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Japan and the Asian Divergence: Market Integration, Climate Anomalies and Famines during the 18th and 19th Centuries

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Abstract

This paper asks whether better integration of rice markets in Japan during the 19th and 20th centuries compared to China and India explains the 'Little Divergence' in Asia and Japan's role in the 'Great Divergence'. It analyses rice prices for 13 markets across Japan during 1720-1857 and finds that Japan had relatively well-integrated rice markets, particularly western Japan. In eastern Japan market integration was partially impeded by distance to Osaka, which was the core market, and the greater ecological vulnerability of rice in northeast Japan to lower temperatures during the 'little ice age' that lasted until the mid-19th century. Relatively well-integrated markets did not prevent major famines during 1732-1733, 1783-1786, and 1833-1838, because stocks and supplies were insufficient to withstand the consequences of sequences of crop failures. Better integration of rice markets is indicative of higher allocative efficiency of markets in Japan which is a likely reason that 'shrinking' episodes caused fewer setbacks in long-term economic growth compared to in China and India.

Keywords: Great Divergence, Famine, market integration, Tokugawa Japan, VAR, ECM
JEL Classification: I39, N15, N35, N45, N75, N95

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1. Introduction

The divergence in long-term economic development between Europe and Asia has been a long time subject of research in economic history. Analysis was long based on qualitative conjecture. At the time when Maddison (1998: 40) estimated that GDP per capita in Europe was well ahead of China, India and Japan in 1700 and 1820, Pomeranz (2000) and his colleagues in the 'California School' argued that the divergence between Asia (represented by the Lower Yangzi area) and Europe (represented by England) started in the late-18th or early 19th century, not before. Since then, a growing number of studies contributed to a quest for quantification to substantiate hypotheses about comparative economic development. Further discussion about the timing and explanations of 'Great Divergence' has spawned different strands of debate during the past 20 years. This paper relates to three such strands.

Firstly, debate about the Great Divergence unfolded in parallel with the understanding that what is now generally referred to as a 'Little Divergence' took place within Europe (Allen 2001). This inspired research into an equivalent 'Little Divergence' in Asia (Sng and Moriguchi 2014). Improved estimates of long-term economic growth in China, India and Japan summarised by Broadberry (2016: 36-37) reveal that Japan pulled ahead of India in terms of GDP per capita in the early 18th century and of China in the late-18th century. It is still unclear why this occurred; the estimates for Japan substantiated patterns of long-term growth in Japan (Bassino *et al.* 2019), not the reasons for Japan's superior performance relative to India and China.

For that purpose, a second strand of debate is relevant. Despite refutations by the 'California School', received wisdom since North and Thomas (1973) is that institutional development was an important factor behind the Great Divergence, because it secured integrated markets and superior allocative market efficiency in Europe and North America, relative to Asia. Shiue and Keller (2007) put this argument to the test by analysing rice price data in China and wheat prices in Europe to conclude that market integration in England was indeed higher than China and in continental Europe in the late-18th century, but that market integration in the Yangzi Delta was well-advanced by the late-18th century, to a degree comparable to continental Europe. Studer (2008) analysed wheat and rice markets in India and wheat markets in Europe to conclude that India only achieved increasingly more integrated and less fragmented markets since the mid-19th century, and that 'lowland' European markets in the 18th century were better integrated. If Japan pulled ahead of China and India in the late-18th century in terms of GDP per capita, does that imply that market integration and allocative market efficiency were more significant in Japan than in China and India? If so, in what way did superior allocative market efficiency manifest itself in Japan's economic growth?

To answer such questions, a third strand is relevant. In particular, Broadberry and Wallis (2018) have recently argued that economies able to achieve 'a decline in the rate and frequency of shrinking' achieved long-run sustained growth. They established that Great Britain and the Netherlands for that reason achieved superior performance to Spain and Italy during 1270-1870, thus explaining the Little Divergence in Europe. Broadberry and Wallis (2018) considered the impact of asymmetric set-backs caused by epidemics and warfare, but they did not consider famines as a potentially more significant cause of 'shrinking' episodes. Given the high share of agriculture in early-modern economies, the adverse effects of crop failures may have caused occasional famines and temporarily increased excess mortality. Not only could this have caused episodes of 'shrinking' due to negative population growth, but perhaps more significantly because the ensuing uncertainty in food supply may have discouraged structural change in terms of members of farm households permanently leaving the agricultural labour force for non-agricultural pursuits.

Adam Smith argued that well-functioning markets are crucial to mitigating famines.[1] Since then, it has become clear that the allocative efficiency of markets in key parts of Europe was a major factor in alleviating occasional famines (Ó Gráda 2009: 129-157). While it did not prevent famines in all of Europe, it did create the stability of food supply that facilitated structural transformation and mitigated episodes of 'shrinking' in key parts. If this argument is relevant to the analysis of the Great Divergence, Asia may thus have endured 'shrinking' episodes at greater frequency than Europe. Jones (1981) provided qualitative evidence by substantiating his thesis that early modern Europe suffered less frequently than Asia from

[1] 'In an extensive corn country, between all the different parts of which there is a free commerce and communication, the scarcity occasioned by the most unfavourable seasons can never be so great as to produce a famine.' (Smith 1776: 215).

‘catastrophes’ (earthquakes, floods, droughts, diseases, pests, fires, war and famines). In the case of famine, Asia may have required labour in agriculture that could not be involved in non-agricultural pursuits for much longer than was the case in Europe. This limit on structural change may thus have contributed to the Great Divergence.

The significance of famines to this interpretation of the Great Divergence may have been magnified in those parts of Asia highly dependent on rice as staple crop. Rice is grown with a much higher seasonality of labour requirements during the transplanting and harvesting stages than wheat, which led Oshima (1983, 1987: 17-27) to hypothesise that this inhibited structural change and labour specialisation in Asia relative to areas in Europe that depended on wheat as a staple food. Although this hypothesis is mitigated by the fact that rice is not grown across all of Asia with the labour-intensive technologies common in densely populated parts of Asia such as Japan (Van der Eng 2004), the uncertainty of food supply due to low market integration and the high seasonal labour intensity of rice production may have inhibited labour from dropping out of agriculture permanently in pursuit of new non-agricultural employment opportunities, and therefore structural change and specialisation of labour in Asia relative to Europe. What is the evidence of the frequency of set-backs in agricultural production and occurrence of famine in Asia relative to Europe (Great Divergence) and Japan relative to China and India (Little Divergence)? And what is the evidence that famine-related set-backs were a consequence of poor market integration in Asia?

Shiue (2004, 2005) analysed the case of China to argue that grains markets were integrated, but insufficiently to alleviate famines, for which purpose state-controlled granaries and tax relief were used, with imperfect results. Famines persisted in China throughout the 18th, 19th and 20th centuries (Will 1980; Li 1982). In India’s case, McAlpin (1979), Maharatna (1996), Andrabi and Kuehlwein (2010) and Studer (2008: 398 and 421) argued *inter alia* that markets in India were insufficiently integrated to mitigate famines, compared to pre-industrial Europe, until the expansion of India’s railways integrated them since the 1860s. Nevertheless famines persisted in India well into the 20th century. This aligns with overviews of famines in Asia and Europe. There is no verified list of famines in history throughout the world, but a listing in Ó Gráda (2009: 23) confirms that early modern China and India suffered major famines that were much more devastating than in Europe. But what about Japan? Were its markets well-integrated, and was Japan more successful in evading famines during the 18th and 19th centuries, thus evade ‘shrinking’, and achieve the modest net growth that eluded China and India and sustained Asia’s Little Divergence identified by Broadberry (2016)?

At face value, that seems not the case, as Japan during the Tokugawa period (1603-1867)[2] suffered from several severe famines that claimed several hundreds of thousands of lives. The three most dramatic famines of the 18th and 19th century occurred in 1732-1733, 1783-1786, and 1833-1838.[3] Nevertheless, various authors have argued that Tokugawa Japan had achieved a high degree of rice market integration (Miyamoto 1963, 1985, 1988; Iwahashi 1981; Shimbo 1985; Kusano 1996). If so, how can this be reconciled with the occurrence of these and other, often regional famines in Japan? How did the market function in Japan in comparison with China and India, and would this help to understand the Little Divergence in Asia?

Some famines can be explained in terms of entitlement failures (Sen 1981), but it does not seem this was the case in Japan during the 18th and 19th centuries. Most victims were rural commoners who were agricultural producers. In normal years, they had some tradable surplus of grain left after paying land tax, and after storing staple grains for self-consumption and as seed for the next cultivation cycle. No famines were recorded in the main cities of Edo (Tokyo), Kyoto and Osaka. In the event of food crop failure, the Tokugawa government was much more concerned with food supply in the major cities, particularly in Edo, than in the countryside. Rice riots and looting of merchants' granaries occurred nevertheless on several occasions, but starvation was virtually unknown in Edo, Kyoto, Osaka, or among samurai, merchants and craftsmen living in the smaller castle towns (*jokamachi*)[4] that were the seats of administration in the local domains. The two alternative interpretations for the occurrence of famines in a country with a high degree of market integration are either a drastic deterioration of the functioning of markets during famines, or that an exogenous climate shock of exceptional magnitude triggered massive crop failures, thus causing large food availability deficits for Japan as whole, comparable to what have been identified during World War II in Asia, particularly Bengal in 1943 (Ó Gráda 2007, 2008), and in northern Vietnam and Java in 1944-1945 (Huff 2019; Van der Eng 1998).

[2] The Tokugawa period (1603-1858) was one of peace, associated with the development of regional specialisation of production, some proto-industrialisation, and market sophistication. After all, the first futures market in the world, the Dojima rice market, was established in Osaka in the 18th century (Hamori *et al.* 2001; Wakita 2001).
[3] These were the *Kyōhō*, *Tenmei* and *Tenpō* famines (Kikuchi 1997). The famine years are generally identified by the name of the era when a particular Emperor reigned. Crop failures resulted in some excess mortality during other years, but these famines were less severe and regionally confined, such as the 1754-1755 *Horeki* famine.
[4] Compared to Edo, Osaka, and Kyoto, most were rather small towns with a few thousand inhabitants, rather than large cities, but they concentrated relatively higher income groups (merchants, craftsmen, and member of the local administration), and, of course, outside territories under direct control of the *Shōgun*, the main residence of the *daimyō* and their entourage.

To solve the apparent contradiction between famines and market integration, this paper analyses regional rice price data for 13 regional rice markets in Japan during 1717-1857 to establish the extent to which regional differences in the functioning of markets during these famine episodes existed, and thus whether the famines were a consequence of the different degrees to which regions were integrated in the national rice economy. Rice was the most important staple food and by far the most extensively traded item. During the period studied, the Tokugawa shogunate (1603-1868) implemented a deliberate policy of restriction of international trade, strictly enforced from 1635. Therefore, overseas markets had practically no influence on the price of foods items in Japan until it was forced to open up to international trade in 1858 (Huber 1971). The opening up of Japan's economy coincided with an increasing integration of Asian rice markets (Cha 2000), including Japan, and a much higher integration of Japan's regional markets. This corresponded with the disappearance of famine from Japan, but not China and India.

Section 2 of the paper draws attention to some of the idiosyncrasies of grain growing in Japan, evidence of asymmetric shocks on rice markets, and also details of the famine relief policies in Tokugawa Japan. Section 3 examines price data and information on climate anomalies and famines. Section 4 analyses the different degrees to which regional rice markets were integrated and the roles that Osaka played as leading markets. Section 5 establishes how regional markets functioned during each episode of famine during the 18th and 19th centuries by using an Error Correction Model approach. Section 6 concludes with an explanation for the apparent contradiction for Japan experiencing superior market integration and famines during 1717-1857, compared to China and India, and concludes that superior allocative market performance may be part of Japan's leading role during Asia's Little Divergence.

2. Climate anomalies and crop failures as asymmetric shocks

A large part of the Japanese archipelago has a sub-tropical or temperate climate with generous rainfall.[5] Nevertheless, most regions are exposed to recurrent climate anomalies that severely affect rice yields. To a lesser extent, these anomalies also affect the yields of other staple crops

[5] The region along the coast of the Inner Sea has relatively low rainfall. However, the combined effects of sustainable forest use, sophisticated water management, and market integration explain that the region did not experience drought-induced famine since the early modern period (Saito 2002).

that accounted for a substantial share of food supply until the second half of the 19th century.[6] High levels of ecological vulnerability, related to climate anomalies, have been identified across the Japanese archipelago (White 1995). The historical magnitude of some of the subsequent crop failures can be assessed on the basis of fiscal revenues, since a major part of tax obligations was assessed in rice and tax exemptions were granted in regions affected by crop failures as a relief measure. For example, data covering most feudal domains (*han*) of western Japan indicate that, in 1732, the first year of *Kyōhō* famine, fiscal revenues were in a range of 10 to 50% of the preceding five-year average (Kikuchi 1997: 88).

