and Figure B1 in Online Appendix B).

Treaty ports. Last but not least, we control for the effect of economic openness on market integration. After the First Opium War (1840–1842), China was forced to sign a number of treaties allowing foreigners to enter via the so-called treaty ports. A total of 112 treaty ports had been opened by the time the Qing dynasty (1644–1911) came to an end. Limited evidence suggests that treaty ports had led to considerable growth in domestic trade (Keller, Andrés-Santiago, and Shiue 2017) and developed faster after 1978 (Jia 2014). To control for the effect of economic openness on market integration, we use the dummy variable of whether a prefecture became a treaty port in a specific year as a proxy.

Table 2 summarizes the descriptive statistics of the variables of interest.

Baseline Estimation

We begin by demonstrating the negative correlation between population and market integration in the aggregate.[16] Figure 7 shows the relationship between the total population in China and the speed of grain price adjustment estimated using the Band-Tar model across all prefecture pairs (refer to Online Appendix A for details). The negative relationship provides suggestive evidence, but to precisely show this, we turn to regression estimates. The association between population density and market integration in late imperial China is estimated using a fixed-effects model, in which we control for a number of observable characteristics that may be correlated with market integration:

$$MI_{it} = \beta * popden_{it} + X_{it} * \gamma + \alpha_i + \delta_t + trend_{pt} + \varepsilon_{it}, \quad (3)$$

where i denotes a prefecture and t indexes the time periods of 1776, 1820, 1851, 1880, and 1910, respectively. The dependent variable, MI_{it}, denotes the degree of market integration, which is measured by the average *speed* of price adjustment between prefecture i and all other prefectures in period t. The key explanatory variable of interest, $popden_{it}$, stands for population density in prefecture i in period t. In addition to population density, other factors such as economic openness, technical progress, political and climatic disruptions (including warfare) may all bear upon market integration significantly and therefore should be accounted for in the regression analysis. Denoted by X_{it}, we employ treaty ports as a proxy for economic openness; the adoption of maize (a New World crop), the total number of steamboats (and its interaction with waterways) and

[16] Replication files can be found in Gu and Kung (2021).

FIGURE 7
POPULATION AND MARKET INTEGRATION IN LATE IMPERIAL CHINA, 1736–1910

Notes: Market integration is measured by the mean of the absolute value of ρ, where ρ is the coefficient of the Band-TAR model as shown in Online Appendix A.
Sources: Market integration is estimated by the authors based on grain price data collected by Wang (2009) and the Chinese Academy of Social Science (2010). The data on population is collected by Liang (1980).

railroads, as proxies for technical progress; the *likin* tax as a proxy for political barriers; the incidence of warfare as a proxy for possible disruptions due to war; and droughts and floods and deviations from average temperature as proxies for extreme weather, respectively. In addition, we control for the time-invariant, prefecture-specific fixed effects (denoted by α_i) such as land quality and topography, as they may be correlated with population density. We also include period fixed effects, denoted by δ_t, to control for all period-varying factors that may affect market integration. Finally, we also control for the effect of prefecture-specific time trend, $trend_{pt}$, in one of the regressions to account for the possibility that the market may have developed across prefectures in varying degrees. The error term is denoted by ε_{it}, and β is the parameter of interest.

Disproportionate population growth in some prefectures may directly affect their neighboring prefectures via trade, spillovers in price shock, migration, and so on. Omitting this spillover effect would yield biased estimates of the effect of population growth on market integration. To deal with this, we thus estimate standard errors robust to spatial correlation up to 200 km and 500 km based on Conley (1999). We will thus present both robust standard errors and spatially correlated standard errors in our main results.

Panel A of Table 3 reports the estimation results. Column (1) of Table 3 reveals that there is indeed a significantly negative association between population density and market integration. In terms of magnitude, a 100 percent increase in population density will lead to a 0.025 decrease in market integration, which is about 40.2 percent (0.025/0.063) when evaluated at the mean of market integration in Qing China. In the light of the two-fold increase in population during 1741–1851, market integration in this period decreased by roughly 80.4 percent. To further facilitate interpretation, we report standardized (beta) coefficients in row 2. We find that a one standard deviation increase in population density will lead to a 0.6 decrease in standard deviation in market integration.

We then control for the effect of economic openness (treaty ports) and technological progress (steamboat and its interaction with waterways, railroads, and telegraph) (Column (2)).[17] Both the level of significance and the magnitude of population density remains stable. Consistent with Perkins (1969), increasing use of the steamboat, as anticipated, leads to an increase in market integration; this appears to be especially the case in prefectures well served by waterways.

