Assessing market integration in the early modern period*

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Abstract: Empirical tests of market integration are tests of price differences across locations with only tenuous reference to economic theory. We develop a simple model that illustrates the links between price convergence and the gains from trade, providing a theoretical rationale for empirical analysis. We then introduce three panel econometric approaches to assess linear or non-linear price convergence that account for the general equilibrium effects of common shocks. Our application uses grain prices for 209 prefectures of Qing China during the early modern period (1740-1820) finding secular decline of market integration (including in economically advanced regions) from the 1760s.

Keywords: market integration, panel convergence, common factors, early modern China

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1. Introduction

Market integration is directly related to the division of labor and the gains from trade. More integrated markets are beneficial because they produce larger gains from trade. These gains from trade are commonly measured by income increases to a representative agent relative to a counterfactual world of autarky, with the latter being constructed from estimates of bilateral gravity trade regressions in the context of a structural model (Costinot, et al 2014).

Because data on domestic and international trade flows have only been available since the 19th century, the empirical literature studying market integration in pre- and early-industrial economies has relied on commodity market price data to measure and test for market integration (e.g. Bateman, 2011; Brunt and Cannon, 2014; Chilosi, et al, 2013; Federico, 2007; Jacks, 2006; Shiue and Keller, 2007; Studer, 2015). In this price-based literature, market integration is conceptualized as a dynamic process in which markets are viewed as integrating (disintegrating) if prices across locations are converging (diverging) over time.

This paper proposes a theoretical motivation and quantitative tools for the study of commodity market integration in the early modern period and applies these using monthly grain prices for 209 prefectures of Qing-dynasty China (1740-1820). Our paper makes three contributions. First, we provide a simple theoretical framework that illustrates the links between market integration, price convergence and the gains from trade and offers a theoretical rationale for the standard estimation model used in the empirical price convergence literature. In our formulation, neoclassical gains from trade are measured by resource savings which increase in the degree of commodity price convergence. A resource savings formulation of the gains from trade is particularly suitable for early modern economies operating under Malthusian resource constraints, such as in pre-industrial Europe or China.

Our second contribution is methodological. Existing econometric approaches to the study of market integration using panel convergence methods (Parsley and Wei, 1996; Cecchetti, et al 2002; Goldberg and Verboven, 2005; Fan and Wei, 2006) do not account for common shocks with heterogeneous impact across markets and for 'third market' effects. Some of the former aspects are addressed in the existing literature by conditioning on weather or other shocks, but these approaches leave many unobserved time-varying heterogeneities unaccounted. While the latter aspects have been integrated in the study of bilateral exchange rates (Berg and Mark, 2015) and in the distinction between global and local shocks in the analysis of micro price dynamics (Andrade and Zachariadis, 2016; Beck, et al 2016), the aforementioned convergence literature assumes cross-sectional (correlational) independence between the prices of different markets in the panel (Andrews, 2005; Coakley, et al 2006;

Chudik and Pesaran, 2015). By means of a multi-factor error structure we introduce empirical approaches which capture these unobserved heterogeneities in a flexible but agnostic way (Stock and Watson, 2002; Pesaran, 2006; Bai, 2009; Chudik and Pesaran, 2015). Because common factors are orthogonal to each other and can differ in their impact across panel members, they can account for a lot of heterogeneity, and hence a small number of them can capture the highly idiosyncratic evolution of unobserved and/or unobservable processes: prime examples in existing empirical work are the modelling of knowledge spillovers (Eberhardt, et al, 2013), total factor productivity (Calderon et al, 2015; Eberhardt and Presbitero, 2015; Chirinko and Mallick, 2017; Chudik, et al, 2017; Madsen, et al, 2021), or absorptive capacity (De Visscher, et al, 2020). We introduce three empirical variants of price convergence analysis building on the existing panel econometric literature: (a) a benchmark model of heterogeneous price convergence with linear dynamics arriving at a speed of convergence-type panel estimate, (b) an extension representing a sharp hypothesis test of market integration versus market fragmentation assuming linear dynamics (Pesaran, 2007); and (c) an alternative hypothesis test allowing for non-linear price convergence (Taylor, 2001; Cerrato, et al, 2011). All three tests model the movement of a local market price relative to an equilibrium price at a higher aggregate, regional level while accounting for the unobservable general equilibrium effects of a network of markets and of unobserved shocks with heterogeneous impact across markets (e.g. local flooding, locust plague, or drought).[1]

Our third contribution is the empirical analysis that sheds new light on the historical puzzle of the dynamics of market integration in early modern China. Existing literature shows that China's markets were highly integrated before 1800 (Pomeranz, 2000; Shiue and Keller, 2007; Von Glahn, 2016). The social and historical literature agrees that in the decades before the First Opium War (1839-42) Chinese markets were largely fragmented (Wang, 1992: 54; von Glahn, 2016: 361). There is no evidence of cataclysmic economic change in either the qualitative or quantitative data for Qing China during the period. The puzzle is why Chinese markets ended up fragmented in the first half of the 19th century when during the 18th century they supposedly "came closer to resembling the neoclassical ideal of a market economy than did Western Europe" (Pomeranz, 2000: 70) and, market integration "was well and good with China in the eighteenth century" (Sng, 2014: 108)? Our empirical analysis suggests that

[1] In an appendix we extend our panel convergence model to the analysis of price *pairs*, as is the practice in the popular pairwise cointegration approach (Shiue and Keller, 2007). Average results for this dyadic approach are qualitatively identical to the monadic panel estimates.

Chinese market integration had declined long before the death of the Qianlong Emperor in 1799, and in parts of the country from as early as the 1760-70s.[2]

The remainder of the paper is structured as follows: in Section 2 we introduce a simple theoretical model to link market integration to the gains from trade and motivate the canonical empirical approach in the price convergence literature. Section 3 lays out our empirical model and three regression methodologies for the analysis of price convergence. Section 4 introduces the data for Qing China, reports our empirical results and offers additional qualitative evidence for our findings from the economic and social history literature. A conclusion follows.

2. Market integration, price convergence and the gains from trade

Consider *N* locations, each producing grain and cloth by peasant households. Both goods are homogeneous and produced under perfect competition and constant returns to scale with labor being the only factor of production. We focus on the allocation of labor to either grain or cloth, with the total labor hours initially devoted to both goods in location i denoted by L_i. The average cost or price of grain in location i is given by p_i^a and the average cost of producing cloth is normalized to be 1, with costs being measured in labor units.