Temperature, rainfall, and wind velocity data are not available for Japan before the end of the 19th century. However, various sources have recorded climate anomalies for several regions of Japan since the 7th century. They also mention years of famines and indicate the regions that were most affected. Saito (1966) offers a comprehensive compilation of data from these sources, which indicate the occurrence of six different types of hazards: droughts, low summer temperatures, cyclonic winds, floods, locust infestations, and earthquakes.[7] These sources also report four types of climate anomalies: drought, floods, cold winter, and cold summer, usually associated with persisting rainfall (when the monsoon lasts until mid or late August).

The winter months are usually dry in most Japanese regions. Rice and other crops therefore depend critically on spring rainfall. Low rainfall during May-June tends to result in below average crop yields. Drought and floods were generally related to *El Niño/La Nina* oscillations.[8] Regional patterns can also be identified. For example, dramatic floods due to typhoons tend to affect the islands of Kyūshū and Shikoku more frequently than the rest of the country. Northern Japan was particularly sensitive to low late summer temperatures and high precipitation due to the northeast winds (*Yamase*). As indicated in Figure 1, it seems that, overall, natural hazards were more frequent in eastern Japan.

[Figure 1 around here]

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[6] Until the late 19th century, cereals other than rice (barley, wheat, and millet) along with buckwheat, soybeans and other beans, played a major role in the nutrition in rural areas. In some areas, roots and tubers played an important role, in particular sweet potatoes in Southeast Kyūshū. On average, rice accounted for about half of the quantity of staple foods consumed (Umemura *et al.* 1983: 246).
[7] It is likely that locust infestations were related to climate anomalies. Earthquakes had a limited impact on agricultural output, except when causing dykes to break.
[8] Sakashita *et al.* (2016). Major *El Niño* events took place in 1720, 1728, 1791, 1828, 1877-78, 1925-26, 1982-83, and 1997-98 (Yamakawa 1999).

One reason for the severity of famine in Japan was that the general standard of living of most of its population was in normal years barely above subsistence level. Even in Kyōto and Edo, the level of welfare of unskilled workers was comparable to those in Milan or Madrid, which were in the lowest ranges of European cities, and roughly the same as in Beijing and Guangzhou in China (Allen *et al.* 2011: 27-28).

An additional explanation for the severity of Japanese famines is related to the limited carry-over of rice stocks due to storage constraints. Rice had a special role in the safety stocks stored in granaries. Unlike other grains, it can be kept as paddy (unhulled rice) for two or three years without spoiling or loss of nutritional value. By contrast, other grains such as barley, millet and buckwheat, tended to spoil rapidly in storage due to the hot and humid climate in most of Japan during July-September. Hence, local communities were able to cope with a single bad harvest year, but their resilience was limited during a succession of poor or catastrophic harvest years. During 1720-1857, the number of years with crop failures exceeds that of famines. A comparison of the dates of natural hazards and famines in a region of Kyūshū shows that excess mortality only occurred after successive years of crop failure (Kalland and Pedersen 1984: 40).[9]

Demographic data reveal high excess mortality during famines, either due to starvation or to pathologies related to malnutrition. Using population census data, Saito (2002: 232) estimates that during the *Tenmei* famine the population declined by 925,000, while the loss of people was 1.1 million during the *Tenpō* famine.[10] The famines hit some regions more severely than others. For example, in the Fukuoka domain (in northern Kyūshū), death registers of Buddhist temples confirm that around 20% of the population perished during to the *Kyōhō* famine (Kalland and Pedersen 1984: 42-43).[11] Records of domains of the Tōhoku region (northeast Japan) indicate that more than 260,000 people died in 1783-1784, the most devastating years of the *Tenmei* famine, which equates to 13% of the population in 1786

[9] The relatively short *Kyōhō* famine that started in 1732 after a series of poor harvests, was mostly due to crop destruction by insects (Kalland and Pedersen 1984: 40).
[10] Earlier estimates by Nakajima (1976) indicate losses of 1,003,986, 1,119,159, and 293,775 people during the *Kyōhō, Tenmei* and *Tenpō* famines, respectively. Hanley and Yamamura (1977) argue that the impact of *Tenmei* and *Tenpō* famines was mostly regional and did not significantly affect demographic change. Their claim is not supported by more recent studies and could at best describe the situation in the core Kinki region around Osaka and Kyoto, although it should be noted that Osaka lost 11% of its population during the *Tenpō* famine (Hayami 1986).
[11] However, the same sources contain few traces of the impact of the *Tenmei* and *Tenpō* famines (Kalland and Pedersen 1984: 32).

(Kikuchi 1997: 161).[12] Saito (2002) argues that, in early modern Japan, famines acted as a demographic corrective, in the sense of a Malthusian check on relative overpopulation, for a given set of resources, institutions, and techniques (Malthus 1798).[13] Indeed, between the early 18th and the mid-19th century, the Japanese population remained at a plateau slightly above 30 million until famines disappeared after the mid-19th century and a steady population growth started that lasted about 100 years.

Cold summer temperature appears to have been the most important single cause of crop failure in Tokugawa Japan. Some of these temperature anomalies were related to massive volcanic eruptions.[14] Grain farmers generally preferred to grow rice, rather than other staple grains such as wheat, barley, buckwheat and millet, because the land productivity of rice was much higher; both in terms of yield per grain sowed, as grain production per hectare. However, rice yields are extremely sensitive to the low temperature of rain or irrigation water during the period when rice seedlings are transplanted to the fields. Yields are also sensitive to low air temperature during the periods of pollination and ripening. The critical daily mean temperature that allows safe transplanting is approximately 15°C and the mean of air temperature for the ripening of the Japonica rice variety is approximately 20°C to 25°C (Ohta and Kimura 2007: 191). This is particularly problematic in the eastern part of the Tōhoku region, where average summer temperatures observed are still only slightly above to the minimum required for rice cultivation.

This sensitivity of Japonica rice to lower temperatures of irrigation water and air is particularly relevant in the context of the impact of the 'little ice age' from the 14th to the mid-

[12] Regional population data reported in Ushio, Kurokawa and Nakamura (1974, 378).

[13] The recurrent waves of epidemics also claimed many lived but their impact on demographic growth was comparatively small (Saito 2002). Jannetta (1992) reached the same conclusion in her study based on death registers from the Hida region (present day Gifu prefecture) during the *Tenpō* famine. The evidence assembled by Howell (1989) suggest a declining demographic trend in villages located in Awa, Kazusa and Shimosa, three domains located at short distance of Edo (present day Chiba prefecture). It should be acknowledged that, in some regions, demographic stagnation resulted from the combined effect of famines and epidemics. In the study based on population registers (*shumon aratame cho*) of Yambe village (in present day Yamagata prefecture, in the Tōhoku region) where mean crude death rates was 2.5% during the period 1760-1870, mortality peaks appeared as result of crop failures (crude death rates of 5.5, 4.0, 5.9, 8.3, and 6.5% in 1784, 1795, 1801, 1824, 1837) but reached comparable levels during epidemic outbreaks of measles, smallpox and other unspecified diseases (respectively 4.4, 4.4, 5.0, and 6.6% in 1782, 1803, 1813, 1848).

[14] The eruption of Mount Asama (in central Japan) in 1783 has been regarded as the main cause of the *Tenmei* famine (Totman 1993: 238-239). Acid volcanic ashes temporarily reduced land fertility in some areas, but the series of volcanic eruptions that occurred in Iceland in 1783 – the *Laki* event – had a more significant impact (Zielinski *et al.* 1994). These eruptions released around 95 megatons SO_2 into the atmosphere over a period of 5 months (Thordarson and Self 2003: 24) and resulted in acid rain, followed after a few months by low temperature across the northern hemisphere, including Japan. The cooling of the northern hemisphere (by -1 to -3°C) lasted for several years (Highwood and Stevenson 2003).

19th century, when global temperatures were below average, also in Japan (Yamakawa 1999; Saito 2010). It is particularly relevant in the colder northeast region of Japan, where farm households faced a trade-off between the risk of crop failure or decreased yields when growing rice and the certainty of lower grain yields when growing other grains, particularly millet, the main staple in the colder northeast region of Japan, even though it too was somewhat sensitive to low temperatures (Walker 2001: 336). In the most advanced regions, double cropping allowed a reduction of the dependency on the main rice harvest. Winter cultivation of barley, wheat, and buckwheat on paddy fields was common in western Japan, although the yields of these crops are also sensitive to abnormally low temperatures. Thus, the yield sensitivity of each staple crop to climate anomalies differed markedly across regions, which means that regional markets and economies were exposed to asymmetric shocks.

The situation was more complex if we consider regional differences in the crop mix. For example, the share of rice in total staple food production was high in the core region of western Japan; the Kinki area around Kyoto and Osaka. Consequently, there was considerable variation across regions in the degree to which total output was sensitive to low summer temperatures. Yield sensitivity to this kind of anomaly was (and still is) higher in eastern part of the Tōhoku region, but during the 18th and 19th centuries rice accounted on average for less than half of total staple output in that part of Japan. Furthermore, normal temperatures were at the time significant below levels today, which exacerbated the exposure to climate shocks in most Japanese regions.

Saito (2002: 229) processed data collected by historians in order to identify the climate anomalies that triggered famines in Japan since the 7th century. He concluded that drought was a major cause of famine until the 17th century, but less common thereafter. In the 18th and 19th century, most famines were triggered by low temperatures and by excessive rainfall in summer. Of the 40 years that recorded a cool (*i.e.* unusually cold) July-August during 1714-1864, 10 were years of famine. Low spring rainfall (dry May-June) was at most a factor aggravating famines: 39 years of dry May-June were recorded for the same period, of which 5 were years of famines (Saito 2002: 229). The most likely explanation for the lower impact of drought during the 18th and 19th century is the conversion of dry fields into irrigated paddy fields that occurred in the 17th century in a context of rapid demographic growth. Irrigation made rice cultivation less dependent on rainfall. The probable downside was that this process of intensification resulted in an increase in the share of rice in the crop mix, and therefore a much higher sensitivity of food output level to low summer temperatures.

Two studies provide information about annual changes in temperature. One comprises a reconstruction of springtime temperature series in Kyōto, based on the date of full blossom of cherry trees (Aono and Kazui 2008). The other contains July temperatures in Edo based on historical documents (Mikami 2008: 192). Both provide information allowing us to assess the role of low temperatures as explanatory factor of famines. The *Tenmei* famine indeed occurred during years with summer temperatures in Edo below the mean of 22°C: 1783, 1784, and 1786. Similar climate anomalies coincided with severe crop failures and local famines in 1728, 1755, or 1758. The *Kyōhō* and *Tenpō* famines also were the results of crop failures triggered by back-to-back years of below average temperatures (*i.e.* a mean temperature in July between 22 and 24°C). This finding indicates that the local economic systems were able to cope with once-off shocks but not to the disruptive impact of back-to-back events, a common feature in famine history (Ó Gráda 2007: 7).

The cost of interregional shipment of rice and other foodstuffs, and the existence of interregional trade barriers in Japan could be explanations for the severity of these famines. Maritime transportation was restricted by the size of the vessels. The Tokugawa government prohibited the construction of large tonnage vessels to prevent unauthorized international trade. Most Japanese interregional roads were unsuitable for bulk haulage. Since there were few bridges, rivers had to be crossed by portage. Shiue (2002) and Shiue and Keller (2007) have shown in the case of 18th century China that high transportation costs do not necessarily prevent market integration. In early modern in Japan too, rice and other staples were extensively traded over long distance, particularly from the key rice producing areas of the Hokuriku region, along the Sea of Japan in western Japan, to Edo or Osaka via the northern (the straits of Tsugaru) and southern (the straits of Shimonoseki) maritime routes, respectively.

