Market Responses to Climate Stress: Rice in Java in the 1930s

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Abstract

Do markets in less-developed countries abate consequences of climate stress? Rainfall is an important factor in rice production in Indonesia. This paper uses changes in regional rice prices across the 19 residencies in less-developed Java to assess how rice markets responded to variations in rainfall during 1935-1940. It finds that rice markets were highly integrated across Java. The El Niño-induced episodes of lower than usual rainfall in 1935 and 1940 did not have a negative effect on levels and variations in regional rice prices, nor did they have adverse consequences for the supply of rice. Adaptive responses of firms specialising in the trade of rice are likely to have mitigated regional deficiencies in food production caused by climate stress.

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JEL codes: N55, O13, Q13, Q54

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Introduction

Drought affects agricultural crop production. It potentially delays sowing, planting and harvesting; it reduces areas planted and harvested, and it decreases average crop yields. This can have calamitous consequences for food supply in communities in less-developed countries that depend on subsistence crop production. Potentially, it may affect the economic and political stability in societies that depend largely on locally produced surpluses of food crops.

The 2007 report of the Intergovernmental Panel on Climate Change (IPCC) warns that increasing temperature will decrease crop productivity countries at low latitudes; increase the frequency of drought that lowers crop yields, and increase crop damage and failure. It expects these effects to affect crop production negatively, especially in subsistence sectors in Asia, and increase the risk of hunger.[1] These expectations are grounded in analysis of available evidence on climate change and its impact on crop production. However, the Asia chapter of the 2007 IPCC report has little to say on the economics of these predictions for Asian countries.[2] The 2007 Stern Report echoes many aspects of this IPCC report. It does offer substantiation for its dire predictions regarding food supply, but generally on the basis of macro-economic modelling of food production.[3]

Notwithstanding climate change and its possible impact on crop production, it appears likely that markets for food crops may work to mitigate food deficiencies in areas affected by drought and falling food production. The price mechanism in unfettered markets may provide incentives that direct flows of staple foods from surplus to deficit areas. Markets may also induce technological and institutional changes that benefit farm agriculture and mitigate the factors that would otherwise result in lower crop yields and increasing crop failure.[4] The 2007 IPCC report ignores this. The Stern report acknowledges that the effects of climate change will depend on the degree of adaptation that economies may generate, but notices that the transaction

[1] IPCC, Summary, 11-12, 18; Cruz *et al.*, Asia, 479-82.
[2] The only economic considerations offered in volume 2 of the 2007 IPCC report are declarations that sustained economic growth, industrialisation and urbanisation will aggravate problems of pollution and therefore climate change in much of Asia, which by implication have negative consequences for crop production and food supply. Likewise, the agriculture chapter in volume 3 of the IPCC report on mitigation of the impact of climate change says little about the economics of climate change and agricultural production that substantiates the claims in volume 2. This chapter expresses concerns about an increase in Asia in methane production and the concomitant release of CO_2 in the atmosphere due to the growth of demand for animal products in the continent, before discussing policy options to reduce greenhouse gas emissions.
[3] Stern, *Economics of Climate Change*, 83-98.
[4] Ruttan, *Technology, Growth and Development.*

costs of such processes require clarification.[5] In other words, there is ample scope for research into the adaptive responses of economies to climate change.

This paper touches on some aspects of technological change in rice production in Indonesia that pre-empted the apocalyptic predictions about food supply in densely populated Java voiced frequently during the 20th century. However, its main purpose is to address the question whether food product markets in a less-developed country can indeed be expected to mitigate food deficiencies. There are some conditions under which markets may be expected to do this. First, societies should have sufficiently developed communication and transport facilities to facilitate trade. Second, local markets should be in direct or indirect contact with distant markets that are potential sources or destinations of surplus produce. Third, the population in a deficit area should have the means to purchase staple foods from distant surplus areas. Such conditions cannot be taken for granted in less-developed countries. It is often thought that farmers in less-developed countries largely produce for subsistence, are hardly in contact with distant national and global markets, and are subject not to market forces, but rather to forces of the 'moral economy' of a local community.[6] Consequently, it has been argued that times of drought affect less-developed countries much harder than it affects developed countries, and that by extension government intervention in food crop markets and proactive behaviour by government agencies may be required to protect consumers and producers, stabilise prices and achieve an equitable distribution of available food.[7]

Despite such arguments in the literature, two key questions require further scrutiny. Can it be assumed that people in less-developed countries largely produce for subsistence and are hardly in contact with wider product markets? Will times of drought necessarily have severe consequences for societies in less-developed countries? This paper addresses those questions on the basis of the case of rice production in Indonesia's core island of Java, which in the past and still today was an underdeveloped part of the world.[8] The paper focuses on 1935-40, years for which a unique set of relevant data is available. It uses regional rainfall data to assess the impact of drought – or rather climate stress, as there is no unambiguous measure of drought – on fluctuations in rice production across all 19 regions in Java. The paper then uses regional rice price data to assess the responses of rice markets in these 19 regions to production fluctuations.