For both Europe and India, railroad expansion in the nineteenth century improved market integration considerably (Andrabi and Kuehlwein 2010; Burgess and Donaldson 2017, Jacks 2006). However, the same does not apply to late imperial China, as the railway had yet to become a major mode of transport (for grain at least) even during the final years of the dynastic rule (Yan 1955).[18]

Measured by whether a prefecture is a designated treaty port, economic openness has no significant effect on market integration. While Columns (2)–(5) show that there is a (marginally) significantly negative relationship between treaty ports and market integration (at the 10 percent level), it disappears after we control for the multiple levies of *likin* tax in Column (6), which is not unreasonable given that grain trade accounted for a mere 5.9 percent of the total value of imported commodities during the last few decades of Qing China (Yan 1955).

Columns (3)–(5) further control for the effect of maize adoption, weather conditions (flood, drought, and temperature), and wars on market integration. Again, both the level of significance and magnitude

[17] We have replaced the number with tonnage to check the robustness, and the result is similar (hence not separately reported).

[18] In 1910, the Chinese rail network was merely one-sixth the size of its Indian counterpart (Andrabi and Kuehlwein 2010; Huenemann 1984). Even in the United States, where the railway had played a sharply more salient role in spurring economic growth, Fogel (1964) similarly found that canals contributed more to growth than did railroads.

TABLE 3
DETERMINANTS OF MARKET INTEGRATION IN CHINA, 1776–1910

Variables	(1)	(2)	(3)	(4)	(5)	(6)	(7)
Panel A							
Population density (*ln*)	–0.02547	–0.02526	–0.02481	–0.02469	–0.02482	–0.02273	–0.02247
Standardized beta (β)	–0.60063	–0.59452	–0.59383	–0.59051	–0.59369	–0.66739	–0.67512
(Robust standard errors)	(0.00675)***	(0.00649)***	(0.00645)***	(0.00653)***	(0.00658)***	(0.00616)***	(0.00614)***
(Conley spatial errors 200km)	[0.00487]***	[0.00470]***	[0.00467]***	[0.00462]***	[0.00465]***	[0.00541]***	[0.00541]***
(Conley spatial errors 500km)	[0.00544]***	[0. 00513]***	[0.00510]***	[0.00481]***	[0.00481]***	[0.00566]***	[0.00570]***
Total number of steamboat		0.00080	0.00118*	0.00105	0.00083	0.00483***	0.00488***
		(0.00064)	(0.00066)	(0.00067)	(0.00070)	(0.00091)	(0.00092)
Total Number of Steamboat*Waterway		0.00159**	0.00159**	0.00154**	0.00159**	0.00128*	0.00126*
		(0.00067)	(0.00067)	(0.00067)	(0.00068)	(0.00073)	(0.00074)
Duration of railroads		–0.00117	–0.00116	–0.00138	–0.00140	0.00020	0.00022
		(0.00157)	(0.00157)	(0.00155)	(0.00157)	(0.00252)	(0.00251)
Telegraph		0.00345	0.00348	0.00302	0.00303	–0.00035	–0.00025
		(0.00765)	(0.00763)	(0.00751)	(0.00751)	(0.00785)	(0.00790)
Treaty ports		–0.01149*	–0.01147*	–0.01092*	–0.01056*	–0.00925	–0.00984
		(0.00613)	(0.00619)	(0.00618)	(0.00624)	(0.00648)	(0.00656)
Maize adoption			–0.00210	–0.00207	–0.00200	–0.00134	–0.00142
			(0.00153)	(0.00153)	(0.00153)	(0.00157)	(0.00158)
Multiple Levy*Post1853						–0.01753***	
						(0.00641)	
Flood	No	No	No	Yes	Yes	Yes	Yes
Drought	No	No	No	Yes	Yes	Yes	Yes
Temperature	No	No	No	Yes	Yes	Yes	Yes
War	No	No	No	No	Yes	Yes	Yes
Observations	1,112	1,112	1,112	1,112	1,112	867	867
R-squared	0.70413	0.71101	0.71239	0.71506	0.71535	0.69372	0.68947
Number of Prefectures	226	226	226	226	226	177	177
Panel B							
Lagged population density (ln)	–0.00556	–0.00699	–0.00662	–0.00693	–0.00691	–0.00529	–0.00533
(Robust standard errors)	(0.00346)	(0.00344)**	(0.00338)*	(0.00342)**	(0.00340)**	(0.00331)	(0.00313)*
(Conley spatial errors 200km)	[0.00234]**	[0.00227]***	[0.00222]***	[0.00222]***	[0.00220]***	[0.00216]**	[0.00201]***
(Conley spatial errors 500km)	[0.00285]*	[0. 00264]***	[0.00260]**	[0.00243]***	[0.00239]***	[0.00226]**	[0.00207]***
Observations	876	876	876	876	876	680	680
R-squared	0.73911	0.75071	0.75300	0.75928	0.75994	0.76130	0.75734
Number of prefectures	226	226	226	226	226	177	177