Various studies analysed the correlation of price series to establish that a comparatively high degree of regional market integration had been attained since the 18th century (Miyamoto 1963, 1985, 1988; Iwahashi 1981; Shimbo 1985; Kusano 1996). Osaka played a leading role in this trade as the dominant city of the Kinki region, and as Japan's commercial hub. It was also the location of the Dojima rice futures market since 1730, although informal transactions were already common practice in Osaka before that date (Wakita 2001: 537). Edo, at that time one of the biggest cities in the world with a permanent population above a million, was the major destination of rice and other food items shipped either from Osaka or directly from other regions.[15]

Using available freight rate data, it is possible to establish to what extent transportation costs hindered rice trade. In the case of maritime shipment to Edo of rice originating from 10 different locations on the coast of the Bōsō peninsula (present-day Chiba prefecture, east of Tokyo), at a distance ranging between 30 and 150 km, freight rates were roughly equivalent to 3% of the value of the rice shipment per 100 km.[16] The linear relationship between freight rates and distance suggests that, in normal circumstances, the cost of shipment over 1,000 km was at most around 30% of rice price.[17] The difference between prices in Osaka and coastal markets of western and eastern Japan is broadly consistent with this measure of transportation cost. Rice was also cultivated in inland locations. Part of it was collected as tax and shipped to Osaka, Edo and other destinations. In the region corresponding to present-day Nagano prefecture, overland transportation services provided by officially recognized operators were at least twice as costly as shipping by river and sea (Wigen 1995: 33). However, the cost of sending goods by private carrier on horseback was only half the cost of using the official counterpart (Wigen 1995: 49). This implies that the cost of overland and maritime transportation was comparable.[18]

Rice was, by far, the most important commercial item in early modern Japan. On the demand side, rice was the staple food of the urban population and therefore the most important single consumption item for most urban households.[19] On the supply side, a significant part of rice output was collected as taxes by local rulers (*daimyō*), (or by the national ruler or *Shōgun*) and then either sold to merchants in Osaka and Edo, or locally. Part of the proceeds of these taxes was distributed to military officers (*samurai*) as stipend (part of it being sold by *samurai* to local urban merchants). According to estimates by Miyamoto (1988: 22) for the early 19th

[15] The *Shōgun* government imposed the alternate residence system (*sankin kotai*) on the *daimyō* (Totman (1993: 108-111, 150-152). They were required to reside alternatively in Edo and in their domains. Part of the rice or other items collected as tax in domains had to be shipped and sold in Osaka (or other markets) in order to finance expenditures by the *daimyō* and their entourage in Edo.

[16] Based on data reported by Ogasawara and Kawamura (1982: 173).

[17] Most regional markets were located at a distance in a range between 50 and 1,000 km of Tōkyō or Osaka. The maximum length of maritime routes was around 1,500 km (*e.g.* from Echigo, on the coast of the See of Japan, to Edo). Suzuki (1965, 43-56) discusses rice transportation but provides only limited information on freight rates.

[18] In that case, the cost of land transportation of 100 kg rice would have been around 3% of the value of the shipment. This may seem implausibly low, but we have to remember that 3 kg rice was roughly equivalent the weekly intake of an adult male, if rice was the staple food. At Edo or Osaka prices, 3 kg rice was equivalent to around 4.5 kg of barley (Mitsui Bunko 1989: Tables 7 and 8), which has about the same caloric and protein content as rice, and was the main staple of rural commoners in a large part of Japan.

[19] *Samurai*, merchants, and craftsmen, and their dependants, altogether more than 10% of the population.

century, out of a total average yearly rice output of 27 million *koku*[20], 7.20 million *koku* was collected as tax, of which 4.97 million was available for sale (around 27% and 18% of total rice output, respectively). According to the same estimates, agricultural producers had on average a yearly surplus of 1.36 million *koku* for sale to local merchants (around 5% of total rice output).[21] We can gauge, at the regional level, the importance of the shipments to Osaka and/or Edo by *daimyō* in the 19th century, as percentage of rice output, by combining information on rice shipments in the Bunsei era (1818-1829) and regional data on agricultural output in the early 1880s Meiji period.[22] Shipments by *daimyō* accounted for 12%, 19%, and 14% of rice output in respectively the Shikoku, Chugoku, and Kyūshū regions in central and southern Japan (mostly to Osaka), and 4% in the Tōhoku and Hokuriku regions in western and northern Japan.[23]

Tokugawa Japan was, in normal circumstances, a free trade area.[24] However, when faced with a succession of bad harvest years and the outbreak of a famine, the *daimyō* introduced emergency trade restrictions, including a ban on rice shipments to Edo and Osaka.[25] A ban on shipment could make sense as a temporary emergency measure enforced by the *daimyō*, when the price elasticity of demand was higher for urban residents than for rural consumers. This was clearly the case in early modern Japan; living standards were much higher in Edo, Kyoto, and Osaka, and probably in most castle towns, than in the rural areas.

A quantitative assessment of the impact of trade restrictions during Japanese famines is impossible due to the lack of data. However, private traders in Osaka purchased only around 1.5 million *koku* and the Shogun received directly in Edo 0.4 million *koku* from the surrounding Kanto region (Miyamoto 1988: 23), which is equivalent to 5.5% and 1.5% of total rice output, respectively. The main part of the interregional shipments (*i.e.* across the borders of the domains)

[20] One *koku* is equivalent to 180 litres, or about 150 kg in the case of husked rice. By convention, rice output was measured in Japan in husked rice equivalent.

[21] Miyamoto (1988) also indicates that, due to wastage (estimated at 0.15 million *koku*), the quantity actually available consumption in urban areas for direct consumption as food was 3.35 million *koku*, while 1.5 million *koku* was used for processing as sake, vinegar, confectionery and other products. He does not provide details regarding the share of rice collected as taxes in total wastage.

[22] Estimates of average yearly shipment of husked rice to Osaka from 8 domains (Banshu, Dewa, Choshu, Kaga, Kumamoto Hiroshima, Saga, Toride) in the Bunsei era (1818-1830) reported in Miyamoto (1981: 283, Table 3). Regional yearly output series are unavailable before the 1880s. Considering that total population remained stable until the 1870s, rice output in early Meiji is an acceptable proxy for the late Tokugawa period.

[23] Shipments to both Edo and Osaka for the Tōhoku, almost entirely to Osaka and other markets of western Japan for the Hokuriku region.

[24] Although in principle internal migrations were subject to restrictions, large numbers of people travelled across the country, including officials on missions, merchants, and craftsmen. Commoners travelling during weeks or months for pilgrimages accounted for the largest numbers (Vaporis 1994).

[25] The *daimyō* used to ship to Osaka or Edo the rice that had been already sold in advance, probably in an attempt to maintain their reputation. They imposed trade restrictions and granted tax exemptions only in case of recurrent crops failures. The gap between rice spot prices and futures prices tended to increase during famines.

was rice collected as tax. Hence, what really mattered in most regions was the decision of the *daimyō*, in the event of a crop failure, to ship outside their domain rice collected as tax, which they had sold in advance to Osaka or Edo merchants.[26] Anecdotal evidence suggests that the *daimyō* were inclined to take the risk of reducing locally available food supply below subsistence level in order to preserve their reputation among Osaka traders, when the crop failure occurred after a sequence of reasonably good harvest years, but that they tended to default in the case of a repetition of crop failure years (Kikuchi 1997).

Apart from trade restrictions during famines, *daimyō* could also grant partial or total land tax exemptions. This reduced the quantity of rice sold by local public authorities outside the domain and presumably had a positive impact on the local availability of rice. Other measures commonly adopted during famines were the distribution of rice from public granaries and the prohibition or restriction of the processing of rice for *sake* (Iwahashi 1981), which also tended to increase the local supply of rice.[27] Staples other than rice, which in the whole of Japan accounted on average for about half of total staple food consumption in rural areas, were mostly produced for self-consumption.[28] When traded, the relatively low unit-prices of these staples (compared to rice) made their shipment uneconomical over long distances.[29] Information on crop failures for staples other than rice is not available. However, regional level yearly series for the late-19th century suggests that the impact of climate anomalies was relatively low. Hence we can suspect that rice crop failures, which resulted in peak levels in rice price series, aggravated famines to a greater degree than variations in the output of other staples.

3. Regional rice prices, climate anomalies and famines

This section analyses regional rice prices to establish the extent of market integration in Japan, and the market responses to natural disasters and famines. It also examines the sources of data

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[26] It should be acknowledged that, in some cases, the rice sold in advance to Osaka merchants was not actually transported to Osaka or Edo but either sold locally or in other neighbouring regions. Osaka and regional merchants were accustomed to trade titles of ownership of rice without implementing a physical transaction.

[27] Data on quantities of rice distributed or saved are fragmentary and do not allow an assessment of the impact in terms of famine alleviation.

[28] The major exception was wheat. However, production and consumption data for early Meiji suggest that this cereal accounted for only a small percentage of Japanese food supply in Tokugawa Japan. Barley was also an important staple food (particularly for rural households). The breakdown of wheat and barley output is unavailable before the second half of the 19th century.

[29] The prices of wheat and barley (the second most important staple) in Osaka fluctuated in line with the price of rice, which is not surprising as it was a close substitute. Unfortunately, regional prices of staples other that rice are unavailable before 1874.

on regional natural hazards and famines. The analysis is constrained by data availability. Rice is the sole item for which continuous regional data have been collected by generations of Japanese historians. However, except Osaka, price data for markets across Japan are available only on a yearly basis or as biannual series in the case for Edo and Kyōto.

Yearly rice prices are available for 13 markets during 1720-1857: Banshū (near Himeji city), Bocho (present-day Yamaguchi prefecture, Hagi is the castle town), Fukuchiyama, Hiroshima, Osaka, Saga, and Kumamoto, in western Japan; Nagoya in central Japan; Aizu, Dewa (Shonai domain, Tsuruoka is the castle town), Echigo (Nagaoka is castle town), Edo, Sendai, and Yonezawa in eastern Japan (see Figure 2).[30] Table 1 provides information regarding the localization of these markets and their distance to Edo and Osaka.[31] Price data are for the new rice of the year (*shinmai)* that commanded a premium over old rice (in store from previous years). Price data in western Japan were expressed in silver *monme* (weight of 3.75 grams) and in eastern Japan in gold *ryo* (approximately 15 grams of pure gold).[32] Series reported in gold *ryo* are converted into silver *monme* by using the gold value of silver *monme* in Osaka implied by rice prices expressed both in *ryo* and *monme*.[33]

[Figure 2 around here]

Apart from conversion factors, there are two issues that are specific to these prices: (a) they were recorded by local administrations for local accounting purposes and may not be

[30] Apart from Edo and Osaka, these data were recorded in relatively small cities. Edo had above one million inhabitants during this period, and Osaka around 400,000. Nagoya had around 120,000 inhabitants, and other cities between 10,000 and 50,000). Price data for Banshu are for a rural market close to Himeji; data for Sendai are also for a nearby rural market from 1834. Available series for Kyoto do not cover the entire period under investigation. Information on retail prices of rice in Osaka and Kyoto reported in Mitsui Bunko (1989) indicates that rice prices were similar in Kyoto and Osaka. Fukuchiyama is located in the present-day Kyoto prefecture (close to the Sea of Japan), but it is at a greater distance from Kyōto than Osaka. Price series for Yonezawa were not used due to missing data. Prices series for Shinshu and Minami Shinano (in present day Nagano prefecture), that cover the entire period studied, differ until 1735 but are almost identical for the rest of the period for reasons that are not reported; both series were ignored.

[31] These regional rice prices series are adjusted for changes in quality for a given market (Iwahashi 1981, Yamasaki 1983). Within a given local market, it was common to distinguish between high, medium, and low quality rice. In Osaka and other major markets, differences in quality were related to the region of origin (local varieties). Osaka prices show that differences related to varieties of rice (and therefore origin) remained stable over time.

[32] Japan had a bimetallic gold-silver system, auxiliary copper coins (*mon*) were used for small transactions. Rice was *de facto* the fourth currency: land taxes were measured in rice, although partly paid in silver (Yamamura 1988), and so were also the stipends paid by *daimyō* and the Tokugawa government to their *samurai.*

[33] Information on gold price in Osaka is available from 1717 onward. The gold-silver exchange rate was fairly stable at around 60 *monme* per *ryo* over the entire period, except during the first three years. This suggests data problems and was the reason to start this study in 1720 rather than 1717.

market prices, and (b) they are annual prices, where monthly prices would be better suited to analysing market integration.