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[5] Stern, *Economics of Climate Change*, 83-4.
[6] Ellis, *Peasant Economics*, 10-13.
[7] Ellis, *Agricultural Policies*, 100-04.
[8] Indonesia's GDP per capita was around $1,100 (in 1990 international dollars) during the 1930s, comparable with countries like Cameroon, Kenya and Nigeria around 2000 (Maddison, *World Economy*).

Rice and Rainfall in Indonesia

Food production and the distribution of food supplies across Indonesia have long been subject to geographic and temporal variations in climate. The Indonesian archipelago straddles the equator and temperature is relatively constant across the year and across the region. Precipitation patterns are the main source of temporal and geographic climatic variation.[9] Average rainfall is between 1,500 and 4,000 mm per year, and in some mountainous regions rainfall of 6,000 mm per year can occur. Across the country, the Western part is much wetter than the Eastern part, with the exception of Papua and West Irian.[10] More than half of Indonesia's population, or 130 million people, currently live in the core island of Java, which is just over twice the size of The Netherlands and produces 52 percent of the main staple food; rice. Figure 1 confirms that even within this densely populated part of Indonesia the Southwest is much wetter than the Northeast, with variations across the island largely as a consequence of its mountainous geography.

(Figure 1 about here)

The El Niño-Southern Oscillation (ENSO) climate pattern strongly influences temporal and geographic rainfall variations across Indonesia.[11] Sufficient and timely rainfall is a major prerequisite in the production of rice, the main staple crop in the country. Particularly in densely populated Java, insufficient and/or untimely rainfall associated with the ENSO pattern has had consequences for rice production and food supply. An El Niño event tends to postpone the onset of the wet season, which delays the main harvest, depletes food stocks and increases food shortages in the lead-up to the main rice harvest in June-July. It is likely that farmers developed adaptation strategies to mitigate the adverse impact of El Niño-related climate stress on their livelihoods.[12] Nevertheless, major drought-related famines occurred during 1849-50 in Demak and Grobogan and 1900-02 in Semarang (all in Central Java), while seasonal malnutrition long existed in the poorer regions in Central Java.[13]

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[9] Average temperature is 26 to 27º C throughout the year, but humidity varies considerably during the year. Above an altitude of 250 meters, local temperature decreases by about 0.5º C per 100 meter.

[10] Bakosurtanal, *Indonesia Rata-Rata Curah Hujan*.

[11] ENSO is a pattern of climate variability that recurs in the equatorial Pacific. Its is characterised by anomalies in the surface temperature of the Pacific Ocean that are referred to as El Niño and La Niña, as well as concomitant fluctuations in sea-level air pressure referred to as the Southern Oscillation. El Niño is linked to an extreme anomaly in the Oscillation in the form of a rise in air pressure in Southeast Asia and the West Pacific, and a decline in air pressure in the East Pacific. Both alter patterns of wind, rainfall and temperature, which caused dry spells in Southeast Asia lasting one or two years and prolonged in particular the dry season (Yasunari, Temporal and spatial variations; Yoshino *et al.* Agricultural production).

[12] Recent studies demonstrate this to be the case, see *e.g.* Keil *et al.*, Vulnerability. However, little is known about farmers using such practices in the past.

[13] Van der Eng, Famines.

Already in the 19th century, when Indonesia was a Dutch colony, colonial officials expressed concerns about overpopulation in Java. Nevertheless, in structural terms the general food situation only became precarious in the 1920s, when Java ran out of land for agricultural production. The stock of agricultural land has since decreased due to urbanisation. Net population growth accelerated to 1.4 percent per year during the 1930s, thus increasing the pressure on the agricultural sector to increase rice production. Consequently, in a situation where most rice was produced for subsistence, the further growth of rice production became a delicately balanced process of yield-increasing technological change in the form of irrigation facilities and improved rice varieties.[14]

In this situation, crop failures and/or delayed harvests caused by drought could potentially have dire consequences. Indonesia indeed experienced the consequences of the ENSO phenomenon during these years.[15] Still, despite significant fluctuations in rainfall caused by the El Niño weather pattern, there is only evidence of acute and disastrous famine across Java during 1944-45.[16] Until the 1970s, per capita rice consumption remained roughly constant at 85 kilo per year. Total annual per capita food consumption in Java and Indonesia remained at level, only to increase significantly since the 1970s.[17] By the end of the 20th century, Indonesia as a whole was able to absorb the consequences of El Niño-induced droughts on food production without catastrophic famine. For example, Indonesia weathered the severe drought of 1997-98, which coincided with a general economic crisis.[18] Why then didn't climatic changes during the 20th century have a greater impact on the supply of rice, Java's main staple crop, if population growth and the growth of food supply were so delicately balanced since the 1930s?