We illustrate the relationship between price convergence, market integration and the gains from trade by considering three benchmark cases. In the benchmark case of *complete fragmentation*, all *N* locations operate under autarky, where each location consumes what it produces. In Figure 1, the consumption vector of location i is denoted by C_i and lies on the production possibilities frontier (PPF) whose locus is determined by the labor hours L_i and the location-specific grain price p_i^a.[3]

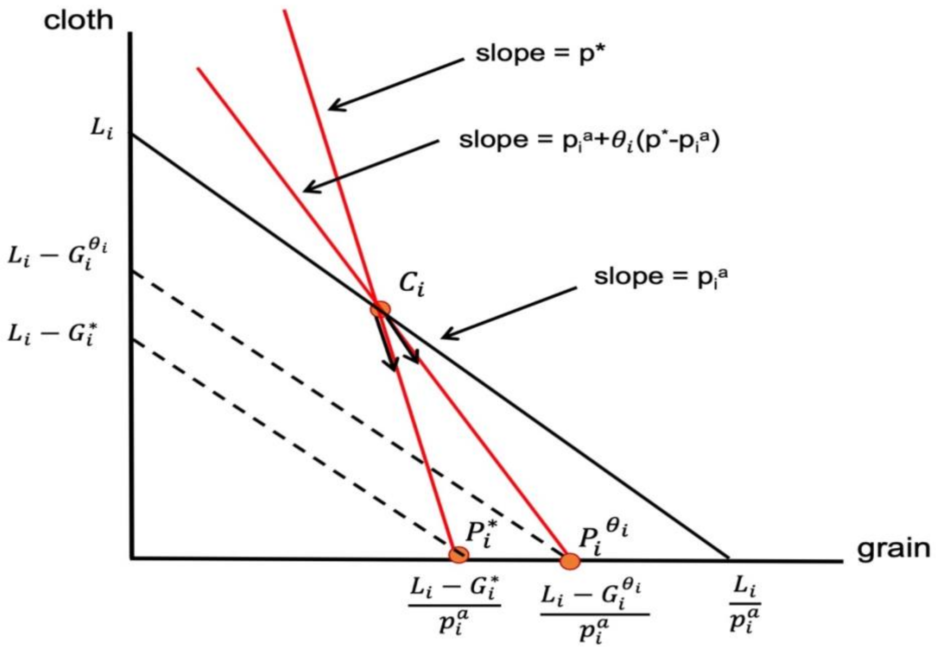
Now consider the second benchmark case of *full integration* or full price convergence where all *N* locations move from autarky to a free trade equilibrium. The opening up of trade between locations with different prices for the same good creates new opportunities for arbitrage profits for traders. Trade between locations occurs via a centralized port: traders make arbitrage profits by buying grain in low-price locations to sell it at a higher price at the port. These arbitrage activities will drive up the price of grain in low-price locations and drive down the price in high-price locations until all prices converge to a centralized port price p^*.[4] In a

[2] An Appendix demonstrates that during the 18th century China's most advanced region(s) diverged from the high and constant level of market integration in England and Belgium during the same period.
[3] The exact position of C_i depends on peasants' preferences, but these do not need to be specified.
[4] By Walras' law, we only need to consider the equilibrium for grain.

competitive equilibrium the arbitrage profits from trade will then just cover the resource costs of shipping goods from location i to the port.

Peasant households will obtain a welfare gain from trade resulting from the port price of grain being different from the autarky price. Figure 1 illustrates the aggregate gains from trade for peasants in location i assuming $p_i^a < p^*$. Under full integration, the port price p^* defines a terms of trade line that goes through consumption point C_i and has a slope of p^*, with trade occurring along the terms of trade line and permitting a separation between consumption and production.

Figure 1 – Market integration and the gains from trade



We employ a non-utilitarian resource savings formulation of the gains from trade, which is reminiscent of Amartya Sen's (1993) capability approach to social welfare.[5] Equating resources with capabilities, resource savings increase welfare by enhancing capabilities, which can (but do not have to) be used for, higher consumption. We illustrate this by assuming that the household keeps consumption initially at point C_i. This implies that reallocating labor from cloth to grain production and buying cloth on the market at a lower relative price $1/p^*$ than the opportunity cost of producing it at location i at $1/p_i^a$ saves labor while keeping consumption

[5] Our resource savings formulation is a modern re-formulation of the 18th century rule of the gains from trade employed by the classic writers. See Bernhofen and Brown (2018) for a historical discussion of the 18th century rule and how it compares to Samuelson's consumer based formulation, which is the standard in the trade literature. Bernhofen and Brown (2023) develop a more formal treatment of this resource savings formulation for a general neoclassical economy.

fixed at C_i. Figure 1 depicts the case where location *i* produces at point P_i^* and sells grain for food along the terms of trade line p^* to obtain the same consumption level C_i as without trade. However, the new production point P_i^* requires fewer labor hours than the production point C_i under autarky. This can be seen by noticing that P_i^* lies on the dashed (new) production possibility set defined by the new reduced labor hours $L_i - G_i^*$. If X_i^* units of grain are sold for M_i^* units of cloth, the labor savings can be calculated as $G_i^* = M_i^* - p_i^a X_i^*$, which implies that the labor savings from trade increase the more labor hours are devoted to producing grain for the market and the larger the difference between the market price p^* and the autarky price p_i^a, noticing that $p^* = (M_i^*/X_i^*)$.

If the labor savings G_i^* are used to produce either more grain or cloth, the households in location *i* are able to obtain a higher utility from increased consumption, employing the standard utilitarian gains from trade measure.[6] But the labor savings could be devoted to other activities like human capital acquisition or relief of the elderly from participating in farm work. Individual peasant households might use their labor savings in different ways. But because labor hours are additive, the location-specific overall welfare gains are the aggregate labor savings across all peasant households in location *i*, i.e. $G_i^* = \sum_k G_{ik}^*$ with *k* being a peasant household index.

Now we examine the hybrid case of partial integration where the price in location *i* lies between the *autarky* price p_i^a and the *full integration* price p^*. The introduction of an integration parameter θ_i helps us to instrumentalize the case of partial integration and the corresponding gains from trade in the context of equation (1):

$$p_i = p_i^a + \theta_i(p^* - p_i^a) \quad 0 \leq \theta_i \leq 1, \tag{1}$$

where p_i denotes the port price under partial integration. The integration parameter θ_i captures the degree to which location *i* is integrated with the other locations via the centralized trading port. If $\theta_i = 0$ for all *i*, we are in the benchmark autarky case where each location *i* is operating on its autarky PPF with no gains from trade. If $\theta_i = 1$ for all locations *i*, we are in the benchmark case of *full integration* where p_i has completely converged to p^* and each location *i* obtains its *maximum gains* G_i^*. Under full integration, gains from trade are at their maximum because the price p_i in location *i* is at the maximum distance from the location's opportunity cost p_i^a. The case of partial integration is illustrated in Figure 1 by the terms of trade line with

[6] An advantage of our production approach to welfare is that we do not have to specify anything about consumer preferences.

slope $p_i^a + \theta_i(p^* - p_i^a)$. The production point for location i is given by $P_i^{\theta_i}$ with the corresponding labor savings from trade given by $G_i^{\theta_i}$. A higher degree of integration relates to a larger integration parameter θ_i, which corresponds to p_i being closer to p^* causing larger gains from trade $G_i^{\theta_i}$ for location i.