As to the first issue, a close examination of the data suggests that prices recorded by the administration were not administrative prices. They reflected in fact wholesale market prices, because the local administration recorded the selling price for large amounts of rice that were collected as tax. Price volatility, measured as coefficients of variation for 3 or 5-year periods in each market, did not differ markedly across regions. The price volatility in the price data suggests therefore that prices recorded by the local administration are good proxies of the actual market prices, as Figure 3 confirms. Prices in gold *ryo* and in silver *monme* for Osaka, prices in silver *monme* for Bocho, Fukuchiyama, Banshu, Hiroshima, Kumamoto, Nagoya, Saga, and prices in gold *ryo* for Aizu, Dewa and Edo are from Iwahashi (1981); prices in gold *ryo* for Echigo, Sendai, and Yonezawa, are from Yamasaki (1983). Most prices were recorded for cities or towns that are either seaports or river ports at short distance of the estuary, with the exception of Aizu and Dewa which are located inland.[34]

[Figure 3 about here]

The short-term and long-term rice price volatility in Osaka is highly correlated with variations in the overall level of consumer prices. This largely reflects the high weight of rice in any consumer price index that can be calculated on the basis of plausible expenditure baskets. Additional explanations are that rice is an important input in the processing of some other important consumer goods, such as rice wine (*sake*) and rice vinegar. In addition, part of the urban wages in cottage industries were partly paid in kind and traditionally measured in terms of a quantity of rice. Overall, rice prices were more volatile than those of other consumption items, which suggests a lower income elasticity of demand for rice than for other items. If so, it is likely that the current incomes and savings of most urban households allowed them to maintain their consumption of rice at level instead of having to change to consuming cheaper substitutes such as barley, naked barley, millet, buckwheat, sweet potatoes, or other tubers, when rice prices increased.[35]

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[34] Tsuruoka is 23 km from the port of Sakata. Due to the geography of Japan, particularly the elevation of mountain ranges and the importance of maritime transportation, it is not appropriate to use the straight-line distance in order to assess transportation cost to Osaka and Edo, the major destinations for rice collected as tax revenue.

[35] Nevertheless, these grains were commonly consumed in urban areas as well; barley as porridge and wheat mostly as noodles. Wheat was also an important input for other products of the food processing cottage industry, and barley was also used as animal feed.

As to the second issue, it would be best to use monthly prices to analyse regional market integration for agricultural commodities that are produced in an annual cycle. Nevertheless, it appears acceptable to rely on yearly series that were recorded in October or November for two reasons. Firstly, the only market for which monthly prices are available – Osaka – shows a high degree of seasonality of the wholesale rice price.[36] In other words, prices were fairly stable for most of the year between the harvest in September and the month of June. The average of the 3-month period (centred) coefficient of variation (CV) for 1821-1857 is between 0.024 and 0.031 in January-April, but increased markedly between 0.041 in May and 0.085 in September before gradually decreasing to 0.033 in December. This can be interpreted as the result of Osaka merchants forming expectations between May and September about the coming rice harvest on the basis on information received from different regions on climate conditions and events such as typhoons. The CV decreased after the rice harvest in September and remained at a low level until into May. Interregional rice shipments mostly took place after the harvest, between September and April (Iwahashi 1978: 174), during which rural manpower was available for land transportation by horseback or portage to seaports or ports of river navigation.

A second justification for the use of yearly prices is that local prices were influenced by the harvest in the previous year and by expectations about the next harvest, but also by the remaining stocks from previous harvests stored in public and private granaries. Rice storage by the *daimyō*, by private merchants and by producers themselves provided a buffer in the event of crop failure of rice and other staples. Thus, in addition to the demand of urban consumers, the demand for rice was also related to its role as a food safety stock, particularly in regions where non-rice emergency crops were not available.[37] The increase in the CV of monthly prices in Osaka during June-September was not only determined by expectations about the coming harvest, but also by the amounts of paddy from previous years stored by Osaka merchants, and possibly paddy storage in other regions.[38] Freshly produced rice traded at a premium, but, regardless of the preference for the newly produced rice, the old rice was a close substitute, particularly in the event of crop failure. Therefore, a low level of stocks due to rice crop failures

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[36] Monthly rice price data are from Miyamoto (1963: 122-124). On rice price seasonality in the Osaka market, see Miyamoto (1975: 225).

[37] That was the case in a major part of eastern Japan. Sweet potato, the main staple in southern Kyūshū, was commonly grown as an emergency crop in coastal areas of western Japan (along with yams and other roots and tubers). Its cultivation slowly expanded eastward in the 19th century. American potatoes were known, but their cultivation was not very significant until the Meiji era.

[38] Miyamoto (1975) offers a study of the relationship between the level of storage and price for the period 1724-1859. Unfortunately, little information is available on the quantities of rice stored in other regions.

during previous years influenced the price of the new rice. This supports the suitability of annual rice prices to analyse market integration.

A third reason to persist with yearly prices is that these have been commonly used in studies on market integration, as often being the only available data. Annual data have been used to study market integration, *e.g.* in early modern Europe (Persson 1999: 68-70; Jacks 2004, 2005), in 18th and 19th century India (Studer 2008), and between Asia and Europe in the 17th and 18th centuries (De Zwart 2016) and the 19th and early 20th centuries (Chilosi and Federico 2015). Apart from availability, a reason justifying the use of annual data is that regional price adjustment was long a relatively slow process. As Studer (2008: 413) argued, even in Europe price adjustments remained until the 1870s a relatively slow process that involved many months if not years, rather than weeks. Only the spread of faster and more cost-efficient transport and communication facilities, *i.e.* steamships and telegraph, changed this. Lastly, yearly data are well suited for the analysis of market integration using an Error Correction Model for time series analysis (see section 5 below).

Regional-level information on natural hazards and famine years has been compiled and summarised in Saito (1966) in binary terms, *i.e.* existence or absence for a given region and a given year of excess rainfall or drought episodes or of famine. Figure 4 shows the sample of regions for which we have price data. The identifies famine years do not differ markedly from the information for the 46 Japanese regions. Our sample can be therefore regarded as representative. Using additional information reported in Saito (1966), Figure 5 shows for each region of our sample the number of years with excess rainfall and with drought. It appears that the number of natural hazards is not correlated with the number of famines. In Figure 6, the histogram of the markets affected by either excess rainfall or drought in any given year reveals that the peaks in the series do not match the timing of the famines. This suggests that the three major famines that affected Japan during the period studied resulted from the conjunction of adverse climate conditions in a number of regions rather from specific local shocks inducing local crop failures.

[Figure 4 around here]

[Figure 5 around here]

[Figure 6 around here]

4. Price convergence and the role of Osaka as leading market

This section analyses two related aspects of regional market integration; price convergence and price adjustment. Firstly, a simple comparison of deviations from trend of annual rice prices in the two largest rice markets in Japan in Figure 7 reveals that rice prices were relatively volatile in the two major urban markets of Osaka and Edo during much of the 18th and 19th centuries. Nevertheless, rice prices spiked in both markets during the key famine periods, as well as other years, but not in all, so that there appear to have been symmetric and asymmetric shocks impacting on Japan's rice market. Hence, the correlation between annual deviations in both markets is imperfect, but the correlation coefficient is high at 0.71.

[Figure 7 about here]

The high level of Japanese regional rice market integration during the 18th and early 19th century is evidenced by the price correlation between pairs of markets (Miyamoto 1988, 394-395) associated with the role of the Osaka rice market, shown in Table 1. As expected, price correlation with Osaka was higher with rice markets of western and central Japan that were located at relatively short distance, and higher with market of eastern Japan. Although geographical distances were relatively short the mountainous terrain required rice shipment by sea. For instance in the case of Echigo, rice shipment to Osaka took a long maritime route, the most convenient one being along the coast of the Sea of Japan and the straits of Shimonoseki. Nevertheless, Table 2 shows that Japan had achieved a higher degree of market integration than China (Yangzi River area) and Europe (mostly the western part) calculated by Shiue and Keller (2007) for the late 18th century. The high level of integration relative to China is confirmed by a comparison of rice markets cointegration in Japan and China for the period 1791-1831 showing that, although the level of market integration in the Yangzi Delta was comparable to Japan, it was lower than in Western Japan, and lower for China as a whole than for Japan as a whole (Yao & Zheng 2016: 259). Table 2 also reveals that Japanese market integration in the mid-19th century (a period that includes the *Tenpō* famine of 1833-1838) was comparable to Europe and much higher than in India.

[Table 1 about here]

[Table 2 about here]

We analyse the same issue on the basis of the coefficient of variation (CV) of regional prices, which is a simple measure of price convergence. Figure 8 confirms that the CV for the 13 markets decreases until the 1833-1838 *Tenpō* famine.[39] However, a different impression emerges when the CV is disaggregated for eastern and western Japan. Clearly, the CV was significantly lower in western Japan and at a level that indicates a high degree of market integration since the early 18th century, associated with the role of the rice market in Osaka. Much of the convergence of rice prices across Japan in Figure 8 was the result of market integration in western Japan. By contrast, rice markets in eastern Japan (Edo, Aizu, Dewa, and Echigo) were much less integrated, as Figure 8 shows. These results are sensitive to the choice of the period, in particular to the exclusion of the famines years of the 1830s. As price data for additional markets in eastern Japan are not available for inclusion in the comparison of CVs, the analysis proceeds with price adjustments in response to shocks.

[Figure 8 about here]

As expected, rice prices were very similar in Osaka and Edo and the two markets were highly integrated. The fact that rice prices were on average 8% higher in Edo than in Osaka during 1720-1857, suggests that Osaka customers enjoyed gains resulting from the higher degree of market sophistication than Edo consumers, because Edo's rice futures market was not established until 1810 (Suzuki 1965: 163).

Rice prices in western Japan fluctuated within a relatively narrow band relative to Osaka prices (±10% using a 3-year moving average; ±20% using annual data), which implies that the cost of transactions was quite low. The differences in the level of prices are mostly explained by the cost of moving goods and the situation seems to live up to the law of one price. Prices were almost constantly below Osaka level in Saga, a region with a structural rice surplus, and well above Osaka level in Hiroshima, Banshu, and Fukuchiyama. It seems therefore that the role of Osaka market as main hub for rice trade and the sophistication of market mechanisms resulted in economies of scale and efficiency gains compared with regional markets that were located at a relatively short distance.

[39] The *Tenpō* famine had a long-lasting effect on regional market disintegration in eastern Japan, relative to conditions in the pre-famine period. Okazaki (2005) argues that price arbitration declined following the merchant coalition prohibition in 1842. However, the CV of regional prices increased in eastern Japan before that date, in relation with the *Tenpō* famine, while it remained stable in western Japan, as Figure 8 shows.

By contrast, rice prices in eastern and central Japan markets were almost constantly below Edo levels and fluctuated in a wider band. This indicates that regional prices were subject to a greater degree to asymmetric shocks, combined with the effects of high transportation costs, seasonality in transportation, and the carry-over of rice stocks from earlier years (either for commercial purposes in the case of merchants holding stocks, or as a buffer against the risk of crop failures in the case of public authorities and farmer households). It is not surprising to find large deviations from what could be perceived intuitively – in absence of specific detailed information on transportation costs – as the band equilibrium between pairs of markets. This feature has been observed in other countries where a high degree of seasonality of transportation existed, for example in 18th and 19th century India (Studer 2008).

In order to evaluate regional integration and to assess whether Osaka and Edo were leading markets, the analysis uses a Vector Autoregressive (VAR) model with a Granger Causality Wald Test. Testing price series for non-stationarity using Augmented Dickey-Fuller tests with a trend and 2 lags enables us to reject the null hypothesis for all markets at the 1% level.[40] The implication is that rice was transferred from surplus regions to Osaka or Edo and that part was from there eventually transferred to deficit regions. For that reason, we should expect to find a causality running from price determination in Osaka and/or Edo to price setting in regional markets. Due to the seasonality of transportation, high costs of transhipment, and the fact that regional prices were influenced by the size of the local harvest and by local storage capacity, it is likely that price adjustment was not instantaneous in most regions and that producers and local merchants were price takers. Although the low price level, relative to Edo, in some markets of eastern Japan indicate high costs of shipment to Edo, we should not expect autarky prices in these regions. As indicated in section 3, sizable quantities of rice were shipped to Edo or Osaka by *daimyō* and local merchants from all over Japan, including from some remote inland domains. In order to tests these different hypotheses, for each market the analysis estimates the following VAR model in log form:

$$\Delta P_{i,t} = \alpha + \beta \Delta P_{i,t-1} + \gamma \Delta P_{j,t-1} + \delta \Delta P_{k,t-1} + \chi \Delta P_{l,t-1} \cdots + \varepsilon \qquad (1)$$

The dependent variable $\Delta P_{i,t}$ is the yearly variation of the rice price in market *i* for year *t*, while the variations of the rice price in *t-1* in market *i* and in other markets *j, k, l etc.* are independent

[40] Further testing with 3 lags yielded similar results: (above or close to 5% level for all markets, except Aizu which is at the 10% level.

variables. The analysis estimates equation (1) pair-wise for all rice markets, assessing Granger causality using Wald tests. Table 3 presents the results for binary relationships for which the null hypothesis (no Granger causality) is rejected with p-value at the 10% threshold.