To start answering that question, some aspects of the production of rice, Indonesia's main staple crop, need to be discussed. Apart from taste preferences and cultural traditions, there are no obvious reasons to explain the predominance of rice, as other food crops yielded equally high or higher amounts of calories per harvested hectare.[19] Only in terms of financial returns per hectare was rice produced on irrigated fields (*sawah*) more rewarding than other crops. Rice on such fields benefited from the fertilising effect of silt in irrigation water tapped from streams and from the use of labour-intensive, yield-increasing production methods.

[14] CKS, Voedingsproblemen, 656-72.
[15] There is no certainty about the timing of the ENSO phenomenon in Indonesia, as will be explained below. No publication has hitherto used the massive amount of data on rainfall from ca. 5,000 rainfall stations across the archipelago since the mid-19th century to establish the timing of ENSO in Indonesia.
[16] The famine of 1944-45 caused excess mortality in Java affecting 2.4 million people (Van der Eng, *Food Supply in Java*, 40). This was not primarily caused by the drought that reduced crop yields and delayed the main harvest in 1945, but rather by the poorly executed system of regulation and control that the Japanese authorities imposed on rice producers in Java (Van der Eng, Regulation and control).
[17] Van der Eng, Food for growth.
[18] Suryana and Nurmalina, Impact of climate change; Fox, Impact of the 1997-98 El Niño.
[19] Van der Eng, *Agricultural Growth*, 170-78.

Until the 1940s, most rice in Java was grown for subsistence. In the 1880s, rice markets across Java were still poorly integrated.[20] But since the late-19th century, the improvement of communications encouraged rice production in Java for domestic markets, throughout Indonesia. Regular coastal shipping lines, and the expansion and improvement of railways and roads lowered transport costs and marketing risks. Intra-island specialisation of production took hold well before World War I, with some residencies in Java such as Banten, Cirebon and Prianggan in West Java and Besuki and Banyumas in East Java producing a surplus that was shipped to deficit residencies such as Jakarta, Pekalongan, Surabaya, Probolinggo and Yogyakarta.[21]

The degree to which produced rice was marketed is unknown. The share of paddy production milled at big rice mills in Java increased from 6 percent in 1930 to 26 percent in 1939.[22] Farm-pounded rice was also marketed through other channels from villages to urban areas, so that the actual share of marketed rice must have been higher, at least 10 to 30 percent.[23] The increasing purchase of paddy for rice milling during the 1930s was most of all caused by the growing profitability of rice milling, which largely replaced farm-pounding of paddy for the market. Urban consumers long depended largely on rice imported from Thailand and Vietnam, which was generally cheaper and reached Java through the main ports of Jakarta, Semarang and Surabaya. Imported rice was cheaper than domestic rice, in part because of poorer taste and a higher percentage of broken grains, but particularly because the imported rice was harvested and milled in mainland Southeast Asia and shipped to island Southeast Asia (including Java), before the main rice harvest there. Consequently, rice imports diminished seasonal rice price fluctuations in urban areas in Indonesia, and urban rice markets in Java were relatively well-integrated.[24]

The significant growth of production for domestic consumption during the 1930s was largely caused by import protection and a government program of careful stabilisation of rice prices starting in 1939. Net imports dwindled, Java became a net exporter of rice in 1940, and Indonesia as a whole became self-sufficient in rice in 1941.[25] The growth of production was also supported by public investment in irrigation structures and an embryonic government effort to disseminate superior rice varieties and introduce farmers to chemical fertilisers.[26] Elements of these government programs were continued after Indonesia's independence.

Typifying Java's climate is difficult. The presence of very high volcanoes and mountains of 2,000 to 3,000 meters and extensive areas at high altitude cause

[20] Van Zanden, On the efficiency of markets, 1040.
[21] Uemura, Inter-regional trade.
[22] Van der Eng, *Agricultural Growth*, 176.
[23] De Vries (Het Javaansche rijstjaar, 2112) even estimated 40-50 percent, noting that the railways transported 14 percent of the paddy harvest in Java.
[24] De Vries, Het Javaansche rijstjaar, 2111; Marks, Unity or diversity?
[25] Van der Eng, *Agricultural Growth*, 182-86.
[26] Van der Eng, *Agricultural Growth in Indonesia*, 41-56, 85-90, 100.

considerable variation in regional rainfall, winds, temperature, humidity and sunshine. In general terms, there are two seasons: a rainy season (November-March) with rainfall peaks in January-February and a dry season (April-October) with a rainfall trough in July-September. The timing of peaks and troughs, as well as the average amount of precipitation varies across the island, as Figure 1 shows. In West Java rainfall is higher and the dry season wetter than in East Java, where the climate is characterised by very low rainfall during the dry season.