Our model is agnostic about the source of impediments to full integration, but impediments are allowed to be location-specific. These might be shocks of either local or global character. The price integration equation (1) and the corresponding gains from trade Figure 1 provide the theoretical rationale behind our empirical convergence equation. For illustrative purposes, we made some simplifying assumptions that can be relaxed. First, the underlying gains from trade logic does not require constant opportunity costs (i.e. a constant slope PPF) and therefore complete specialization. Second, the underlying logic applies to multiple productive factors and goods. For example, if both grain and cloth are produced from labor, land and capital, the gains G_i^* and $G_i^{\theta_i}$ in Figure 1 become vectors containing bundles of labor, land and capital services saved through trade.[7]

3. Empirical Framework and Methodology

This section introduces three empirical approaches to the analysis of market integration on the basis of price convergence in the panel while flexibly accounting for shocks: (i) our baseline approach assuming linear convergence dynamics, (ii) a variant studying a sharp hypothesis test for price convergence vs non-convergence (market integration vs fragmentation), and (iii) an extension to a sharp hypothesis test which does not assume linearity. Lastly, we propose a rolling window analysis as a means to capture 'dynamic evolution' of market integration rather than a snapshot in time.

3.1 Baseline Setup: Linear Price Convergence

Empirical analysis and tests of market integration take a dynamic approach. Prices are subject to shocks that take time to recover, if at all. A price convergence model postulates that markets are more integrated the quicker prices return to their equilibrium level after a shock. The 'return to equilibrium' relates to the change in the nominal price P_{it} in location *i relative to* an

[7] In the case of more than two goods, the resource savings are calculated as the domestic input requirements of location i's imports minus the input requirements of all of location i's exports, see Bernhofen and Brown (2023) .

'equilibrium proxy' $\bar{P}_t$, defined as $\tilde{p}_{it} = \left(\ln P_{it} - \overline{\ln P_t}\right)$, which we elaborate on below. Our price price convergence model is given by

$$\Delta\tilde{p}_{it} = \beta_i \tilde{p}_{i,t-1} + \boldsymbol{\gamma}_i' \boldsymbol{f}_t + \varepsilon_{it}, \tag{2}$$

where the dependent variable is the change in the relative price between t-1 and t. The first term on the right-hand side contains our parameter of interest, β_i, which is the location-specific speed of convergence. If there is no price convergence, any shock will have a permanent effect on relative price movements and β_i will be zero. This corresponds to our benchmark autarky case in the previous section where θ_i is zero, prices fluctuate randomly around their autarky levels and there are no gains from trade to location *i*. Price convergence implies that β_i will be negative and the magnitude of β_i measures the convergence speed: the larger β_i (in absolute terms), the faster prices converge. More integrated markets are associated with more arbitrage activities and faster price convergence. Quicker convergence implies larger deviations of location-specific prices from their autarky benchmark levels, corresponding to a higher θ_i in equation (1) and larger location-specific gains from trade

The second term in equation (2), $\boldsymbol{\gamma}_i' \boldsymbol{f}_t$, accounts for changes in relative prices from location-specific responses to common shocks. The term $\boldsymbol{\gamma}_i' \boldsymbol{f}_t$ combines unobserved common factors $\boldsymbol{f}_t$ with market-specific factor loadings $\boldsymbol{\gamma}_i$.[8] A non-zero loading in both locations *i* and j would induce cross-sectional dependence. If, for example, the component f_t^k relates to common weather shocks affecting multiple locations then the corresponding factor loading γ_i^k captures the location-specific impact of these shocks. A weather event such as excessive rainfall will affect low-lying locations near flood-prone rivers differently from locations on a plain or at an elevation. Our empirical implementations are robust to local shocks as well as 'global' shocks that affect all locations in the entire sample (Chudik, et al, 2011).

Prices are also affected by the network structure of trade, the influence of other locations (third markets) on the prices between a specific pair of lcoations. The combination of $\boldsymbol{\gamma}_i$ and $\boldsymbol{f}_t$ in (2) captures the relative trading costs for each location with its neighboring or more distant locations. The relative magnitude of factor loading γ_i^k across locations is driven by many determinants including remoteness, river access, terrain, local climate, security of roads, and availability of porters. A defining feature of our common factor framework is that it allows us to remain agnostic about which of these determinants are present in the data (see Eberhardt, et al, 2013; Eberhardt and Presbitero, 2015, or Madsen, et al, 2021).

[8] Note that a location-specific intercept α_i is included in this multi-factor error structure.

Implementation of equation (2) requires an 'equilibrium proxy', $\bar{P}_t$, to which the price in location i is assumed to converge. The observed price data relate to the (theoretical) p_i observed over time, i.e. p_i becomes p_{it}. Conceptually, the unobserved location-specific average production costs p_i^a are subject to time and location-specific random shocks. Because p^* is the outcome of arbitrage activities across *all* markets, and based on information contained in *all* location-specific production costs, it can be empirically approximated by $N^{-1}(\sum_{i=1}^{N} p_{it})$, i.e. $\bar{P}_t$. Examples for the equilibrium proxy price include averages by physio-geographical regions, political regions (such as within state or provincial borders), or agro-climatic regions (such as staple crop patterns).

The main estimating equation is a heterogeneous Dickey and Fuller (1979) panel regression for the relative price $\tilde{p}$:

$$\Delta\tilde{p}_{it} = \alpha_i + \beta_i\tilde{p}_{i,t-1} + \sum_{\ell=1}^{p_i} \delta_{i,\ell}\, \Delta\tilde{p}_{i,t-\ell} \tag{3}$$
$$+\phi_i\, \overline{\Delta\tilde{p}}_t + \varphi_i\, \bar{\tilde{p}}_{t-1} + \sum_{\ell=1}^{p_i} \xi_{i,\ell}\, \overline{\Delta\tilde{p}}_{t-\ell} + \varepsilon_{it},$$

where bars indicate cross-section averages across (all) locations in the sample. β_i is the location-specific speed of convergence parameter and captures the degree to which location i is integrated within the larger economy. A β_i of 0 in (2), corresponds to a θ_i of 0 in equation (1), which means that p_{it} fluctuates randomly around p_{it}^a with no gains from trade to location *i*. A larger value of β_i in (2) in absolute terms corresponds to a larger θ_i in (1) and larger gains from trade for location *i*. α_i captures permanent price wedges across locations.[9] The last term on the first line of equation (3) contains lags of the dependent variable, which capture short-run behavior as is standard in *augmented* Dickey-Fuller regressions.

This first line of equation (3) is identical to the standard panel convergence implementations in Parsley and Wei (1996), Goldberg and Verboven (2005), or Fan and Wei (2006). The second line contains cross-sectional averages of the dependent and independent variables following Pesaran's (2006) Common Correlated Effects (CCE) approach. This augmentation can capture the heterogeneous impact of common shocks and the trade network. The cross-section averages ($\overline{\Delta\tilde{p}}, \bar{\tilde{p}}$) can be constructed by physio-geographical regions, political regions, agro-climatic regions, etc. These terms capture the unobserved common factors; the location-specific parameters (ϕ_i, φ_i and $\xi_{i,\ell}$) allow for the heterogeneous factor loadings.