[Table 3 about here]

Prices in most markets of western Japan were driven by changes in Osaka. As the most important rice-producing region of northern Kyūshū, with a structural rice surplus, Saga played an understandable role in the determination prices in nearby Kumamoto, but also in Banshu and Hiroshima in western Japan, in Aizu and Edo in eastern Japan, as well as Fukuchiyama and Echigo that were located close to the coast of the Sea of Japan. The last two relationships highlight the importance of the maritime route linking the Pacific coast of western Japan and the regions on the coast of the Sea of Japan. The fact that a causality is also identified from Saga to Osaka indicates that the functioning of regional Japanese rice markets was more complex than a straightforward price determination in Osaka in relation to the role of the Dojima rice futures market located in the city. No clear picture emerges for eastern Japan, except the absence of any influence from Edo. The results regarding role of Osaka and Saga are robust to the exclusion of the peripheral surplus markets of eastern Japan. Considering that price volatility was lower in Osaka than in Saga, and the fact that the only Japanese rice futures market was located in Osaka, it appears safe to follow the conclusions of Japanese historiography that identified Osaka as the leading market is spite of some ambiguities in the results of the causality test.

5. Markets functioning during famine episodes

Having established the degree of integration of Japan's rice markets, the question now is how they functioned during periods of famine and to what degree they mitigated famines during the 18th and 19th centuries. This section uses an Error Correction Model (ECM) for that purpose. The methodology is congruent with that adopted by Ó Gráda (2001) and Ó Gráda and Chevet (2002) to study the functioning of markets during famines in 19th century Finland, and late 17th

and early 18th century France.[41] It would be possible to measure error correction coefficients for any pair of markets. However, section 4 substantiated Osaka's role as the leading market. For that reason, this study focuses on processes of price adjustment *vis-à-vis* prices in Osaka.

While Ó Gráda (2001) and Ó Gráda and Chevet (2002) relied on monthly data, the analysis in this section uses annual data for reasons discussed in section 3. Their findings underline that the ECM approach suits annual data as well as monthly data. The first step is to estimate the following standard ECM:

$$\Delta logP_{i,t} = \alpha + \beta\Delta logP_{A,t} + \gamma(logP_i - logP_A)_{t-1} + \varepsilon \qquad (2)$$

For each market *i*, the constant term α indicates the price gap with the leading market *A*, while the coefficients β and γ indicate respectively the synchronisation of prices in *i* and *A*, and the speed of adjustment of P_i to the difference between P_i and P_A in *t-1*. If markets are efficient, the two conditions that should be met are $0 < \beta < 1$ and $\gamma < 0$. The results of estimating the model are in Table 4. All β and γ coefficients are significant and have the expected sign. In all cases the coefficient α is also significant. The error correction coefficients estimated on the basis of annual price data for Japanese regional markets are in a range between -0.428 (Dewa) and -0.866 (Hiroshima). This compares to an implicit annual estimate of -0.648 (= 12 months × -0.054) in the case of Toulouse and Angoulême during 1680-1712 (Ó Gráda and Chevet 2002: 725). Although these estimates indicate that there were delays in the co-movement of regional prices and that the entire correction of price differentials in response to a shock required more than one year, the fact that most markets in Japan were at a greater distance to Osaka than the distance between Toulouse and Angoulême confirms the high degree of regional market integration in 18th and 19th century Japan, compared to France in the late 17th century.

[Table 4 about here]

The next step consists of measuring how markets functioned in response to exogenous shocks by considering natural hazard and famine variables. For that purpose, the analysis specifies a more elaborate ECM, which is an extension of equation (2) and a variant of the analysis used in Ó Gráda (2001: 583-584) and Ó Gráda and Chenet (2002: 723-724). The

[41] Due to the lack of precise information on the cost of transportation between pairs of markets, we cannot adopt the Threshold-ECM method used by Ejrnaes and Persson (2000), and Jacks (2005).

variation takes account of the 1732-1733 *Kyōhō*, 1783-1786 *Tenmei*, and 1833-1838 *Tenpō* famines in order to establish whether these famine shocks were symmetric and affected all rice markets equally, or not. The *Tenmei* famine resulted mostly from a series of volcanic eruptions in Iceland in 1783 that induced a significant cooling across the northern hemisphere during several years. It can therefore be expected that regional markets of northeast Japan were more synchronised during that famine than during the *Kyōhō* and *Tenpō* famines. The model to test this is an extension of equation (2) and specified as follows:

$$\Delta logP_{i,t} = \alpha + \beta\Delta logP_{A,t} + \gamma(logP_i - logP_A)_{t-1} + \delta_{KH}DFam_{1KH} + \delta_{TM}DFam_{1TM} + \\ + \delta_{TP}DFam_{1TP} + \zeta DFam_2(logP_A - logP_i)_{t-1} + \varepsilon \qquad (3)$$

$DFam_1 = DFam * \Delta logP_{A,t-1}$ during famines years
$DFam_{KH}$ = 1 during the *Kyōhō* (KH) famine years 1732-1733, 0 in other years
$DFam_{TM}$ = 1 during the *Tenmei* (TM) famine years 1783-1786, 0 in other years
$DFam_{TP}$ = 1 during the *Tenpō* (TP) famine years 1833-1838, 0 in other years
$DFam_2$ = 1 during famine years, 0 in other years

If $\delta < 1$, markets are less synchronised during famines than normally, and if $\delta > 0$ markets are more synchronised and integrated, while $\zeta < 1$ implies that markets adjust more slowly during famines.

Table 5 presents the results of estimating model (3) with Osaka as leading market. Estimates of ζ are positive and significant for a number of regional markets, which indicates that they adjusted more slowly during famines: Banshu and Hiroshima in western Japan, Aizu, Dewa, Echigo, and Sendai in eastern Japan. The coefficient is not significant for Bocho, Fukichiyama, Edo, and Saga, which indicates that the adjustment process in these markets was the same during famine years. Looking at the estimates of δ, coefficients are significant in only a few cases. They are always negative, which indicates a lower synchronisation during famines. Banshu and Fukuchiyama in western Japan, Aizu, Dewa, Nagoya and Sendai in eastern and central Japan, were less synchronised during the *Kyōhō* famine. Hiroshima was the sole market less synchronised during the *Tenmei* famine, confirming this was a mostly symmetric shock, as expected. During the *Tenpō* famine, only Banshu and Hiroshima were less synchronised. Consequently, it appears that there is no systematic pattern and that, overall, the functioning of Japan's rice markets did not profoundly change during the three major famines.

[Table 5 around here]

To assess the extent to which local shocks affected price movements, the analysis uses ECM tests with dummy variables specific to each local market and natural hazard (*i.e.* instances of excess rainfall or drought) on the one hand and famines on the other hand. The results in Figure 6 show no correlation between yearly series of natural hazards and the main famine years. In addition, almost no significant result is obtained when replacing DFam1 and DFam2 in equation (3) with region specific dummies, four in total, to represent excess rainfall (Dr1 and Dr2) or drought (Dd1 and Dd2).[42] Using region-specific famine dummies yields positive and significant coefficients for DFam2, indicating a slower adjustment during famines, for Banshu (at the 5% level), Aizu (5% level), and Sendai (1% level). These results are consistent with those presented above when we used a single dummy variable for all markets during famine years.[43] Together, these results indicate that local natural hazards had a limited impact on rice markets. This suggests that the three major famines that affected Japan in the 18th and 19th centuries due to climate anomalies had a limited effect on the functioning of Japan's rice markets. This finding is consistent with the view that these major famines were caused by food availability deficits triggered by exogenous shocks of exceptional magnitude. Japanese buyers could not rely on foreign rice markets to alleviate these shortages due to the relatively high transportation costs and the fact that these climate anomalies also affected Korea and northern China (Sakashita *et al.* 2016).

6. Conclusion

In the context of three strands of recent studies related to the Great Divergence, this paper analysed the degree to which rice markets across Japan were integrated during the Tokugawa period. The paper tried to resolve two issues: (a) the apparent contradiction that Tokugawa Japan had well-integrated markets but suffered from massive famines, (b) whether markets in

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[42] The only exceptions are for Dr1 with Nagoya (negative and significant at the 5% level) and Saga (positive and significant at the 5% level) and for Dr2 with Nagoya (negative and significant at the 5% level). The dummy variables for drought do your yield any significant coefficient is observed for drought.

[43] However, a positive coefficient is obtained for Echigo (significant at the 5% level). For Fam1, the coefficient is significant for Kumamoto (positive) but only at the 10% level.

Japan were better integrated than India and China and that better allocative efficiency could help to explain the Little Divergence across Asia since the late-18th century.

The paper offered qualified evidence of rice market integration in Japan during the 18th and 19th centuries. Overall, regional rice markets were fairly well integrated in normal circumstances. As such, natural hazards did not affect market integration. The resilience of economic systems was put to its limits when such hazards occurred in succession. However, section 5 differentiates between western and eastern Japan. Rice markets in western Japan were well-integrated relative to the rice market in Osaka during 1720-1857. Some regions of western Japan experienced famines in spite of a high degree of regional integration, relatively low transportation costs, and the existence of sophisticated market mechanisms in Osaka. In the event of natural hazards, shipment of rice or other staples grains from surplus to deficit regions was generally possible. Rice markets in eastern Japan markets were also reasonably well integrated if we consider how high transportation costs were, particularly in inland regions that relied on land transportation. However, in the event of famine, regional markets in eastern Japan tended to shift to autarkic prices, possibly due to trade restrictions. Still, the most likely explanation is that transportation costs were so high and disposable monetary incomes so low that shipments of large quantities of rice were uneconomical.

In addition, rice markets in western Japan experienced the impact of the 'little ice age', an episode of low average annual temperatures that lasted until the mid-19th century. It decreased temperatures in Japan and heightened uncertainty and crop failures in rice production, especially in north-eastern Japan. Rice growing in that region was on the cusp of ecological feasibility/vulnerability due to rice being susceptible to lower temperatures of irrigation water and also lower air temperatures during plant growth in summer. This uncertainty required farm households throughout Japan to maintain a high reliance on non-rice grains (barley, buckwheat and particularly millet) as staple grains. These grains accounted for around half of total output of staples. However, they were less-suitable for storage, and therefore trade with distant markets, because of their higher risk of spoilage and the fact that distant markets focused on rice, the preferred staple food throughout Japan. This situation increased the susceptibility in eastern Japan to famine, due to the difficulties of storing non-rice crops in granaries. More importantly, it made it more difficult for rice markets across Japan to work towards alleviating famines in eastern Japan. This shortcoming lasted until the 'little ice age' ended and the risk to households associated with producing rice decreased in the late 19th century. Consequently, non-rice staple grains became less important as farm households switched to rice that was the preferred staple grain and was also better suited to storage and long distance trade.

Japan did not experience any famine during the remainder of the 19th century and during the 20th century in spite of the recurrence of crop failures triggered by climate anomalies.[44] What is more, the population started to expand since the mid-19th century, and the share of full-time employment in agriculture started to decrease. A combination of factors explains this development. Regional prices gradually converged toward the price levels in Osaka and Tokyo around 1900. The power revolution in maritime and, later, land transportation drastically reduced the cost of transport over long distances. Hence, in the event of a crop failure, a rice surplus in the north-eastern Tōhoku region was available for shipment to Kyūshū in the southwest, or the other way around.