Notes: Robust Standard errors in parentheses; *** p < 0:01, ** p < 0:05, *p < 0:1; Constant terms are not reported. Both prefecture and period fixed effects, and prefecture-specific time trend are controlled for.
Source: See the text.

of population density remains stable, whereas maize adoption has no direct effect on market integration.[19]

Column (6) examines the hypothesized negative effect of the *likin* tax. As this tax was implemented in 1853, we interact it with a time dummy of post-1853. Compared to regions where the *likin* tax is collected just once, the multiple levying of this tax has the effect of reducing market integration by 0.018 after 1853 (significant at the 1 percent level), which, when evaluated at the mean of market integration, amounts to a sizeable 27.8 percent. However, the inclusion of this variable in the model increases the magnitude of population density from –0.025 to –0.023, which decreases the overall effect of population density on market integration from 40.2 to 36.5 percent. But since the method of levying *likin* tax is not clearly known in some provinces such as Henan, Shanxi, Yunnan, and Zhili, we drop those provinces from our sample, and the number of observations is thus reduced from 1,112 in Column (5) to 867 in Column (6). To address the issue of sample selection bias caused by missing observations of *likin* in these provinces, Column (7) re-estimates the relationship between population density and market integration using the smaller sample in Column (6) and obtains basically the same result. The coefficient of population density remains statistically significant at the 1 percent level and with a similar magnitude in the estimates for which all covariates are controlled. Overall, the findings in Table 3 confirm that the association between population density and market integration is not only statistically significant but also economic meaningful; a 100 percent increase in population density will lead to a 0.023–0.025 reduction in market integration, which is about 36.5–40.2 percent when evaluated at the mean of market integration in late imperial China.

To exclude the possible reverse causality of better-integrated markets leading to increased population density (Albers, Pfister, and Uebele 2018), we use the lagged term of population density as our independent variable to re-examine the relationship. In other words, the log of the 1820 population is used in the 1851 panel. Note that we must drop the 1776 panel as there is no estimate for the prefecture-level population before then. As reported in Panel B of Table 3, the result of a negative coefficient remains consistent, although the coefficient for the population is now smaller in magnitude.[20]

[19] The finding of maize accounting for a near 19 percent increase in the Chinese population during 1776–1910 but failing to raise per capita income and urbanization (Chen and Kung 2016) is consistent with these results.

[20] As robust standard errors do not account for the spillover effect of population growth on neighboring regions via grain trade, price arbitrage, and perhaps even migration, there is likely a loss of precision in some estimates in Panel B.

https://doi.org/10.1017/S0022050721000437 Published online by Cambridge University Press

In addition to reverse causality, one may also be concerned that the summary measure of market integration incorporates the distance between two trading prefectures, which is highly correlated with transportation costs. Moreover, there may also be the concern that there are only five data points for population, so we are unable to make use of the price data more fully in the regressions. To allay these concerns, we consider a different type of regression in which we make use of the price gap between prefecture pairs—specifically the importers and exporters—as the dependent variable and take the natural log (ln $(p_{i,t}/p_{j,t})$ or $\ln p_{i,t} - \ln p_{j,t}$), where p_{it} and p_{jt} denote the prices respectively of importer i and exporter j in period t. According to the law of one price, prices for the same good sold in two different markets should be identical if those markets are well integrated. Even where there are transaction costs, the prices for the same good in the two markets will reach an equilibrium level after adjusting for temporary shocks. That is, in a set of perfectly integrated markets, ln $(p_{i,t}/p_{j,t})$ should be a positive constant; the smaller ln $(p_{i,t}/p_{j,t})$ is, the more integrated the markets are. As the dependent variable now assumes the form of prefecture pairs (of an importer pairing with an exporter), the independent variables in Equation (3) also take the form of prefecture pairs. Specifically, population density now refers to its average between the importer and exporter. To illustrate, if the population density is 200 people per square kilometer in an exporting prefecture and 100 in an importing prefecture, then the average between this particular pair is 150 people per square kilometer. Reported in Columns (1)–(7) of Table 4, the regression confirms a negative relationship between population density (measured by the average between pairs of importing and exporting prefectures) and market integration (measured by the log of the price gap between the importing and exporting prefectures), reaffirming our earlier finding.

To verify the demographic role of the Taiping Rebellion in *reversing* the market integration, in Online Appendix C, we conduct a counterfactual analysis of how recovery from population loss may lead to more integrated grain markets by exploiting the historical context of China in late imperial times using a difference-in-differences (DID) analysis. We show that prefectures exposed to the Taiping Rebellion, and hence suffered population losses, ended up with a higher level of market integration. These results shown in Online Appendix C further imply that the Taiping Rebellion released the mounting population pressure built up beforehand.