[9] We further include monthly dummies to account for the effect of dissimilar harvest seasons – these are omitted in equation (3) for simplicity.

In our theoretical discussion, a larger location-specific integration parameter θ_i corresponds to larger location-specific resource gain by $G_i^{\theta_i}$. The additivity property of our gains from trade measure implies that the economy-wide gains from trade are given by $\sum_i G_i^{\theta_i}$. Since the common correlated effects mean group-estimator $\hat{\beta}_{MG} = \sum_{i=1}^{N} \omega_i \hat{\beta}_i$ is calculated as the (weighted) average of the location-specific estimated convergence parameters,[10] a larger absolute mean group estimate corresponds hence to larger average gains from trade across all locations: i.e. $(\sum_i G_i^{\theta_i}/N)$. Instead of reporting the speed of convergence coefficient or its average, we transform the estimates into 'half-lives', $\hat{\beta}_i^{HL}$, and the corresponding average half-life, $\hat{\beta}_{MG}^{HL}$: these capture the number of months until half the effect of a shock has dissipated and can be calculated as $\ln(0.5)/\ln(1+\hat{\beta}_i)$ for $\hat{\beta}_i$ from equation (3). Half-lives have an intuitive and economically meaningful interpretation and are readily comparable across samples.

The above setup has parallels to the trade gravity literature, which models the trade flow from location *i* to location *j* as a function of economic mass, trade frictions and, more recently, a trade network effect, referred to as 'multilateral resistance' (see Anderson and van Wincoop, 2003; Santos Silva and Tenreyro, 2006). In an appendix we introduce and estimate an equivalent empirical price convergence model for commodity price *pairs* (the logarithm of the price ratio between markets *i* and *j*) in a Dickey and Fuller (1979) regression, where each of the $N(N-1)$ price pair equations is augmented with the cross-section averages of all regression terms for all locations (containing *i*, *j*, and all other locations). The cross-section averages capture the multi-factor error structure, which in turn proxies the unobserved multi-lateral resistance influencing the relative movement of prices in *i* and *j* (see also Desbordes and Eberhardt, 2019).

3.2 Intuition for the Empirical Implementation

We can provide the intuition for the cross-section average augmentation approach in three simple steps. For ease of illustration, we assume a single factor f_t and no serial correlation:

$$\Delta\tilde{p}_{it} = \beta_i \tilde{p}_{i,t-1} + \gamma_i f_t + \varepsilon_{it}, \tag{4}$$

First, at each point in time we take the cross-section average of equation (4): $\overline{\Delta\tilde{p}}_t = \bar{\beta}\bar{\tilde{p}}_{t-1} + \bar{\gamma} f_t$, with $\bar{\varepsilon}_t = 0$ since ε_{it} is assumed white noise.

[10] Instead of uniform weights, $\omega_i = N^{-1}$, for the Pesaran and Smith (1995) Mean Group estimate we adopt robust regression to estimate weighted averages, which are robust to outliers (Hamilton, 1992).

Next, we solve the resulting equation for the common factor: $f_t = (1/\bar{\gamma})[\overline{\Delta\tilde{p}}_t - \bar{\beta}\bar{\tilde{p}}_{t-1}]$. Finally, we plug this back into equation (4) to yield:

$$\Delta\tilde{p}_{it} = \beta_i\tilde{p}_{i,t-1} + (\gamma_i/\bar{\gamma})\left[\overline{\Delta\tilde{p}}_t - \bar{\beta}\bar{\tilde{p}}_{t-1}\right] + \varepsilon_{it}$$

$$\Leftrightarrow \Delta\tilde{p}_{it} = \beta_i\tilde{p}_{i,t-1} + \phi_i\overline{\Delta\tilde{p}}_t + \varphi_i\bar{\tilde{p}}_{t-1} + \varepsilon_{it}. \quad (5)$$

This approach enables us to account for the unobservable common factor f_t with heterogeneous factor loadings γ_i by a combination of (i) cross-section averages of observable variables $[\Delta\bar{\tilde{p}}_t, \bar{\tilde{p}}_{t-1}]$, and (ii) heterogeneous parameters ϕ_i and φ_i. Crucially, we are able to identify β_i, even though we allow for $\tilde{p}_{it}$ and f_t to be correlated.

The common factor framework is used very widely in the empirical analysis of macro panels to capture time-varying unobserved heterogeneity. Theoretical work and simulations have shown that the augmentation with cross-section averages is very powerful, providing consistent estimates of β_i in the presence of non-stationary factors, structural breaks, and cointegration or non-cointegration of the model variables (Kapetanios, et al, 2011; Chudik and Pesaran, 2015).

3.3 Sharp Hypothesis Test of Linear Price Convergence

The above empirical implementation yields estimates for price convergence half-lives, providing a useful metric for comparison *across* diverse samples, e.g. for price data collected at different reporting frequency. These estimates however do not provide a straightforward answer to the question of whether locations are integrated or fragmented during the sample period. In econometric terms, as the speed of convergence approaches zero, the implied half-life approaches infinity: once markets become fragmented, the half-life mathematically *has* to explode. In economic terms, the issue revolves around the prospects for arbitrage *actually taking place*. One could argue that it is immaterial whether the estimated half-life is 50 or 100 months, since such estimates imply that no price arbitrage is taking place and that markets are *functionally* disintegrated.

In order to avoid such arguments, we develop an extension to our baseline panel convergence analysis in the form of a 'sharp' hypothesis test of fragmented markets in all locations as the null hypothesis. Here we build on the *t*-ratios associated with the estimated location-specific convergence parameter for β_i from equation (3), i.e. $\hat{t}_i = \hat{\beta}_i/se(\hat{\beta}_i)$. As is common in the panel time series literature, we compute the unweighted average for these *t*-ratios across locations as our test statistic for the null hypothesis of fragmented markets (see

Im, et al, 2003, among many others). The distribution for the averaged *t*-ratios is non-standard, and we therefore need to simulate critical values (see Pesaran, 2007). In our empirical application below we apply a 10% significance level for this hypothesis test and adopt 10,000 iterations of a model with a constant but no trend term, two lags in the augmented Dickey-Fuller regression and the additional lag augmentation with cross-section averages. Simulated critical values are constructed specific to the sample dimensions.

3.4 Sharp Hypothesis Test of Non-Linear Price Convergence

Taylor's (2001) contribution to the analysis of the law of one price raises concerns over the analysis of price differentials between two locations when there exists a 'band of inaction' for price adjustment in which no arbitrage occurs despite a non-zero 'price gap'. The standard assumption of a linear AR(1) specification for the adjustment dynamics is then shown to lead to significant bias in the convergence parameter estimates as well as a substantial loss of power for a unit root test applied to the price gap. If traders do not immediately engage in arbitrage as soon as a minimal price gap emerges, then the continued divergence of relative prices until physical trade becomes viable (i.e. profitable) may distort the empirical analysis of price convergence hypothesis testing.