Since the 1870s, rainfall in Java has been monitored by an increasingly extensive network of rainfall stations. Meteorologists used small subsets of these data during the colonial era to analyse climate patterns and to identify and predict droughts.[27] Subsets were used in later studies as well, but the entire dataset has never been analysed.[28] Later studies confirmed broad similarities in the timing of dry years with Darwin and India, as well as with the Southern Oscillation Index.[29] Quinn *et al.* used rainfall data for Jakarta only and maintained that 1938 was a year with less than normal rainfall.[30] They also summarised work by Berlage who used data on sea salt production in Madura to establish that 1932, 1935 and 1940 had been drought years.[31] Kripalini and Kulkarni used rainfall data from 200 rainfall stations in Indonesia during to identify ENSO patterns for the whole Indonesia and identified 1935 and 1940 as years with significantly less than normal rainfall.[32] Using data from 40 stations in Java, Hackert and Hastenrath identified 1936 as such a year.[33] Davis used data from the International Research Institute for Climate Prediction to identify 1930 and 1941 as drought years.[34] In short, there is no unanimity about the timing of drought years in Indonesia in the 1930s.[35]

Rainfall matters considerably to crop production, particularly rice. Low and/or late rainfall during the rainy season can lead to: (a) a reduction in the amount of land

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[27] *E.g.* Berlage, *Further Research*. Much of this work is summarised in *e.g.* Schmidt-ten Hoopen and Schmidt, *On Climatic Variations*; Sandy, *A Preliminary Statistical Investigation*.

[28] The rainfall data have been published annually since 1879 by the Royal Magnetic and Meteorological Observatory in Batavia, and after Indonesia’s independence by the Bureau of Meteorology and Geophysics and its predecessors in Jakarta.

[29] *E.g.* Quinn *et al.*, Historical trends, 667-70; Hackert and Hastenrath, Mechanisms, 748.

[30] Quinn *et al.*, Historical trends, 667-70.

[31] Quinn *et al.*, Historical Trends, 675-76; Berlage, *Fluctuations.*

[32] Kripalini and Kulkarni, Rainfall variability, 1162.

[33] Hackert and Hastenrath, Mechanisms, 748.

[34] Davis, *Late Victorian Holocausts*, 253.

[35] The years identified in the sources in this paragraph contrast significantly with the now digitised and widely used data on long-term El Niño occurrences in Quinn *et al.*, El Niño Occurrences, and Quinn and Neal, Historical record’. On the basis of a multitude of studies and with reference to data from the Pacific side of South America, these two studies concluded that 1932, 1940 and 1941 were years of ‘strong’ and 1939 and 1943 of ‘moderate’ El Niño intensity. The diversity of impressions of drought years in Indonesia, and the discrepancies with data from other parts of the Pacific suggests that great care needs to be taken when typifying and dating Southern Oscillation occurrences and therefore drought years. This conclusion echoes the results of a conference that investigated the opportunities to consolidate available ENSO data into a single historical data set (Dias and Tourré, Variations). It concluded that there are still considerable uncertainties regarding ENSO variability.

prepared for rice production, because rain water is required to soften the soil for puddling and fertilising; (b) an increase in crop failures as insufficient rain stunts the growth of rice plants or caused the plants to wither; (c) a reduction in average yield for the same reason. Rainfall also matters, because a wetter tropical climate tends to deplete the potassium content of the soil and raise acidity, while it has nuanced effects on other nutrients in the soil that all impact on the productive capacity of the soil.[36]

There is considerable region-specific variability of soil quality across Java.[37] This may impact on the correlation between rainfall and rice production. Even though that is in principle the case, farmers can usually more than compensate for adverse local soil and climate conditions, provided suitable technologies are available.[38] Indeed, in the more densely populated parts of Java, farming communities invested in creating irrigation and drainage works that channelled water from streams and rivers to and from agricultural land, and distributed it across individual fields. The quality of these structures varied, but government support had by the late-1930s created a sophisticated system in many areas, supported by the construction of major reservoirs that could release water during the dry season to facilitate multiple cropping.[39] While the use of fertiliser and superior rice varieties was at that stage still marginal, farm households were able to increase yields through labour-intensive techniques such as meticulous preparation of fields (ploughing, harrowing, puddling), transplanting of seedlings from seed-beds, manual pest control and careful harvesting.[40] Consequently, in labour-surplus areas, where agriculture was the mainstay of the population, additional labour input could increase crop yields, albeit with decreasing marginal productivity.