THE MECHANISM BEHIND THE ASSOCIATION

We now examine the mechanism through which population growth halted market integration from around 1736 onwards by dividing China

TABLE 4
ALTERNATIVE MEASURE OF MARKET INTEGRATION, BY PREFECTURE PAIR

	The Log Grain Price Differentials between Prefecture Pairs						
Variables	(1)	(2)	(3)	(4)	(5)	(6)	(7)
Average population density between prefecture pairs	0.0426*** (0.00377)	0.0453*** (0.00379)	0.0417*** (0.00377)	0.0279*** (0.00391)	0.0290*** (0.00391)	0.0230*** (0.00390)	0.0314*** (0.00392)
Year*log of Distance	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Total number of steamboat		Yes	Yes	Yes	Yes	Yes	Yes
Total Number of Steamboat*Waterway		Yes	Yes	Yes	Yes	Yes	Yes
Railroads		Yes	Yes	Yes	Yes	Yes	Yes
Telegraph		Yes	Yes	Yes	Yes	Yes	Yes
Treaty ports		Yes	Yes	Yes	Yes	Yes	Yes
Maize adoption			Yes	Yes	Yes	Yes	Yes
Flood				Yes	Yes	Yes	Yes
Drought				Yes	Yes	Yes	Yes
Temperature				Yes	Yes	Yes	Yes
War					Yes	Yes	Yes
Multiple Levy*Post1853						Yes	
Observations	133,402	133,402	133,402	123,157	123,157	118,286	118,286
R-squared	0.105	0.120	0.121	0.153	0.156	0.169	0.162
Number of prefecture pairs	43,631	43,631	43,631	42,579	42,579	39,980	39,980

Notes: Robust standard errors in parentheses; *** p<0.01, ** p<0.05, * p<0.1; Constant terms not reported. Both prefecture pairs and period fixed effects are controlled for.
Source: See the text.

into regions based on whether or not they were able to produce a grain surplus and trade. The grain-surplus prefectures were heavily involved in grain crop production, whereas the grain-deficit prefectures were specialized in cash crop production; hence more commercialized and enjoyed a higher standard of living.[21] To ensure that the classification of prefectures is not correlated with, and thus endogenous to, population growth, we use grain price as a check. Specifically, we plot the grain price trend for the period in Figure D1 in Online Appendix D, which shows that grain price in the deficit prefectures was higher than that in the surplus prefectures; it was lowest in the self-sufficient regions and weakly correlated with those in the other two regions.

Regional Patterns of the Association between Population Growth and Market Integration

The results of the estimates, based on Equation (3) with sample restrictions based on Wang and Huang (1989), are reported in Table 5. Columns (4)–(6) of Table 5 control for the effect of *likin* tax (*Multiplelevy*Post1853*), whereas Columns (1)–(3) do not. The estimate in Column (1) suggests that a 100 percent increase in the population

[21] Prefectures that specialized in the production of tea and silk, for example, were typically richer (Li 2000).

https://doi.org/10.1017/S0022050721000437 Published online by Cambridge University Press

TABLE 5
EFFECT OF POPULATION GROWTH ON MARKET INTEGRATION IN CHINA, BY REGIONS, 1776–1910

Variables	Grain-Surplus Region (1)	Self-Sufficient Region (2)	Grain-Deficit Region (3)	Grain-Surplus Region (4)	Self-Sufficient Region (5)	Grain-Deficit Region (6)
Population density (*ln*)	–0.03000	–0.0671	–0.0123	–0.03106	–0.04487	–0.01156
(Robust standard errors)	(0.01104)***	(0.0253)**	(0.00988)	(0.01151)***	(0.02893)	(0.01007)
(Conley spatial errors, 200km)	[0.00746]***	[0.0169]***	[0.00771]	[0.00777]***	[0.01819]**	[0.00780]
(Conley spatial errors, 500km)	[0.00810]***	[0.0143]***	[0.00807]	[0.00831]***	[0.01367]***	[0.00805]
Multiple levy*Post1853	No	No	No	Yes	Yes	Yes
Other controls[1]	Yes	Yes	Yes	Yes	Yes	Yes
Observations	364	154	349	364	154	349
R-squared	0.81447	0.74500	0.70600	0.81757	0.76382	0.70646
Number of prefectures	76	31	70	76	31	70

Notes: [1]Control variables include the total number of steamboats and its interaction with waterway, duration of railway, telegraph, maize adoption, flood, drought, temperature, war, prefecture, and period fixed effects, and prefecture-specific time trend. Robust standard errors in parentheses; *** $p < 0.01$, ** $p < 0.05$, *$p < 0.1$; Constant terms are not reported.
Source: See the text.

density within the grain-surplus regions will lead to a 0.030 decrease in market integration there, which is about 47.6 percent (0.030/0.063) when evaluated at the mean of market integration in these regions. The pertinent coefficient remains statistically significant after controlling for *likin* tax; the larger magnitude of –0.031 is now translated into a 49.2 percent decrease in market integration in the grain-surplus regions (Column (4)).