For simplicity of exposition Taylor (2001) employs a three-regime threshold autoregression (TAR) in his simulations, whereby the price gap represents a *random walk* (nonstationary) process in the interval $[-c, +c]$ and a *mean-reverting* (stationary) process if it is outside these bounds. His derivations show that if a linear AR(1) is imposed on a TAR process the estimated speed of convergence and thus half-lives may be seriously biased, with the implication that estimated half-lives are a multiple of their true values.

In case of the TAR specification, this adjustment between regimes is sharp, in the sense that the price gap is assumed to switch from a random walk to a mean-reverting process right there on the edge of the 'band of inaction.' An alternative smooth transition autoregression (STAR) model assumes that this transition is smooth(er) (Kapetanios, Shin, and Snell, 2006), which perhaps comes closer to the notion of different traders having different 'reservation' price gaps before they engage in trade and hence arbitrage.

We extend our analysis of price convergence to nonlinear adjustment dynamics in the form of an exponential smooth transition autoregression (ESTAR) model (Kapetanios, et al., 2006; Cerrato, de Peretti, Larsson, and Sarantis, 2011). We assume that the relative price series, $\tilde{p}$, is generated by the following dynamic nonlinear heterogeneous panel STAR model:

$$\tilde{p}_{it} = \beta_i \tilde{p}_{i,t-1} + \tau_i \, \tilde{p}_{i,t-1} \, Z(\eta_i; \tilde{p}_{i,t-d}) + \boldsymbol{\gamma}'_i \boldsymbol{f}_t + \varepsilon_{it}, \tag{6}$$

where $\tilde{p}_{i,0}$ is given and ε_{it} white noise. In case of the ESTAR model the transition function $Z(\cdot)$ is defined as an exponential function, namely $Z(\eta_i; \tilde{p}_{i,t-d}) = 1 - \exp\,(-\eta_i \tilde{p}^2_{i,t-1})$, with $\eta_i \geq 0$ and the delay parameter *d* set equal to unity, as is common practice in this literature. The parameter τ_i determines the *width* of a band of inactivity as well as the *speed* at which the process returns to it. Taking these equations together and expressing the ESTAR model in first differences we get

$$\Delta\tilde{p}_{it} = \phi_i \tilde{p}_{i,t-1} + \tau_i \tilde{p}_{i,t-1} \, [1 - \exp(-\eta_i \tilde{p}^2_{i,t-1})] + \boldsymbol{\gamma}'_i \boldsymbol{f}_t + \varepsilon_{it}, \tag{7}$$

where $\phi_i = \beta_i - 1 = -(1 - \beta_i)$.[11] Cerrato, et al (2011) derive a *t*-test for the null of a nonstationary process (market fragmentation) in all locations.[12] In addition to the factor structure this test allows for serial correlation (like in a standard Augmented Dickey-Fuller test), which is accounted for by adding lags of the dependent variable to the equation. The test is based on the following auxiliary regression estimated separately in each location *i*:

$$\begin{aligned} \Delta\tilde{p}_{it} = \alpha_i + \beta_i \tilde{p}^3_{i,t-1} + \delta_{i\ell} \textstyle\sum_{\ell=1}^{p_i} \Delta\tilde{p}_{i,t-\ell} \\ + \phi_i \overline{\tilde{p}^3}_{t-1} + \textstyle\sum_{\ell=0}^{p_i} \varphi_{i\ell} \overline{\Delta\tilde{p}^3}_{t-\ell} + \varepsilon_{it}. \end{aligned} \tag{8}$$

The test statistics is constructed from the *t*-ratios of the estimated β_i coefficients, of which there are *N*, and from which an unweighted average is computed akin to the Im, et al (2003) panel unit root test statistic. Critical values for this average *t*-statistic are non-standard and the simulated values are provided by Cerrato, et al (2011).

In the previous section we introduced a test to investigate nonstationary versus stationary price gaps *with linear dynamics*, whereas the test developed here allows for *non-linear dynamics*. What if the process studied is stationary but the assumption of non-linear dynamics is wrong? Simulations suggest that in this case the Cerrato, et al (2011) test still has good power properties.

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[11] What does such a stationary ESTAR process look like? In an appendix we provide four simulated time series (we ignore the heterogeneous panel and common factor structure) to illustrate the generic ESTAR process; in all four cases we set $\phi_i = 0$, i.e. each *y* is *nominally* a random walk process. We simulate 1,800 time series observations and discard the first 900. The graphs present a subset and the full 900 observations.

[12] The alternative is a stationary ESTAR process (integrated markets with nonlinear price convergence) in *some* locations. Note that this heterogeneous alternative hypothesis is present throughout our testing of stationarity versus nonstationarity: once we moved from homogeneous to heterogeneous models the rejection of the null no longer implies the alternative is likely to be present for *all* cross-section units.

3.5 The Dynamic Evolution of Price Convergence

Existing empirical approaches to price convergence estimation are typically applied to the full time series of the panel, with the results (re)presenting the *average* level of integration over the entire time horizon. In our application below, we implement the convergence analysis using a rolling window that takes advantange of the availability of high-frequency data to better capture the longer-term dynamics of market integration. This enables us to pinpoint whether any secular change in market integration was a slow and drawn-out process or of a cataclysmic nature, and if change occurred, when clear patterns begin to emerge, and when markets had become fragmented?

4. Empirical Application

4.1 Data and Sources

We use historical Chinese grain price data (1740-1820) for medium quality rice from 131 prefectural markets in 11 provinces of South China, and for wheat from 78 prefectures in six provinces of North China. These data comprise the monthly reported minimum and maximum prices in each prefecture and we follow the literature in adopting the average between these two. The distinction between South and North China reflects the different staple crops and agro-climatic systems (Buck, 1937): South China is a wet-field rice zone with tea production in the hills and North China cultivates dry-field wheat, along with millet, sorghum (*gaoliang*) and coarse grains. Our data cover most prefectures in the 18 provinces of Qing China Proper with the exception of Yunnan. A map of our sample is provided in an appendix.[13]

The Qing state collected these data as part of an elaborate commodity price reporting system, initiated during the reign of the Kangxi Emperor (1654-1722), which became a nation-wide system at the start of the reign of the Qianlong Emperor (1735-1796). Twenty or more commodities were often reported for a prefecture. These reports, which survive in archives in Beijing and Taipei, were compiled by Wang Yejian [Yeh-Chien] and collaborators.[14] We use

[13] Additional analysis using (among others) minimum or maximum prices, prices for alternative quality rice, prices for millet, wheat prices for a larger sample, which includes Southern prefectures were carried out with qualitatively identical results (available on request). In an appendix we also use data for English and Belgian markets for comparative analysis – sources and other details are provided.