Data, Methodology and Analysis

If markets worked perfectly across Java, the price of rice would have been the same in all regional markets, give and take variable transport margins. Figure 2 shows five price series for different rice types that were sold in markets: factory-milled and home-pounded rice in rural areas, low-quality *kampong* or village rice in urban areas, and two qualities of stalk paddy. There were seasonal fluctuations in the price of rice: high in the months leading up to the main rice harvest in May-June, low in June-July following the main harvest. The five series track each other well, which suggests that rural and urban markets for different qualities of rice were well-integrated.

(Figure 2 about here)

[36] Lindert, *Shifting Ground*, 170 and 175.
[37] Lindert, *Shifting Ground*, 175-187.
[38] Strout, How productive are the soils, 48-49.
[39] Van der Eng, *Agricultural Growth*, 41-56.
[40] Van der Eng, *Agricultural Growth*, 178-182.

Underlying the prices in Figure 2 are average rural rice prices for 19 residencies and average urban prices in 86 cities and towns across Java. The equalising impact of rice markets and the degree of integration of these markets can be established on the basis of these rice prices. The coefficients of variation at the bottom of Figure 2 indicate the degree to which rice markets were integrated. Market imperfections prevented full integration, in part because of differences in the seasonality of rice production across Java, as largely determined by differences in rainfall patterns. The seasonality of production is clearly visible in the coefficients of variation of the prices of farm-pounded rice in rural areas, *kampong* rice in urban areas, and of paddy. The coefficients increased during the lean season immediately prior to the main harvest, when supplies of rice were insufficient to overcome spatial price differentials.[41]

In all cases the coefficients show a decreasing trend, which implies an increasing degree of integration of rice markets across Java during the late-1930s. The average coefficients were 0.06 for milled rice, 0.08 for farm-pounded rice, and 0.09 for urban *kampong* rice and both qualities of paddy. The low coefficient for milled rice most likely reflects the fact that rice mills kept paddy in stock during the year to be milled later, while the marketable surplus of farm-pounded rice and paddy would be sold soon after the harvest with a smaller carry-over of marketable stocks to the lean season. The coefficients are significantly lower compared to the coefficient of variation in rice markets across Indonesia during the 1950s-1960s (0.2 to 0.5), as well as staple food markets in famine-struck Bengal in 1942-43 (0.1 to 0.2), and particularly Ethiopia (0.2 to 0.3) and Kenya (0.4) in 1981-85, where artificial obstacles (trade restrictions, price controls or civil unrest) caused very weak spatial market integration and exacerbated famine.[42]

To explain the degree to which rice price divergence across the 19 residencies in Java was caused by the main factors underlying the seasonality of rice production, this paper models the relationship between rice price fluctuations across Java and rice production, as influenced by rainfall patterns. A key measure of climate stress impacting on rice production is insufficient rainfall, as water is a key requirement in rice production for the purpose of preparing fields and nurturing seedbeds and irrigating the planted fields. Consequently, low and/or late rainfall during the rainy season may have had three consequences for rice production in a given residency: (a) a reduction in land prepared for rice production, indicated by the ratio of planted and total irrigated land; (b) an increase in crop failures, indicated by the ratio of harvested area and total planted area during the current year; (c) a reduction in average yield, indicated by the ratio of produced rice and harvested area.

[41] De Vries, Het Javaansche rijstjaar.
[42] Marks, Unity or diversity?; Ó Gráda, Making famine history, 12-14.

(Figure 3 about here)

Figure 3 shows the seasonality of average rainfall in Java during 1934-40, with clearly distinguishable wet and dry seasons. The chart also reveals variability in rainfall patterns over the years. For example, the dry seasons in 1935 and 1940 were unusually dry, started early and were prolonged. This is confirmed in Table 1, which shows significant differences in annual rainfall in the main parts of Java, particularly the wet West and the dryer East. The last column shows that in 1935 and 1940 total annual rainfall in respectively 62 and 79 percent of the sample of 58 rainfall stations was less than the 1934-40 Java average, which identifies them as years with low rainfall and increased climate stress. Figure 3 also shows that preparation of paddy fields and planting coincided with the rainy season, followed by harvesting around 5 months later. The peaks of harvested area are lower than planted area, which indicates that the harvesting season took longer than the planting season.

(Table 1 about here)

As noted above, region-specific variables may have moderated the impact of fluctuations in rainfall and rice production on rice prices. In particular, soil quality, the availability of (semi-) technical irrigation facilities that tap and distribute irrigation water from streams and rivers, population density, altitude, the presence of forested upland areas that can act like 'sponges' that delay and smooth the flow of water into streams and rivers. It is not possible to account for all these factors individually, but the paper uses dummy variables for the residencies to capture the general impact of such residency-specific factors.[43] It is also not possible to take account of the impact of imported rice on markets, which may have helped to smooth rice prices across the year, particularly in urban markets. On the other hand, rice imports into Indonesia were generally destined for urban areas and rice-deficit areas in the Outer Islands, and net rice imports decreased significantly during the 1930s. This effect may be captured by dummy variables for each of the years 1935-40. It is not possible to take account of any possible substitution effects of rice and other staple food crops.[44] Lastly, as a first step to control for any possible endogeneity of

[43] There are few relevant regency-specific indicators that can be used for 1935-40 to capture such regional differences. Population density in the 1930 census year and the share of (semi-) technical irrigation in total irrigated land around 1930 (Van der Eng, *Agricultural Growth*, 53) were used as alternatives for the regional dummy variables, but the results were only marginally different.