By contrast, the coefficient of population density in the grain-deficit regions is statistically insignificant (Column (3)), suggesting that population growth in these regions does not affect market integration, consistent with the above finding. And the result does not change even after we control for the *likin* tax (Column (6)). What this may imply is that although the demand for grain in the grain-deficit regions increased with population growth, they were constrained by the supply response from the grain-surplus regions.

As for the self-sufficient regions, the coefficient of population density is consistently negative, but whose association is rendered weaker after controlling for *likin* tax (compare Column (2) with Column (5)).[22] Given that the coefficients in Columns (2) and (5) are substantially larger than those in (1) and (4), we suspect the former estimates may be driven by extreme values. To find out, we remove those prefectures with the highest three values of the dependent variable one by one. After dropping those prefectures with the two highest values, we indeed find that the estimates

[22] Compared to the other two regions, the volume of the grain trade in the self-sufficient region was typically smaller, hence the speed of grain price adjustment in those areas would also be slower. A *likin* tax imposed in the self-sufficient region would have the additional effect of further denting the already smaller amount of trade, rendering the effect of population growth on the speed of grain price adjustment even slower to the point of insignificance.

become not only smaller but basically insignificant (Columns (3)–(4) of Table E1 in Online Appendix E), confirming that estimates for the self-sufficient regions are indeed driven by extreme values.

An important question concerning our finding of grain supply constraining trade is whether corroborating historical evidence exists. While the population in China was growing rapidly especially during the eighteenth century, grain production had also increased, thanks to the growing diffusion of New World crops, and accordingly, an expansion of cultivated land, intensified cropping patterns, increased fertilizer use, and other technological improvements associated with grain crop production (Perkins 1969). Nonetheless, existing evidence suggests that on balance, available supplies of food per person decreased despite production increases (Guo 1994; Shi 1989, 2011, 2012; Zhang 1991). According to one estimate, for example, although China's total grain output rose by 44.7 percent between 1720 and 1850 (from 127.05 to 183.7 billion kilograms), grain output per capita dropped by 58.3 percent during the same period (from 977.5 to 408 kilograms) (Shi 2012). This overall decline in per capita grain supplies is further borne out by the notable decline in the long-distance grain trade in the same period along the major trade routes of the Yangtze River (in the south), the Huai River (in the north), and the Grand Canal (linking the north and the south) (Cheung 2008; Deng 1994; Jiang 1992; Rowe 1984). Accordingly, customs revenues, collected based on long-distance trade, also declined in tandem during the 1788–1812 period (Fan 1993).

Effect of Population Growth on Grain Trade

We now extend our analysis to examine how population growth in the importing and exporting regions, respectively, affected market integration. In particular, we want to verify that market integration should decline only in the grain-surplus regions. However, since data on the volume of the grain trade in late imperial China are not available, we can only employ data on the *speed* of grain price adjustment to be our dependent variable.

In addition to examining the effect of population growth on inter-provincial grain trade, we also examine its effect on short-distance or intra-provincial grain trade within a single province, given that short-distance grain trade accounted for a significant share of overall grade trade according to one estimate (Wu and Xu 2000).[23] In this context, we

[23] Going by their estimate, as much as 80 percent of total grain was traded over short distances. This was particularly the case in the inland prefectures, where poor river transportation rendered long-distance grain trade prohibitively costly (Keller and Shiue 2007).

https://doi.org/10.1017/S0022050721000437 Published online by Cambridge University Press

thus examine four kinds of grain trade, viz., interprovincial grain trade between the grain-surplus and grain-deficit regions, and intra-provincial grain trade within the grain-surplus, grain-deficit, and self-sufficient regions, respectively, based on the following specification:[24]

$$Ln(speed_{ijt}) = \beta_i * Ln(popden_{it}) + \beta_j * Ln(popden_{jt}) + \gamma_i * Ln(X_{it}) + \gamma_j * Ln(X_{jt}) + \alpha_{ij} + \delta_t + \varepsilon_{it}, \quad (4)$$