[14] The Qing Dynasty Grain Price Database (*Qingdai liangjia ziliao ku*) is hosted at the Institute of Modern History, Academia Sinica, Taiwan. The database is available at http://mhdb.mh.sinica.edu.tw/foodprice/.

medium-grade rice and wheat prices, recorded in taels (*liang* [ounces]) of silver per granary bushel (*cang shi*, about 104 litres).

Historians agree that these price data are reliable and comparable across locations (Wang 1978; Chuan and Kraus, 1975; Marks, 1991, 1998; Shiue and Keller, 2007). However, no historical price data are ever free from errors of omission, neglect or sometimes even manipulation. At times the same price may recur for several months. In the South China sample the share of rice prices that changed monthly are on average 76 percent in the first 40 years and 64 percent in the final 41 years of our sample. For the Lower Yangzi region, the shares are 81 percent and 68 percent respectively. This performance is comparable to wheat markets in the United States for 1800-39 where monthly prices changed for 47 to 81 percent of the sample (Jacks, 2006). Our sample end date, 1820, marks the beginning of a period when data quality deteriorates rapidly. More details on data veracity are provided in an appendix.

We further adopt Skinner's (1977) influential model of 'physiographic macro-regions', which are argued to have shaped local economies.[15] Each of these macro-regions was centred on major river drainage basins, divided and isolated from one another by mountains except where rivers cut between. Although not without its critics the framework provides heuristic power in the conceptualisation of sub-national regions bigger than and distinct from provinces (Bai and Jia, 2021). An appendix lists all prefectures according to their macro-region classification.

Our results adopt the macro-regional average as equilibrium proxy, $\bar{P}_t$, and the cross-section averages of the relative price, including $\overline{\Delta\tilde{p}_t}$ and $\bar{\tilde{p}}_{t-1}$, are also computed at this level of geographic aggregation. A range of alternative specifications yield qualitatively similar results and are available on request.

4.2 Empirical Results

The upper panel in Figure 2 presents the outlier-robust average half-lives from our benchmark panel convergence analysis for the two staple-crop regions: South China, based on rice prices, and North China, based on wheat prices (note the logarithmic vertical scale). These graphs represent regression estimates, not plots of the averaged data, and the 20-year estimation

[15] Within each region there was a rural-urban marketing hierarchy that extended from the densely populated lowland core to the lightly populated upland periphery. This spatial organisation characterised local social life and the regional economies; 30-40 percent of agricultural output might have been sold in local and region markets, but less than 10 percent entered into long-distance trade (Brandt et al, 2014: 53; Xu and Wu, 2007: 207-20 passim).

window start year is indicated along the horizontal axis. These results confirm past narratives that market integration in South China was higher than in the North. Before the 1780s, for each 20-year rolling window period the average half-life in months in South China is typically *lower* than in North China.[16] Our results further indicate that market integration in North and South China regions followed a similar secular pattern: the half-lives increase from the 1760s onwards, reaching values in excess of 24 months in the final decades of our sample.

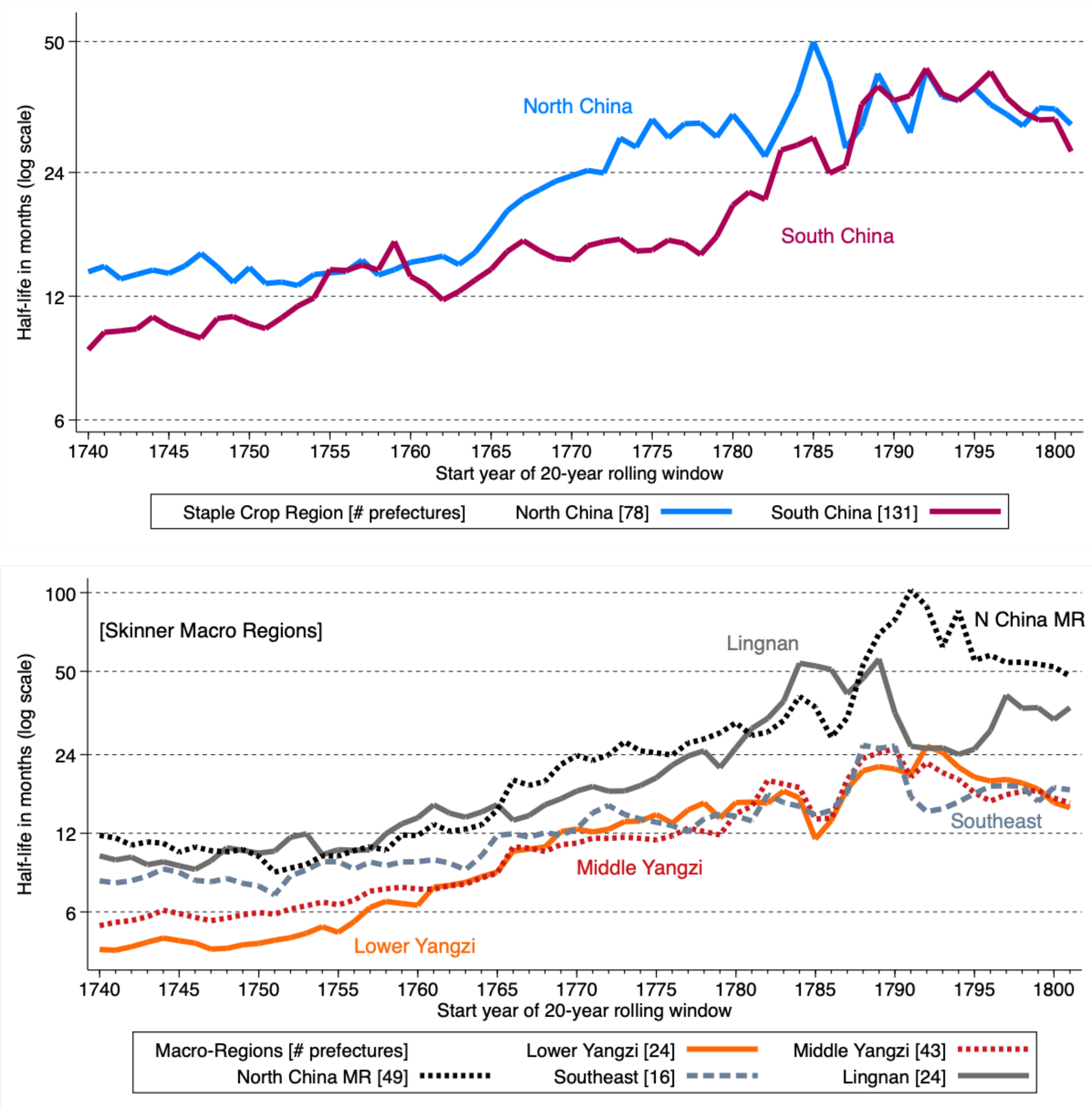
In the lower panel we geographically disaggregate the sample into macro-regions using Skinner's (1977) regional systems concept. In the 1740s we can see clear differentiation in the estimated half-lives of each macro-region. The lowest was the Lower Yangzi, the most developed and richest region in China. This was followed by the Middle Yangzi, the Southeast Coast (Southern Zhejiang and Fujian), Lingnan (or Liangguang: Guangdong and Guangxi) and lastly the North China macro-region.[17] Estimated half-lives were relatively unchanged into the 1760s and thereafter rise for all geographic sub-regions.