[44] Monthly prices for four other food crops are available. The average coefficients of variation for 1935-40 were 0.29 for fresh maize cobs, 0.15 for maize, 0.16 for fresh cassava, and 0.20 for dried cassava chips. This suggests that the degree of integration of markets for these products was considerably lower across Java than for rice.

the explanatory variables caused by the seasonality of rice production, the model uses dummy variables for each of the months of the year.

On that basis, the following model is used to explain variations in the residency-average prices of milled, respectively pounded rice:

$$P_t^r = c + \alpha R_{t-5}^r + \beta C_t^r + \gamma H_t^r + \delta Y_y^r + d^r + d^y + d^m + \varepsilon_t \qquad \text{(Equation 1)}$$

P_t^r = price of rice in residency *r* in month *t* (guilders per 100 kg)

R_{t-5}^r = rainfall in residency *r* in month *t-5* (millimetres)

C_{t-5}^r = cropping ratio, defined as planted area in month *t-5* / total irrigated land in year *y* in residency *r*

H_t^r = harvesting ratio, defined as harvested area in month *t* / total planted area during year *y* in residency *r*

Y_y^r = average stalk paddy (*padi*) yield in residency *r* in year *y* (ton per hectare)

d^r = dummy variable for each of the 19 residencies

d^y = dummy variable for each of the years 1935-1940

d^m = dummy variable for each of the 12 months of the year

ε_t = error term

Appendix 1 lists the sources of monthly data for 19 residencies on rainfall, irrigated area, planted area, harvested area and the rural retail prices of milled and home-pounded rice. Unfortunately, average crop yields and therefore estimated total paddy production are only available on an annual basis. Table 1 shows the summary statistics of the variables. Like in Figure 2, the price of milled rice was on average 21 percent higher during 1935-40 than the price of pounded rice. The standard deviation was higher for pounded rice than for milled rice, which most likely reflects the fact that rice mills kept paddy in stock to take advantage of higher prices during the lean season, while farm households did not hold stocks for commercial reasons. Monthly rainfall was on average 184 mm, or a significant 2,208 mm per year. During the peak month 66 percent of irrigated land would be planted with rice crops, while during the peak harvesting month 49 percent of planted area would be harvested, confirming that harvesting was staggered, as mentioned above.

(Table 2 about here)

Table 2 confirms that the prices of both types of rice are correlated. Rainfall is moderately correlated with the cropping and harvesting ratios, but not with rice yields.[45] The correlation is not high enough to cause concerns about multicollinearity, but the paper will test for this. The fact that correlation is not more significant may reflect the tempering effect of man-made irrigation structures on cropping and harvesting ratios, as well as on yields. Where such structures involved reservoirs, they reduced the dependence of rice farmers on the availability of irrigation water for land preparation, seed-bed preparation and the early stages of growth of the rice plant. This allowed farmers to select the moment of planting on the basis of factors such as the availability of labour, rather than just the availability of rainwater. Proper land preparation and timely irrigation during seed-bed preparation, transplanting and maturation furthered paddy yields per hectare.

The cropping and harvesting ratios are also positively correlated, as can be expected, but the correlation is only moderate. The likely reason is that the time from planting to harvesting varied only slightly across the regions in Java, depending on the preference of farmers for early or late-maturing rice varieties. This correlation should not cause multicollinearity problems, as the planted areas used to calculate these ratios are different; respectively planted area 5 months prior and total planted area during the year.

The ordinary least squares (OLS) regressions to estimate the coefficients of for the full model in Equation 1 were carried out with the *regress* command in Stata 9.0 and Table 3 summarises the results.[46] The F statistic indicates that the explanatory power of both models is significant. In both cases, the coefficients of the key variables have the expected negative sign. They indicate that an increase in rainfall 5 months prior, an increase in the amount of land planted with rice 5 months prior, an increase in the area harvested with rice and an increase in the rice yield all reduced the price of rice, and *vice versa*. All are statistically significant at least at the 10% level. The rainfall coefficient is small, because the value of rainfall is large relative to the price of rice. The values of the coefficients are higher for pounded rice than milled rice, which suggests that the market for pounded rice was more susceptible to temporal changes in rice production. A likely reason is that rice mills moderated price fluctuations in markets for milled rice by holding stocks of paddy that would be milled for sale during the lean season when prices increased. Another likely reason is that imported milled rice would come onto the market at that time.