where $speed_{ijt}$ denotes the speed of price adjustment from prefecture j to prefecture i in period t, and where prefecture j is a grain exporter and prefecture i a grain importer, respectively. To identify the importers and exporters we follow our strategy of identifying the grain-deficit and grain-surplus prefectures by defining prefectures with a higher and a lower grain price as importers and exporters, respectively; that is, $p_{it} > p_{jt}$. To proxy for the size of the market, we employ population density in prefecture i and that in prefecture j in period t ($popden_{it}$ and $popden_{jt}$). In principle, as population in prefecture i grows, it will need to import more grain, in which instance the speed of price adjustment is expected to increase.[25] In contrast, population growth in prefecture j will reduce the volume of tradable grain, which will therefore reduce the speed of price adjustment between the two prefectures. The vectors of covariates for prefecture i and prefecture j are denoted by X_{it} and X_{jt}, respectively, which are essentially the same as in Equation (3); a_{ij} denotes prefecture-pair fixed effects, which are included to capture the time-invariant prefecture-pair characteristics that may be related to population density and the speed of grain adjustment such as distance and waterways; and δ_t captures the period fixed effects that may affect the adjustment of grain prices. As Equation (4) assumes a panel data structure, the distance variable (between two trading prefectures) is automatically dropped. The error term is denoted by ε_{it}. In Equation (4), the error term ε_{it} is spatially correlated since each pair-wise observation on the speed of price adjustment, $speed_{ijt}$, belongs to two distinct groups—the exporting prefecture j and the importing prefecture i. To overcome the problem of spatial correlation, we cluster the standard errors at each node of the pair using the two-way clustering of the standard errors proposed by Cameron, Gelbach, and Miller (2011). The parameters of our interest are β_i and β_j.

[24] In this model, the basic unit of analysis is a prefecture-pair consisting of an importer and an exporter. About 2.1 percent of the prefecture pairs were dropped because these pairs contain observations of fewer than 80.

[25] While population trends are slow-moving, an increase in the volume of trade effectively creates more arbitrage opportunities for grain traders, thereby speeding up the process of price adjustments. This has the virtuous effect of reducing the marginal cost of grain trade (Ejrnæs, Persson, and Rich 2008).

TABLE 6
THE EFFECT OF POPULATION GROWTH ON THE SPEED OF GRAIN PRICE ADJUSTMENT, 1776–1910

Variable	Inter-Provincial Trade			Intra-Provincial Trade		
	From Grain-Surplus to Deficit-Region (1)	From Grain-Surplus to Deficit-Region (Subsample)[1] (2)	From Grain-Surplus to Deficit-Region (Subsample)[2] (3)	Within Grain-Deficit Region (4)	Within Grain-Surplus Region (5)	Within Self-Sufficient Region (6)
Population density in importers (*ln*)	–0.24102	0.67930	0.28783	1.46361	1.69935**	0.55309
	(0. 66271)	(0.84537)	(0. 84158)	(0.96356)	(0. 74473)	(2.54247)
Population density in exporters (*ln*)	–1.66343***	–1.66656***	–1.16887†	–0.71204	–1.75398**	–0.52886
	(0. 54244)	(0.56539)	(0. 72142)	(0. 99146)	(0.72068)	(2.0310)
Number of observations	31,943	8,669	25,074	5,772	5,944	1,756
Number of importers	91	32	91	91	107	31
Number of exporters	106	57	106	91	107	31

Notes: Dependent variable is the speed of price adjustment from exporting to importing prefectures. Control variables include the total number of steamboats and its interaction with waterway, duration of railway, flood, drought, temperature, war, maize adoption, and period and prefecture-pair fixed effects. [1]The interprovincial trade subsample includes prefecture-pairs of the exporting provinces of Anhui, Hunan, Jiangxi, and Sichuan, and prefecture-pairs of the importing provinces of Fujian, Jiangsu, and Zhejiang. [2]This subsample includes all interprovincial trade observations except for those in Column (2). Two-way clustered standard errors in parentheses; *** p < 0.01, ** p < 0.05, *p < 0.1; †p=0.105; Constant terms are not reported.
Source: See the text.

In Table 6, we estimate the effect of population density in both importing and exporting prefectures without controlling for the effect of the type of *likin* tax employed. In the case of interprovincial trade between the grain-surplus and grain-deficit regions, we assume that grain would be shipped from the surplus region to the deficit region, but not vice versa. Following this reasoning, importers are thus located in the grain-deficit regions, whereas exporters are in the grain-surplus regions, respectively (Columns (1)–(3)).

Column (1) examines the effect of the population density of the exporting and importing regions on the speed of price adjustment between the grain-surplus and grain-deficit regions. It shows that population growth in the exporting prefectures significantly reduces the speed of grain price adjustment between the two regions. In terms of magnitude, a 1 percent increase in the population density of the exporting prefectures will lead to approximately a 1.6 percent decrease in the speed of price adjustment between the grain-surplus and the grain-deficit regions. By contrast, population growth in the grain-deficit regions does not affect the speed of grain price adjustment. Together, these results suggest that population growth in the grain-deficit regions—which increases the demand for traded grain—is *not* a sufficient condition for markets to become more integrated into these regions, due presumably to the supply constraint in the grain-surplus regions.