These panel convergence results show a secular market disintegration in the larger rice and wheat staple-crop region samples as well as in the macro-region sub-samples. Market disintegration began in the second half of the eighteenth century and accelerated in the last three decades. Even two decades before the death of the Qianlong emperor in 1799 (his official reign ended in 1795), the estimated half-lives reported in Figure 2 had already more than *doubled* in both Northern and Southern prefectures compared with the mid-century levels.

[16] These patterns reflect the advantage of water transport in the South over land modes in the North (Rawski, 1972; Elvin, 1973; Evans, 1984; Kim, 2008), giving rise to the proverb *nan chuan bei ma* – take a boat in the South, a horse in the North (Elvin, 1973: 136).

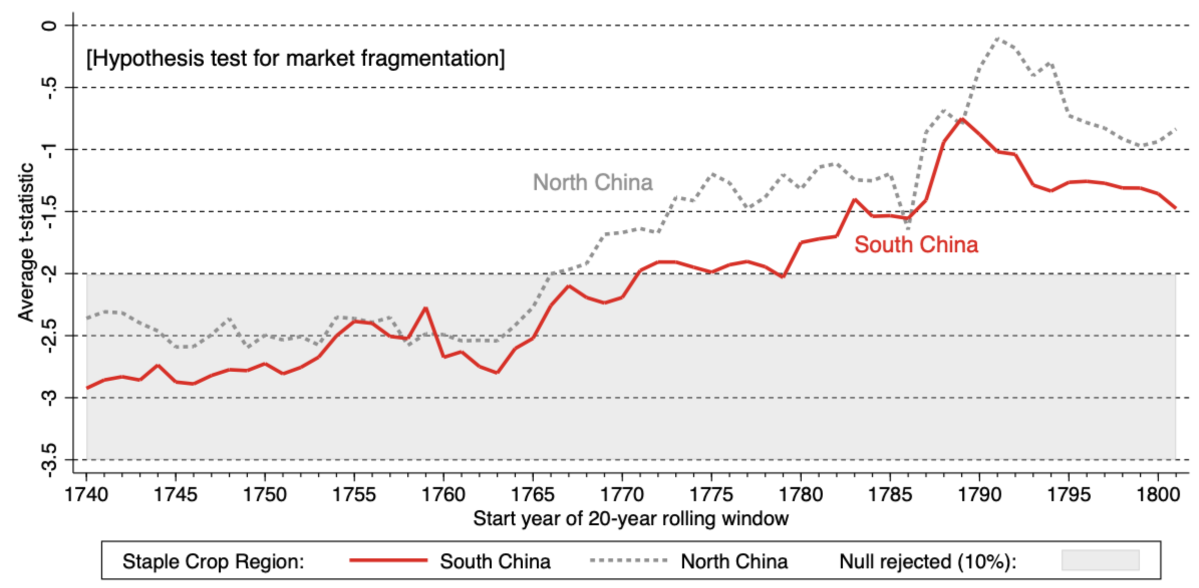
[17] Results for the Northwest macro region and the Upper Yangzi macro are excluded for ease of illustration.

Figure 2 – Market Integration in South and North China (linear convergence)



Notes: Panel convergence estimates are expressed in half-lives and presented on a logarithmic scale, hence the half-life *doubles* between each consecutive horizontal line. The top panel presents the averages for the two main staple crop regions of China; the bottom panel the averages for five of the eight Skinner macroregions of Qing China proper. We exclude results for the peripheral Upper Yangzi, Yun-Gui and Northwest China macro-regions for ease of presentation. The year along the *x*-axis indicates the start of a twenty-year rolling estimation window (which moves one year at the time): for each year we report the average half-life based on $\hat{\beta}_i$ from equation (5) using the data for year *s* to *s*+19 (a maximum of 360 observations per prefecture). Prefecture counts are reported in the legend of each graph.

Figure 3 – Market Fragmentation Test in South and North China (linear convergence)



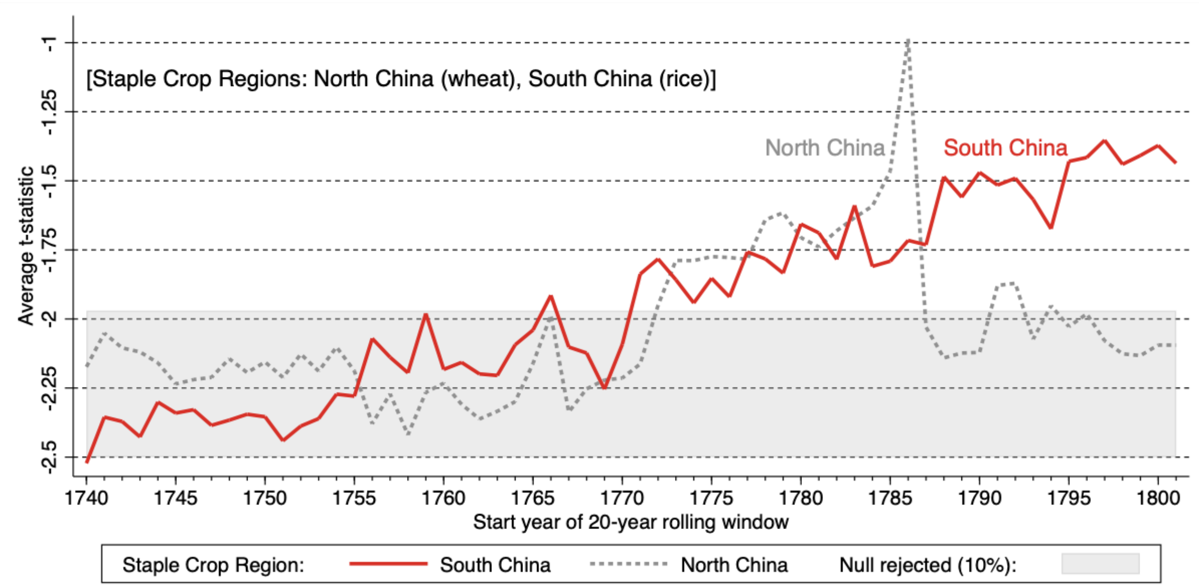
Notes: We plot the unweighted cross-section average of the prefecture-specific t-ratios from the convergence regressions to the regional average price, i.e. those associated with $\hat{\beta}_i$ from equation (5). For an averaged t-ratio in absolute terms above (below) the critical value, indicated by the shaded (unshaded) region in the graph, we (cannot) reject the null of a unit root in the relative price series. The economic interpretation of this outcome is that markets are (not) integrated. The critical values have non-standard distributions; we simulate them following the setup in Pesaran (2007) for the specific dimensions (N,T) of our Southern and Northern Chinese panel data (10,000 iterations, constant term but no trend, two lags in the augmented Dickey-Fuller regression, additional lag augmentation with cross-section averages). For our Southern sample (N=131, average T=190 for each rolling window) we have critical values of -2.01, -2.06 and -2.15 (10%, 5% and 1%, respectively), in the Northern sample (N=80, avg T = 190 for each rolling window) we have critical values of -2.02, -2.08 and -2.18 (dto). In the plot we adopt the 10% critical value. The number of average time series observations for each rolling window declines somewhat over time: critical values computed for shorter T will be marginally larger (in absolute terms) than those we adopted in our plots above (we adopted the value for average T), implying that the market disintegration result will be reached *earlier* than in the results presented.