Were Japan's markets better integrated than in China and India? Comparisons with other studies led to the conclusion that rice markets in Japan were probably better integrated than grain markets in China and Europe in the late 18th century and early 19th century, and much better integrated than in India in the early 19th century. In addition, since the mid-19th century, when the end of the little ice age resolved the rice/non-rice dilemma for many farm household, eastern Japan became equally well-integrated in national rice markets. Japan has not suffered famine conditions after the 1830s, unlike China and India which were visited by famine well into the 20th century.

Taking rice markets as a proxy, it seems likely that Japan experienced superior allocative efficiency in its markets since the mid-19th century than China and India. Consequently, it was less prone to experience episodes of recurrent food shortages due to crop failures and therefore instances of economic growth 'shrinking' than China and India. It is tempting to conclude that this was a major reason for the Little Divergence in Asia, if the rice market in Japan can be taken as a proxy for the better integration of markets for information, ideas and market opportunities across Japan, compared to China and India. Nevertheless, further research is required to establish whether that was indeed the case.

[44] For example, July temperatures in Tokyo were lower during the first years of the 20th century were lower than during the *Tenpō* famine (Mikami 2008: 192).

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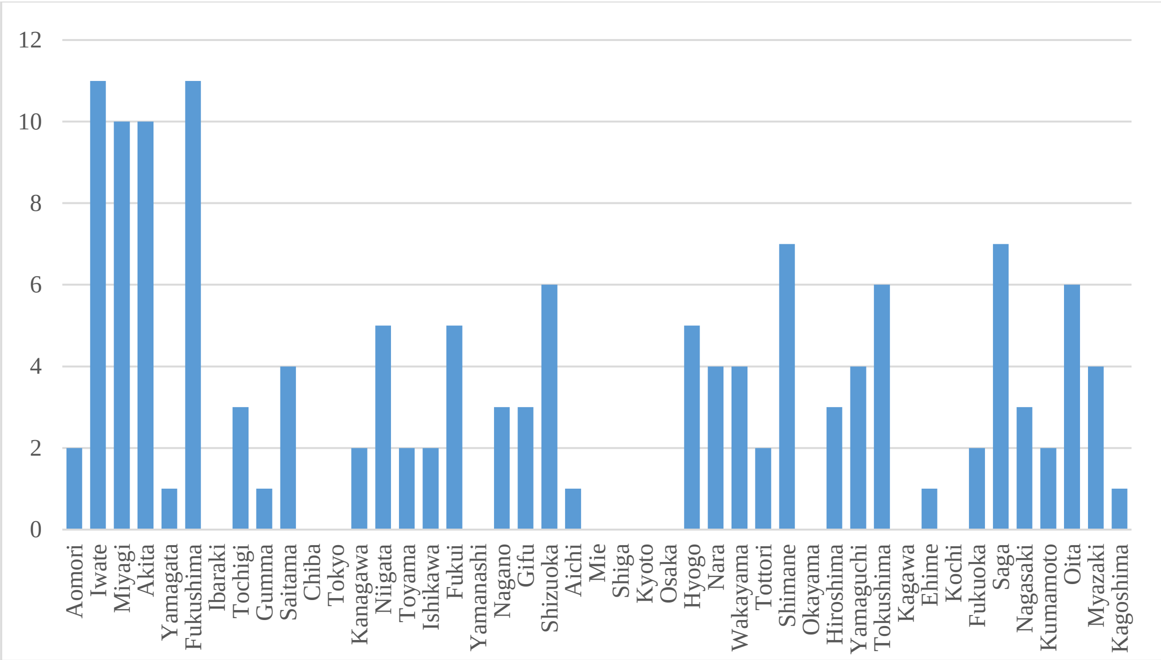

Figure 1: Number of Famine Years during 1720-1857 by Region (46 present-day prefectures, Okinawa excluded)
Source: Saito (1966)

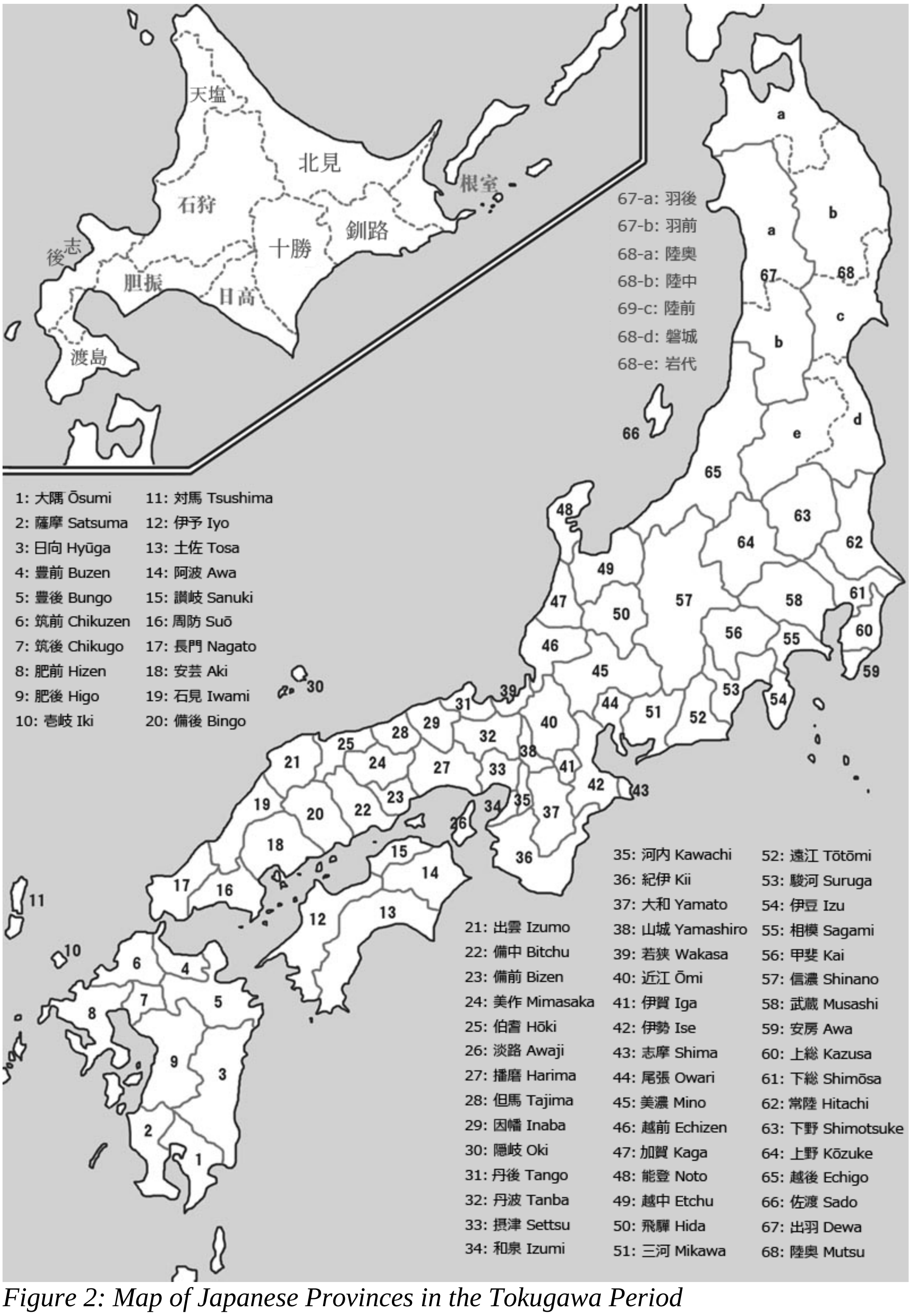

Figure 2: Map of Japanese Provinces in the Tokugawa Period

Notes: The rice market studied are Kumamoto in Higo (province n°9), Saga in Chikugo (7), Bocho centered on Nagato (16), Hiroshima in Bingo (20), Banshu in Harima (27), Fukuchiyama in Tanba (32), Osaka in Settsu (33), Nagoya in Owari (44), Edo at the east of Musashi (58), Aizu in Iwashiro district (68e) and Sendai in Iwase district (68a) of Mutsu province; Echigo and Dewa are the provinces numbered 65 and 67, respectively.

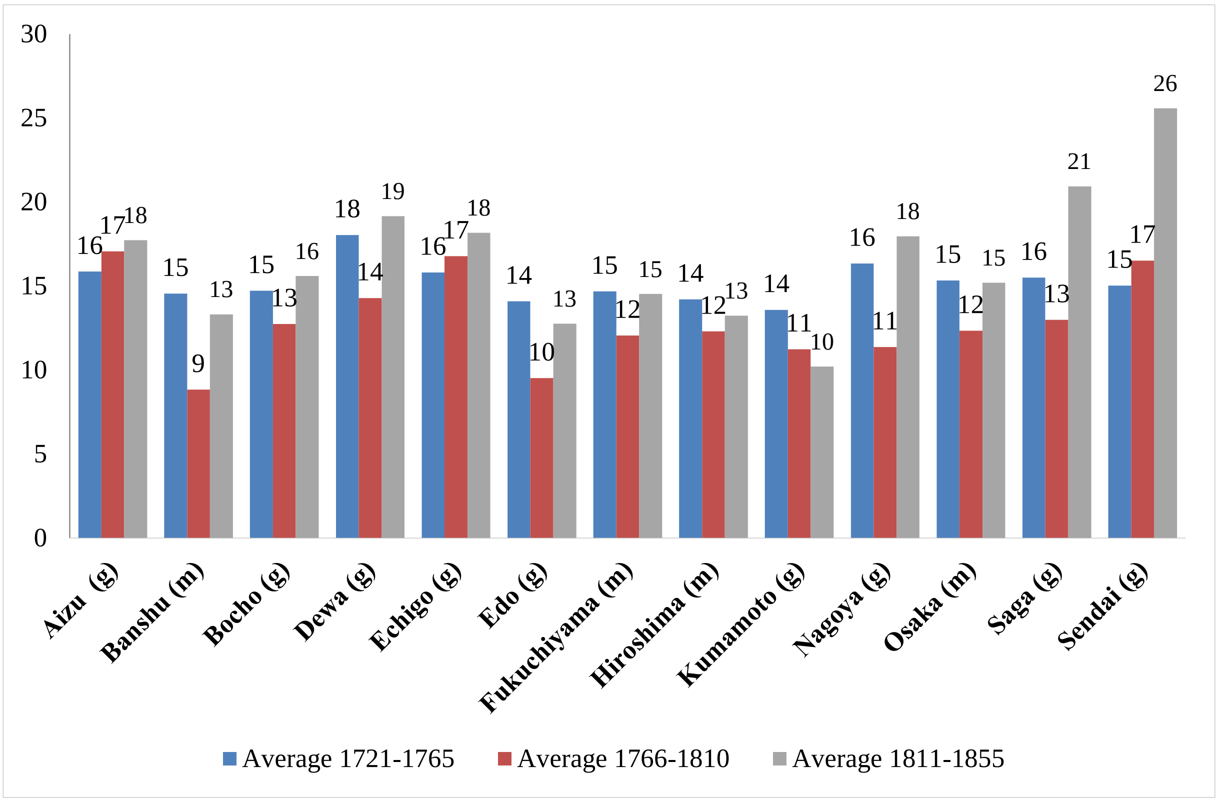

Figure 3. Average Price Volatility by 45-year Sub-Periods, 1721-1855

Note: average for each sub-period (of 45 years) of price volatility measured as 3-year centred coefficient of variation (on a scale 0 to 100); (m) indicates genuine market prices, and (g) indicate price series recorded by the shogunal or the local administration, regarded as proxies for market prices.