(Table 3 about here)

The paper tested for possible multicollinearity problems among the explanatory variables in Table 2 by calculating the mean Variance Inflation Factor,

[45] In order not to complicate the argument, the paper uses 5 months as the time difference between planting and harvesting, even though this lag may have varied slightly between and within regencies.
[46] It was not possible to use first differences and logarithms of the key variables for the regressions, because the variables *R*, *C* and *H* comprised zero values.

which was a low 1.47, suggesting that multicollinearity was not a problem. The paper also tested for possible endogeneity problems among the explanatory variables through a two-stage least squares (2SLS) regression, using R^r_{t-5}, d^r, d^y and d^m as instruments and C^r_{t-5} and H^r_t as the instrumented variables. This was done with the *ivreg* command in Stata 9.0. All regression estimates yielded very similar results as the OLS regression and the coefficients of the key explanatory variables had the same sign and were also comparable. This suggests that endogeneity is not a problem either in the regression results in Table 3.

The coefficients of the residency dummies in Table 3 capture some region-specific factors, although the coefficients were not statistically significant for 9 residencies in the case of milled rice. For example, in the residencies of West Java and in residencies with major ports (Cirebon, Pekalongan, Semarang and Surabaya) the price of milled rice was significantly higher than elsewhere. This may be related to the on average higher quality of rice that consumers there preferred and were able to afford than in other residencies. Conversely, the price of pounded rice was lower in Madiun than in the other residencies, which may be related to the inferiority of the average quality of rice consumed in this poorer region of Java.

Most importantly, the climate stress years 1935 and 1940 identified in Table 1 are not associated with significantly higher rice prices. The 1935 dummy variable was automatically dropped from the estimation, but Figure 2 already indicated that 1935 average rice prices were well below those of 1937-40. The sign of the 1940 dummy variable is indeed positive, but the average rice prices were that year only marginally higher than during 1938, a year without climate stress, according to Table 1. Consequently, variations in rice prices across Java and over time were indeed influenced by geographic and temporal variations in rainfall and their impacts on rice production. However, there is no evidence that episodes of significant climate stress exacerbated variations in rice prices. The analysis therefore underlines that the high degree of integration of rice markets across Java abated the negative consequences of annual rainfall anomalies in the late-1930s.

Conclusion

This paper has shown that rice markets were well-integrated across Java in the late-1930s, despite the largely subsistence-oriented nature of rice production in most of the island and the state of underdevelopment of the country as a whole. Annual fluctuations in rainfall and in aspects of rice production that were influenced by rainfall (rice field preparation, planting of rice, harvesting of rice and rice yields) were significant factors determining temporal price fluctuations across the years 1935-40. However, episodes of El Niño-induced climate stress in the form of lower than usual rainfall in 1935 and 1940 did not have a considerable impact on regional rice prices.

The consequences of such fluctuations in rainfall were not experienced in individual regions in Java in isolation. It therefore seems very likely that integrated rice markets caused rice to be traded from surplus to deficit areas in Java, thereby mitigating rice shortages in regions where rice production was negatively affected by downward fluctuations in rainfall.

The operation of the rice market in Java in the late-1930s has not been discussed in this short paper. But it seems likely that the adaptive responses of the myriad of traders, brokers and paddy processors firms in rice markets mitigated regional deficiencies in food production caused by climate stress.[47] Further research into the rice markets of Java in the late-1930s may explain how exactly the marketing organisations functioned. This may contribute to answering the question whether government intervention in food crop markets and proactive behaviour by government agencies is necessarily required in less-developed countries for the stabilisation of prices and the achievement of an equitable distribution of available food.

The findings of this paper imply that predictions about the impact of climate change on agriculture and food supply in Asia should not be made without due consideration of the economics of food production and the potentially mitigating impact of markets on production shortfalls. More specifically, despite the largely subsistence-oriented nature of food production in less-developed countries and the fact that markets for food products in such countries are often relatively ‘thin’, the case of Java in the late-1930s shows that product markets nevertheless function to mitigate regional deficiencies. Consequently, farmers in less-developed countries cannot necessarily be assumed to lack contact with wider markets, focus only on subsistence production, and be subject to forces of the ‘moral economy’ of their local communities. Likewise, it is not necessarily possible to assume that problems caused by drought will affect people in less-developed countries much harder than people elsewhere, without considering how market forces may abate such problems.