To check robustness, we run the same regression on a smaller sample, based on the historical evidence that interprovincial grain trade was conducted primarily between the grain-surplus provinces of Anhui, Hunan, Jiangxi, and Sichuan, on the one hand, and the deficit provinces of Fujian, Jiangsu, and Zhejiang on the other (Fang et al. 2000; Jiang 1992; Wang 1992), and obtain a similar result (Column (2)).[26]

This finding is of particular importance against the backdrop of declining grain trade within the Yangtze region, as some historians have noted (e.g., Cheung 2008; Deng 1994; Jiang 1992; Rowe 1984). By at least one account, the lower Yangtze region was actively engaged with the middle and upper regions in the long-distance trade of grain for manufactured goods such as cloth up until the middle of the eighteenth century. But with the population growing rapidly in the middle and upper Yangtze, the returns to agriculture were sharply diminishing, and the development of a proto-industry in sectors such as cloth, sugar, paper, and iron, intensified. This led to a noticeable decline in the middle and upper regions' export of grain and other crops to, and their reduced import of manufactured goods from, the lower Yangtze during 1750–1850 (Pomeranz 2000a, 2000b).[27] While Skinner (1977a, 1977b) sees the Chinese economy as only weakly integrated before the advent of railroads and steamships, von Glahn (2016, p. 334) views China as having achieved an "impressive degree of interregional trade and market integration" already by the early Qing. Evidence based on grain market integration suggests that it did reach a peak in 1736 (roughly the first 100 years of the dynasty) before it went into decline. However, we diverge from his opinion that the reversal of a growing trend of market integration was caused by the "onset of political and economic crisis in the nineteenth century" (von Glahn 2016, pp. 334–35); instead, we argue that unchecked population growth was the root cause of these crises. What we are unable to further confirm, however, is whether the decline in trade was due largely to the growing demographic pressure or to the rising income opportunities brought about by family specialization and import substitution in the first place, as families in the grain-surplus regions shifted away from specialization in grain production and export. We leave this topic to future research.

To rule out the possibility that the significant effect of population density on grain trade between the grain-surplus and grain-deficit regions

[26] Amounting to 0.9 billion kilograms, annual grain trade among these provinces accounted for up to half of the long-distance grain trade (Fang et al. 2000). The amount of grain transported along this trade route every year was even larger. According to one estimate, it ranged between 1.05–1.41 billion kilograms, which accounted for one-third to one-half of the total grain transported (Guo 1994).

[27] Due perhaps to wider adoption of New World crops, it is likely that the grain-surplus region experienced a faster increase in its food supply than the grain-deficit region, leading to faster population growth for the former region as a whole. We agree with an anonymous referee that in future research, it would be interesting to examine the underlying reasons behind the decline in trade between the major regions of the active grain trade.

TABLE 7
ROBUSTNESS OF THE EFFECT OF POPULATION GROWTH ON THE SPEED OF GRAIN PRICE ADJUSTMENT, 1776–1910

	Inter-Provincial Trade	Intra-Provincial Trade	
Variable	From Grain-Surplus to Deficit-Region (1)	Within Grain-Deficit Region (2)	Within Grain-Surplus Region (3)
Panel A: Jiang's (1992) Classification			
Population density in importers (*ln*)	–0.55673	1.24205	1.89849**
	(0.62599)	(0.77486)	(0.97726)
Population density in exporters (*ln*)	–3.80481***	–0.69407	–2.11810**
	(0.58503)	(0.76392)	(0.85367)
Number of observations	38,739	7,500	4,216
Number of importers	127	127	94
Number of exporters	71	127	94
Panel B: Deng's (1994) Classification			
Population density in importers (*ln*)	–0.23826	1.22280	1.85415**
	(0.71164)	(0.98855)	(0.73124)
Population density in exporters (*ln*)	–2.60551***	–0.62594	–1.73148**
	(0.57090)	(0.89324)	(0.69437)
Number of observations	42,109	5,340	6,376
Number of importers	81	81	117
Number of exporters	117	117	117
Panel C: Wu's (2001) Classification			
Population density in importers (*ln*)	0.46558	1.05907	2.11497**
	(0.67525)	(0.78851)	(0.95180)
Population density in exporters (*ln*)	–3.62692***	–0.65215	–2.03617**
	(0.54603)	(0.77058)	(0.82156)
Number of observations	40,751	7,068	4,648
Number of importers	117	117	81
Number of exporters	81	117	81
Panel D: Excluding Henan, Hubei, Shanxi, Shandong Provinces			
Population density in importers (*ln*)	–0.82667	1.222780	1.89847*
	(0.75578)	(0.98855)	(0.97726)
Population density in exporters (*ln*)	–3.731089***	–0.62595	–2.11810**
	(0.63553)	(0.89324)	(0.85367)
Number of observations	26,325	5,340	4,216
Number of importers	81	81	71
Number of exporters	71	81	71
Panel E: Employing Another Classification			
Population density in importers (*ln*)	–0.14379	1.22280	1.65685*
	(0.83166)	(0.98855)	(0.85919)
Population density in exporters (*ln*)	–2.01434***	–0.62595	–1.46229*
	(0.60073)	(0.89323)	(0.81286)
Number of observations	38,041	5,340	5,636
Number of importers	81	81	117
Number of exporters	117	81	117