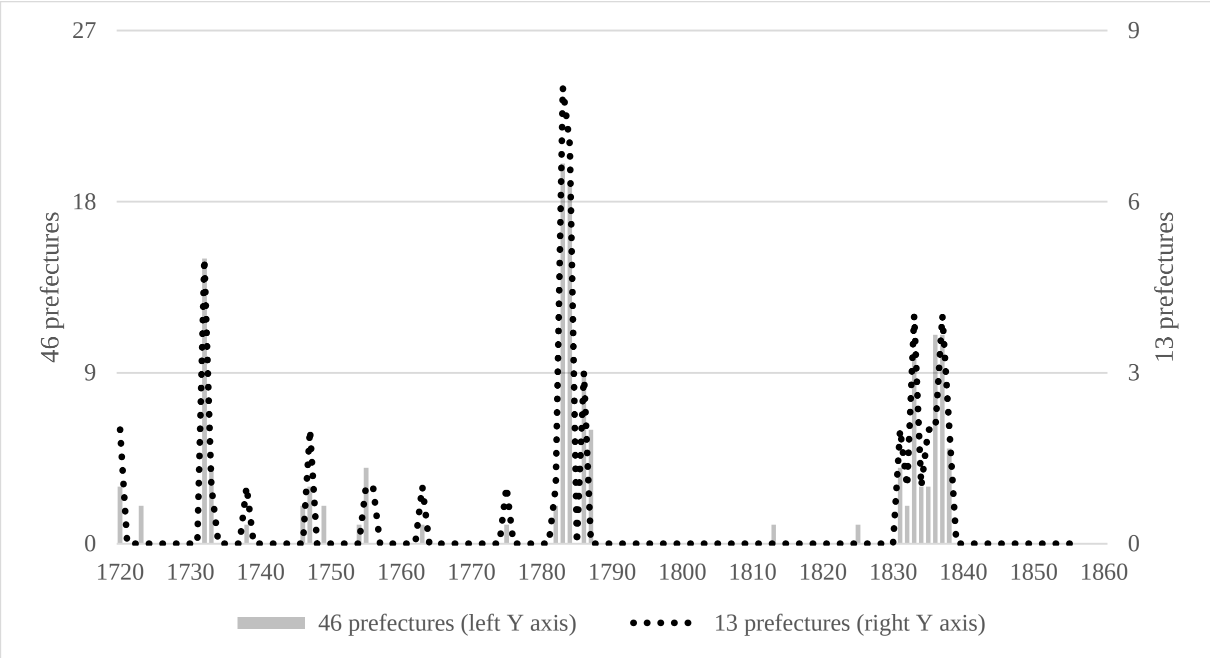

Figure 4: Frequency of RegionsPrefectures Reporting Famine, 1720-1857

Notes: Left Y-axis shows number out of a total of 46 Prefectures, right Y-axis shows number out of the total of 13 present-day prefectures with regional rices markets used in this study. In fact, prefectures did not exist in Tokugawa Japan; we followed the source in aggregating observations to present-day prefecture.

Source: Calculated on the basis of rainfall and drought events reported in Saito (1966) at the prefecture level (excluding Okinawa).

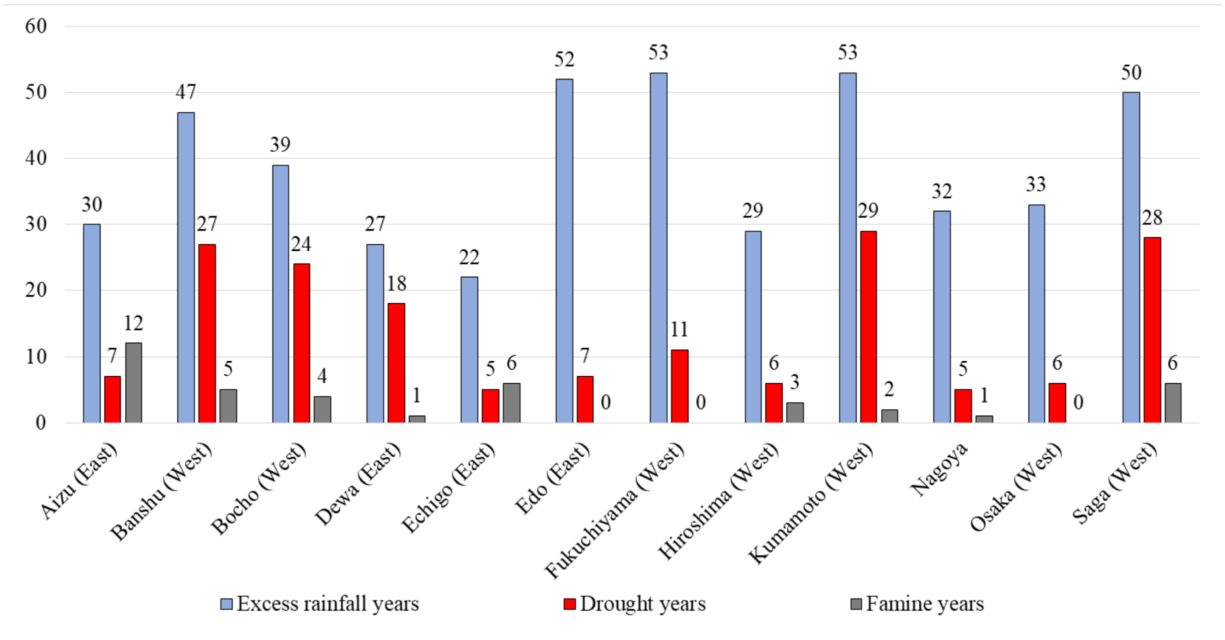

Figure 5: Number of Years with Excess Rainfall, Drought, and Famines during 1720-1857 in the Regions Studied

Sources: Calculated on the basis of rainfall and drought events reported in Saito (1966) at the prefecture level.

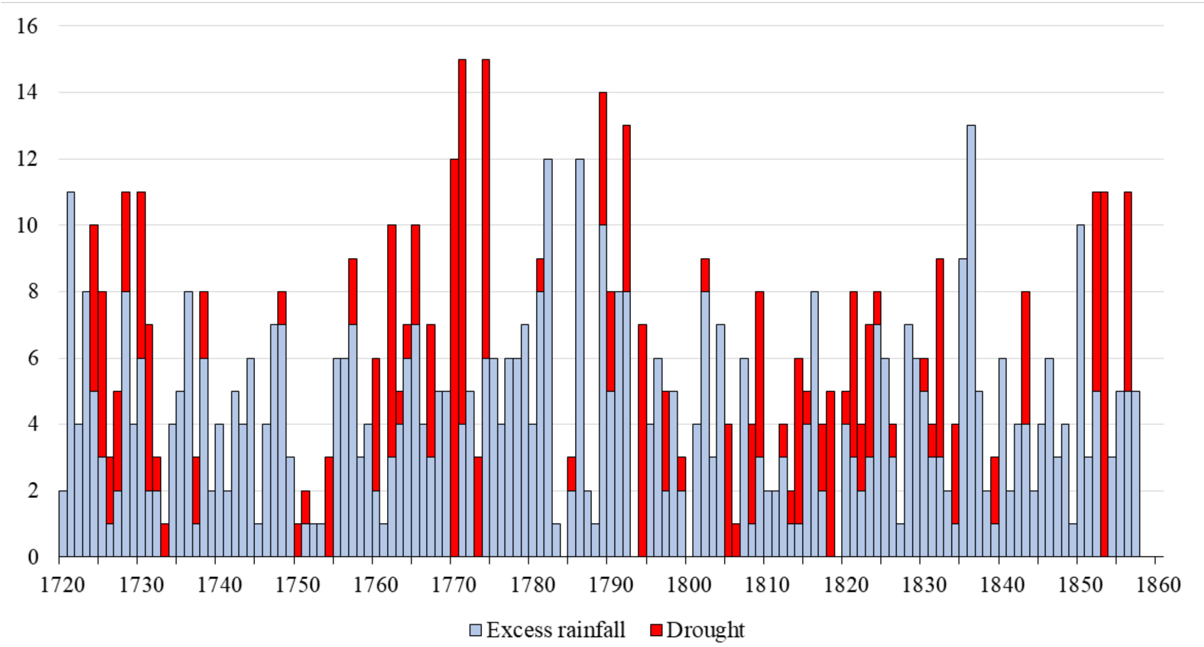

Figure 6. Frequency of Excess Rainfall and Drought in the 13 Regions Corresponding to 13 Rice Markets, 1720-1856

Note: In some prefectures both drought and excess rainfall episodes recorded the same year (*e.g.* drought in spring and excess rainfall in summer). This results in totals higher than 13 for some years.

Sources: Calculated on the basis of rainfall or drought events reported in Saito (1966) at the prefecture level.

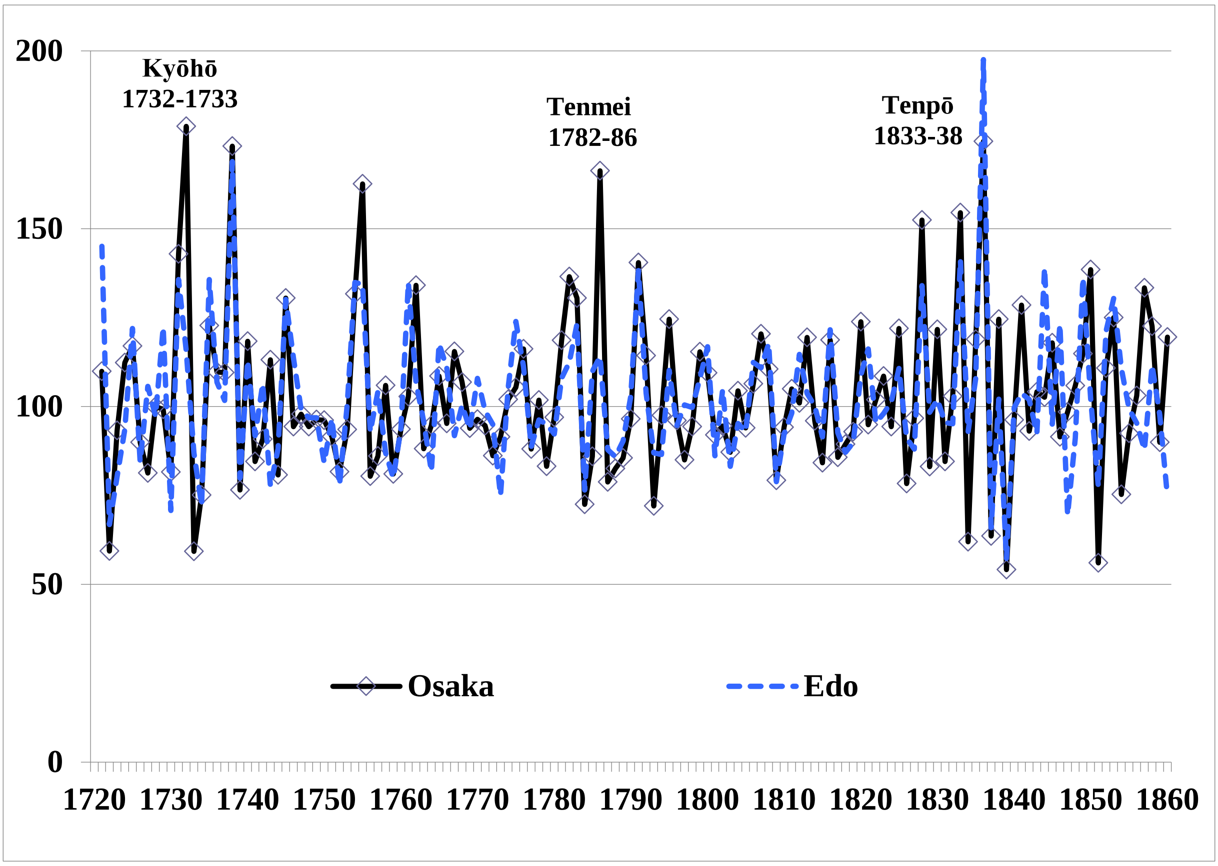

Figure 7: Yearly Rice Price Variations in Edo and Osaka, 1720-1857
Notes: Price in t as percentages of price in *t-1*. The correlation coefficient between the two series is 0.71.
Sources: Calculated from Iwahashi (1981) and Yamasaki (1983).