Figure 3 presents the rolling window results when we adopt a sharp hypothesis test for market integration versus fragmentation, assuming (as in the analysis above) linear price convergence. The *y*-axis represents the averaged *t*-ratios across prefectures of the two staple crop regions, and the area shaded in grey indicates when the null of a unit root (i.e. fragmented markets) is rejected. We are unable to reject a unit root for the relative price series for North and South China from the time windows 1766-85 and 1771-90 onwards, respectively (10% level of significance). These results confirm our above findings that grain markets in China were *already fragmented one or two decades before the death of the Qianlong Emperor*.[18]

[18] Since the time span rather than frequency or length (*T*) of a time series drives the power of the unit root test (Shiller and Perron, 1985), we are reassured that a 30-year time window similarly points to market fragmentation before 1800 – results available on request.

Finally, in Figure 4 we present results for the sharp hypothesis test between market integration and fragmentation allowing for a non-linear price convergence process. For both staple crop regions the null of a unit root process (and hence fragmented markets) cannot be rejected from around the 1770s onwards. The Northern sample indicates a sharp peak for the 1786-1805 window, followed by seemingly stronger evidence for integrated markets over the remainder of the sample period.

Figure 4 – Market Integration in South and North China (nonlinear convergence)



Notes: We investigate nonlinear adjustment dynamics in an ESTAR model, where the null hypothesis of the test is that all relative price series are nonstationary, whereas the alternative hypothesis is that some relative price series follow a stationary ESTAR process. The shaded area marks the region in which we can reject the null at the 10% level. In our empirical setup the null and alternative hypotheses is equivalent to evidence for market disintegration and integration, respectively.

4.3 Discussion

Our findings of secular market disintegration across all regions and sub-regions of Qing China are supported by wide-ranging qualitative evidence from the economic and social history literatures. Many past historians have observed that in the later years of Qianlong "the elements of ultimate ruin [of the Qing] were already present" (Hsu, 1990: 41, 42). Spence (2013: 108-14) argues "a series of crises" in the late eighteenth century erupted from the state's "failure" to address financial, administrative and social needs, bungled military campaigns, increased official corruption, and widespread resentment and civil unrest. The increase in corruption and incompetence produced a "loss of faith" in Qianlong's rule, which "combined with unprecedented population growth and the consequent social, environmental, and economic pressures, gave rise to numerous populous uprisings large and small" (Elliott, 2009: 143). The uprisings and faltering capacity of the bureaucracy stemmed from the profound economic and social change over the eighteenth century, of which none was more important than population growth and internal migration (Elliott, 2009: ix, 146; Brandt et al, 2014: 50-2; von Glahn, 2016: 330, 647). Large-scale migration from the densely populated core to the periphery opened up vast swathes of land. Migrants encroached on the flood plains of lakes and rivers, and pushed into the forested upland watersheds. Their activities had adverse environmental effects. The water control systems at "the heart of farming" in China and its transport network began to fail (Elvin, 2004: 115,120, 125, 128, 460; Pomeranz, 2000: 215, 228; von Glahn, 2016; 329, 361-63). As a consequence, the transport of grains could not but have been adversely affected and in turn the performance of local, regional and interregional markets that depended on access to waterways. Grain-surplus interior provinces had less grain to export, while the rise of local import-substitution industry reduced demand for manufactures from the core regions, diminishing inter-regional trade and in turn market integration between regions as our theory framework postulates.

The cumulative effects of these changes affecting interregional trade and market integration – population growth and migration; degradation of the environment and water-control and transport systems; and the state capacity and performance of officials – pushed down the standard of living. Population growth was insufficiently offset by the increase in per capita cultivated land and the rise in grain yields.[19] By how much incomes fell is a contentious historical debate. Broadberry et. al (2018) concluded that in 1800, per capita GDP was merely 60 percent of the level in 1700. Others argued there was "a persistent decline" from the early 17th century (Xu et al, 2021). These new income estimates have overturned the past concensus that a tripling of population from the late 17th century to the mid-19th century had occurred without an adverse effect on the standard of living (see Brandt et. al. 2014). Not everyone is convinced. Solar (2021) challenged the Broadberry et al findings that forced some minor adjustments (Broadberry et al, 2021), though they stick with the surpisingly high estimates for income c.1700 based on new estimates of arable land. Some sort of downward shift had to be underway in the second half of the eighteenth century if we are to reconcile the consensus that China was very poor in the early nineteenth century and got poorer by the time of the mid-

[19] The role of population in the decline in market integration was more complex than a Malthusian "positive check", as Gu and Kung (2021) argue. Their analysis ignores the internal migration, and the inconvenience of the findings of historical demographers that "preventative checks" were also practiced (Lee and Wang, 20001).

century rebellions. Our empirical results provide quantitative confirmation that grain market integration was already declining from at least the 1770s onwards, earlier in some sub-regions including the economically most advanced Jiangnan region, which support the likelihood of falling income during the 18th century as the gains from trade began to evaporate.

5. Concluding Remarks

The idea that more integrated markets cause welfare gains is one of the central premises of the field of international trade and the economics discipline in general. Based on the theoretical insight that an integrated market must follow the law of one price, empirical studies of market integration have equated the degree of market integration with the degree of price convergence. But the links between the degree of price convergence and economic welfare have, to our knowledge of the literature, been only asserted. This paper has broken new ground by (i) linking the workhorse empirical price convergence model to the gains from trade, (ii) applying estimation methods that account for cross-sectional dependence and non-linear convergence, and (iii) applying these methods to a long panel data set of grain prices in China during 1740-1820. Our panel methods have produced economy-wide integration parameter estimates whose changes correspond to changes in economy-wide gains from trade. Overall, our estimates provide a consistent picture of a gradual decline of market integration in the most advanced regions of China as well as in the Southern rice and Northern wheat-growing areas on a whole. Our quantitative evidence forms a revisionist argument against the 'golden Qianlong era' narrative which dominates the historical literature, and which sets the date for China's fall into poverty in the nineteenth century instead of the 18th century.

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