Notes: Dependent variable is the speed of price adjustment from the exporting to the importing prefectures. Control variables include the total number of steamboats and its interaction with waterway, duration of railway, flood, drought, temperature, war, and maize adoption, and period and prefecture-pair fixed effects. Since there is no dispute in self-sufficient region, we here do not estimate the intra-provincial trade within self-sufficient regions. *** p < 0:01, ** p < 0:05, *p < 0:1; Constant terms are not reported.
Source: See the text.

was confined to only the Yangtze region, we drop those observations associated with this sub-sample and run the regression again in Column (3), and confirm that only the coefficient of the exporting prefectures is significantly negative. Although it is statistically not as significant and its magnitude is smaller than that in Column (1) (–1.169 vs. –1.663), it reaffirms the result that the effect of population growth on market disintegration comes primarily from the supply side.

We now turn to examine the effects of population growth on short-distance or intra-provincial trade for reasons already mentioned. The estimates reported in Columns (4) through (6) show that only population growth within the grain-surplus regions has a significant effect on the speed of grain price adjustment within those regions. In terms of magnitude, an increase of population density by 1 percent in the importing prefectures within these regions will lead to approximately a 1.7 percent increase in the speed of price adjustment in these prefectures, whereas the same increase in the exporting prefectures will result in a decrease of 1.8 percent in the exporting prefectures. On balance, the two effects more or less cancel each other out. Our results are robust to the inclusion of the *likin* tax (refer to Table E2 in Online Appendix E for details).

The validity of our results hinges crucially on the accurate classification of the regions as grain-surplus, grain-deficit, and self-sufficient regions. With the exception of the provinces of Henan, Hubei, Shandong, and Shaanxi, Chinese historians basically agree as to whether a province was able to produce a surplus in the eighteenth century (refer to Table E3 of Online Appendix E for details). To check robustness anyway, we estimate the effect of population growth on the speed of grain price adjustment based on the classifications of other Chinese historians (e.g., Jiang 1992; Deng 1994; Wu 2001) and report the results in Panels A to C of Table 7. In Panel D, we exclude the four provinces over which a consensus is lacking and re-estimate again. Our earlier results continue to hold. One may still be concerned that such classification may change in response to population growth over time. To ensure that our results are robust, we employ an alternative classification based on the views of various economic historians summarized in Table E4 of Online Appendix E and find consistent results in Panel E of Table 7.

CONCLUSION

Because of its close association with modern economic growth, the performance of markets in a Malthusian world remains an important topic for the history of economic growth. By extending the data on China's grain prices to cover a longer period than previously analyzed

(1736–1910 as opposed to 1742–1795), we find that, unlike Europe, the performance of China's grain markets went through a U-shaped pattern. After having reached a peak around the mid-eighteenth century, it experienced a clear decline in tandem with explosive population growth—a period that lasted for about a century. The grain market resumed its growth momentum only after approximately one-sixth of the Chinese population was wiped out by Malthus' "positive checks" in the context of the Taiping Rebellion. While the population also resumed its upward trend in the aftermath of this catastrophe, it grew from a much lower base, with the seeming effect of facilitating market integration.

By unveiling the unique pattern of market development in China and focusing on the role played by the population dynamics underlying such a pattern, our study sheds new light on the differing market performance trajectories between China and Europe. To the extent that the Industrial Revolution excluded China, our finding may thus be taken as a "clean" case demonstrating the tensions between population pressure and the development of markets inherent in a Malthusian or pre-industrial regime. Also, by dividing China into three distinct regions characterized by varying degrees of self-sufficiency in grain production and trade based on grain price, we show that the forces of disintegration came specifically from faster population growth in the grain-surplus-cum-exporting areas, which underpins the overall negative relationship between population growth and market integration for the entire period of our study.

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