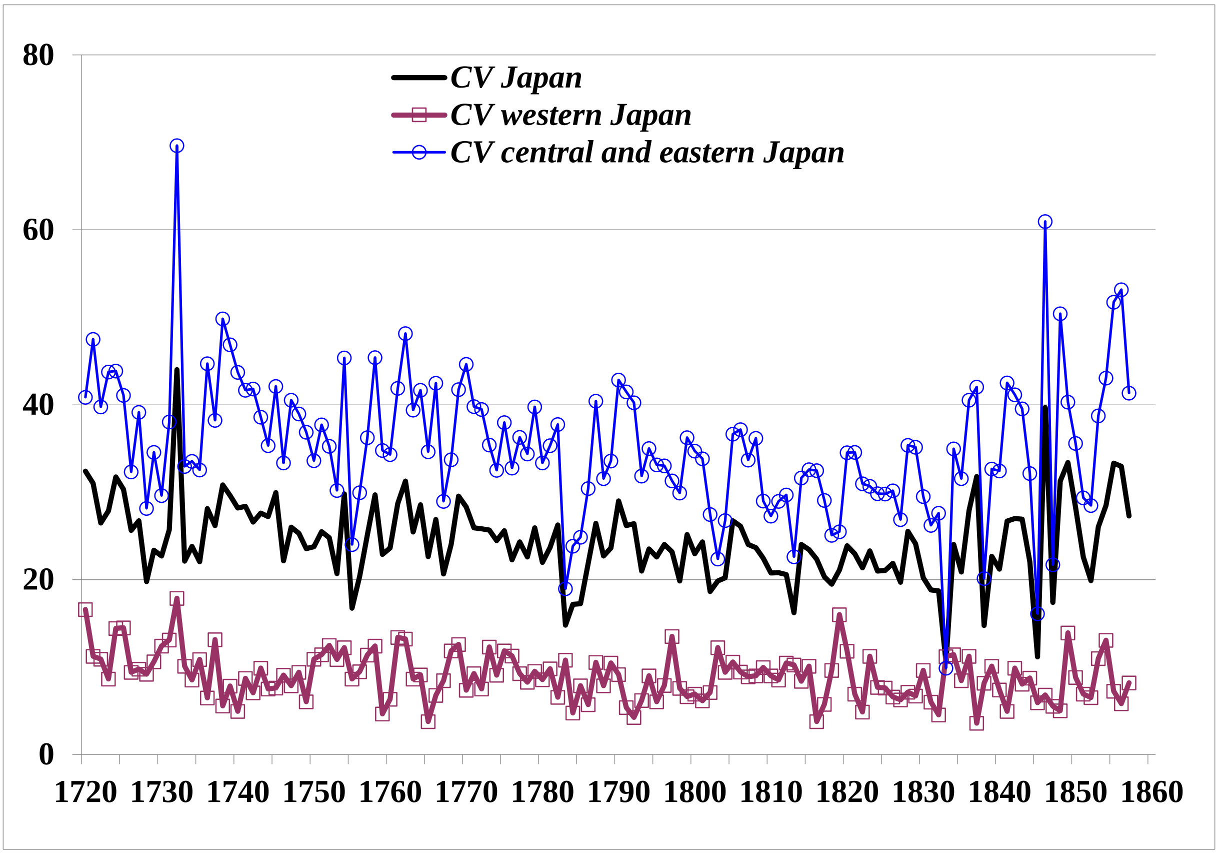

Figure 8: Coefficients of Variation of Rice Prices across Markets in Japan, 1720-1857

Notes: Western Japan comprises Banshu, Bocho, Fukuchiyama, Hiroshima, Kumamoto, and Saga; central and eastern Japan includes Aizu, Dewa, Echigo, Edo, Nagoya, and Sendai. Osaka only included in the CV of total Japan.

Sources: Calculated from Iwahashi (1981) and Yamasaki (1983).

Table 1. Pair Correlation of Rice Price Series for Regional Markets Relative to Osaka

	Distance to Osaka in km	Correlation 1721-1765	Correlation 1766-1810	Correlation 1811-1855
Banshu	88	0.93	0.90	0.93
Fukuchiyama	92	0.92	0.87	0.94
Hiroshima	329	0.94	0.86	0.91
Nagoya	490	0.92	0.83	0.88
Bocho	529	0.93	0.93	0.93
Edo	753	0.86	0.76	0.78
Kumamoto	910	0.88	0.70	0.86
Saga	947	0.89	0.91	0.89
Sendai	1,203	0.69	0.54	0.43
Echigo	1,502	0.46	0.65	0.92
Aizu	1,633	0.69	0.69	0.77
Dewa	1,686	0.87	0.81	0.87

Sources: Calculated for each subperiod of 44 years using annual rice prices from Iwahashi (1981) and Yamasaki (1983).

Notes: Considering the shape of the Japanese archipelago and the high elevation of mountain ranges, using Euclidian distance would result in a major underestimation of actual distance. Distance was measured by land route (proxied as present-day shortest walking distance) for Osaka-Banshu, Osaka-Fukuchiyama, Banshu-Fukuchiyama, or Aizu-Echigo, Aizu-Dewa, Aizu-Sendai. In cases where the maritime route was more common, the distance was proxied using the land route assuming stops at selected points, *e.g.* via Himeji for Osaka-Hiroshima; via Shimonseki for Banshu-Hiroshima, via Hagi, Shimonoseki, Hirado, Nagasaki and Minamishimabara for Echigo-Kumamoto.

Table 2. Comparison of Price Correlations in China, India, Europe and Japan by Geographical Distance of Markets, 1770-1860

Distance of markets (km)	1 China 1770-1794 [n=561] (monthly)	2 Europe 1770-1794 [n=105] (monthly)	3 India 1825-1860 [n=74] (annual)	4 Europe 1790-1820 [n-134] (annual)	5 Europe 1825-1860 [n=111] (annual)	6 Japan 1790-1820 n=[57] (annual)	7 Japan 1825-1857 n=[57] (annual)
<150	0.81	0.83	0.48				
70-150		0.65		0.78	0.83	0.83	0.94
150-300	0.74	0.65	0.35	0.65	0.71	0.67	0.76
300-600			0.14	0.50	0.58	0.83	0.81
300-450	0.68	0.55					
450-600	0.66	0.53					
600-1,000			0.15	0.44	0.61	0.66	0.68
600-750	0.64	0.39					
750-900	0.61	0.33					
900-1,050	0.57	0.30					
>1,050		0.30					
1,000-1,500			-0.01	0.33	0.48	0.59	0.60

Sources: China and Europe in columns 1 and 2, calculation based on monthly data in Shiue and Keller (2007), quoted in Studer (2008, 407); for Europe and India in columns 3, 4 and 5, calculation based on annual data in Studer (2008, 401); for Japan in columns 6, 7, 8 and 9, calculation based on annual data described in section 3.

Table 3: Causality of Annual Variations in Rice Prices in 13 Markets in Japan, 1717-1857

Dependent variable, *ΔP* in:	Independent variable, *ΔP* in:	χ^2	Prob > χ^2
Western Japan			
Banshu	Osaka	3.31	0.069
Banshu	Saga	3.68	0.055
Bocho	Osaka	4.23	0.040
Bocho	Saga	4.60	0.032
Fukichiyama	Osaka	3.43	0.064
Fukichiyama	Saga	6.56	0.010
Hiroshima	Osaka	9.53	0.002
Hiroshima	Saga	6.30	0.012
Kumamoto	Saga	6.87	0.009
Osaka	Saga	4.77	0.029
Saga	Osaka	6.25	0.012
Eastern Japan			
Aizu	Echigo	3.14	0.076
Aizu	Nagoya	4.87	0.027
Aizu	Saga	3.90	0.048
Echigo	Aizu	3.18	0.074
Echigo	Banshu	4.62	0.032
Echigo	Saga	2.93	0.087
Edo	Osaka	2.79	0.095
Edo	Saga	6.28	0.012
Sendai	Bocho	5.34	0.021

Notes: Only binary relationships for which the null hypothesis is rejected with $p<10\%$ are included in the table.
Sources: Calculated as the Granger Causality Wald Test for equation (1) in the main text, with annual rice prices from Iwahashi (1981) and Yamasaki (1983).

Table 4: Estimation of the Standard Error Correction Model Explaining Price Integration across 13 Rice Markets in Japan with Osaka as the Lead Market, 1717-1857

	α	β	γ	R^2
Aizu	-0.398***	0.495***	-0.579***	0.35
	-6.96	*4.24*	*-7.83*	
Banshu	0.013*	0.804***	-0.624***	0.84
	1.97	*26.09*	*-8.97*	
Bocho	-0.049***	0.918***	-0.835***	0.87
	5.62	*28.23*	*-10.22*	
Fukuchiyama	-0.027***	0.859***	-0.471***	0.82
	-3.03	*24.12*	*-7.15*	
Hiroshima	0.035***	0.884*	-0.866*	0.84
	4.28	*25.51*	*-10.46*	
Dewa	-0.201***	0.780***	-0.428***	0.51
	-5.56	*1.90*	*-6.36*	
Echigo	-0.256***	0.920***	-0.678***	0.71
	-7.85	*15.97*	*-8.62*	
Edo	0.107***	0.915***	-0.727***	0.79
	7.37	*21.11*	*-9.40*	
Kumamoto	-0.028***	0.667***	-0.623***	0.71
	-3.11	*17.11*	*-9.34*	
Nagoya	-0.226***	0.563***	-0.560***	0.49
	7.47	*9.19*	*-8.58*	
Saga	-0.092***	0.912***	-0.830***	0.78
	-6.33	*18.55*	*-9.58*	
Sendai	-0.168***	0.773***	-0.615***	0.55
	-6.34	*10.71*	*-8.06*	

Notes: N = 140 for each market, except Yonezawa where N = 137; *t* ratios in italics; *** significant at 1%, 5% and 10% level, respectively;
Sources: Calculated on the basis of equation (2) in the main text, with annual rice prices from Iwahashi (1981) and Yamasaki (1983).

Table 5: Estimation of the Elaborate Error Correction Model Explaining Price Integration across 13 Rice Markets in Japan with Osaka as the Lead Market, 1717-1857

	α	β	γ	δ_{KH}	δ_{TM}	δ_{TP}	ζ	R^2
Aizu	-0.356***	0.429***	-0.488***	-1.901***	0.459	0.150	0.631***	0.47
	-6.66	*3.84*	*-6.78*	*-3.68*	*0.90*	*0.48*	*4.85*	
Banshu	0.011	0.789***	-0.546***	-0.212*	-0.398**	-0.291***	1.092***	0.86
	1.69	*26.43*	*-7.49*	*-1.82*	*-2.59*	*-3.15*	*4.22*	
Bocho	-0.049***	0.907***	-0.845***	0.052	0.054	-1.54*	0.010	0.87
	-5.64	*26.80*	*-9.67*	*0.040*	*0.34*	*-1.68*	*0.04*	
Dewa	-0.230***	0.760***	-0.471***	-1.037**	0.007	0.192	0.523***	0.60
	-6.07	*10.49*	*-6.58*	*-2.27*	*0.02*	*-1.02*	*2.73*	
Echigo	-0.262***	0.892***	-0.674***	-0.452	-0.349	-0.172	0.448***	0.71
	-7.74	*15.24*	*-8.19*	*-1.37*	*-1.25*	*-1.12*	*2.35*	
Edo	0.108***	0.920***	-0.729***	0.171	-0.299	0.022	0.149	0.78
	6.93	*20.44*	*-8.58*	*0.93*	*-1.33*	*0.19*	*0.67*	
Fukuchiyama	-0.028***	0.846***	-0.468***	-0.453*	-0.074	-0.095	0.535	0.81
	-3.08	*22.73*	*-6.30*	*-1.79*	*-0.42*	*-0.88*	*1.57*	
Hiroshima	0.030***	0.846***	-0.785***	0.185	-0.274	-0.280***	1.317***	0.85
	3.64	*23.85*	*-9.02*	*1.31*	*-1.61*	*-2.66*	3.52	
Kumamoto	-0.029***	0.665***	-0.637***	-0.115	-0.182	-0.063	0.095	0.70
	-3.10	*16.51*	*-8.38*	*-0.59*	*-0.84*	*-0.43*	*0.38*	
Nagoya	-0.232***	0.545***	-0.598***	-0.730**	-0.178	0.222	0.216*	0.48
	-7.14	*8.78*	*-7.53*	*-2.42*	*0.62*	*-1.28*	*1.94*	
Saga	-0.094***	0.881***	-0.789***	-0.319	0.149	-0.201	0.430	0.78
	-6.39	*16.80*	*-9.22*	*-1.53*	*0.62*	*-0.137*	*1.57*	
Sendai	-0.165***	0.722***	-0.566***	-1.413***	0.025	0.280	1.135***	0.62
	-6.70	*10.56*	*-7.68*	*-3.74*	*0.08*	*-1.57*	*4.96*	

Notes: N = 140; Student t-value italicised; ***= significant at a 1% level; **= significant at a 5% level, * = significant at a 10% level; KH, TM, and TP stand for Kyōhō famine, Tenmei famine, and Tenpō famine, respectively.

Sources: Calculated on the basis of equation (3) in the main text, with annual rice prices from Iwahashi (1981) and Yamasaki (1983).