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Appendix: Data sources

Rainfall

Monthly rainfall data are available for Java from over 3,000 observatories or rainfall stations across the island since the 1870s, as well as for the other islands in Indonesia from many other observatories since the 1890s. For this paper, monthly data from three observatories in each residency in Java (except Solo) were used, a total of 58:

	Residency	Station	Altitude		Residency	Station	Altitude
1	Banten	Serang	25	11	Yogyakarta	Yogyakarta	113
		Cilegon	19			Sewu Galur	6
		Rangkasbitung	15			Wonosari	210
2	Jakarta	Jakarta	0	12	Solo	Boyolali	418
		Tangerang	18			Klaten	188
		Depok	95			Wonogiri	100
3	Bogor	Bogor	266			Solo	104
		Purwakarta	82	13	Surabaya	Surabaya	5
		Subang	95			Blimbing	70
4	Priangan	Bandung	715			Mojokerto	25
		Cianjur	459	14	Bojonegoro	Bojonegoro	15
		Sumedang	457			Tuban	0
5	Cirebon	Indramayu	10			Bakulon	80
		Karangkendal	1	15	Madiun	Madiun	66
		Ciahur	298			Ngawi	50
6	Pekalongan	Pekalongan	9			Ponorogo	92
		Brebes	3	16	Kediri	Kediri	62
		Tegal	0			Badas	93
7	Semarang	Semarang	2			Sukabumi	304
		Kendal	2	17	Malang	Malang	445
		Salatiga	584			Pasuruan	5
8	Rembang	Rembang	0			Wono Aseh	37
		Blora	90	18	Besuki	Blimbing	450
		Ngawen	75			Bondowoso	255
9	Banyumas	Purwokerto	73			Jember	83
		Cilacap	6	19	Madura	Waru	159
		Purworejo	44			Paseseh	0
10	Kedu	Wonosobo	756			Bangkalan	5
		Kebumen	21				
		Kutoarjo	15				

Sources: 1934-39 *Regenwaarnemingen in Nederlandsch-Indië* [Rainfall observations in the Netherlands Indies] (Batavia: Koninklijk Magnetisch en Meteorologisch Observatorium); 1940 *Regenwaarnemingen in Indonesië* [Rainfall observations in Indonesia] (Jakarta: Koninklijk Magnetisch en Meteorologisch Observatorium).

Planted and harvested area, rice production

Starting in 1916, the predecessor of the Central Office of Statistics in Indonesia implemented a meticulous system of monthly reporting on area planted and harvested with farm crops. Its purpose was to improve the forecasting of food production in Java. Production was estimated by multiplying harvested area with estimates of crop yields that were for rice obtained from an extensive network of test plots maintained by the Land Tax Service and for other crops from test plots maintained by the Agricultural Extension Service. This meticulously organised system yielded monthly data on planted and harvested areas with food crops and annual data on food crop production. For the 1930s, only 1935-40 data have been published disaggregated by month and the 19 residencies in Java.

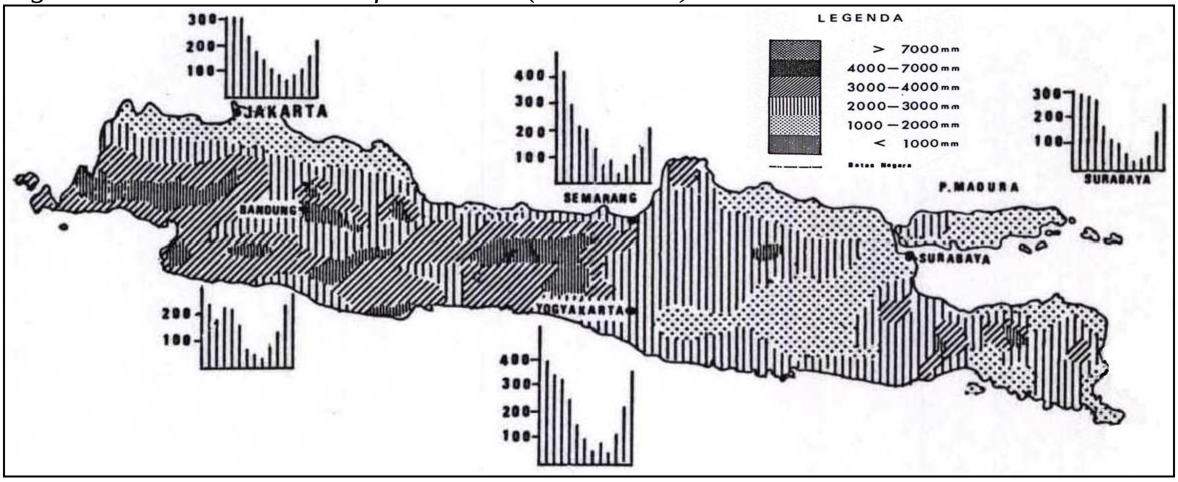
Source: 1935-40 *Indisch Verslag* [Annual report of the Netherlands Indies] (Batavia: Centraal Kantoor voor de Statistiek).

Food crop prices

Since 1919, the Central Office of Statistics collected monthly rural prices of the most important food items. Since 1924 the Office used prices from 119 rural markets to calculate and publish Java-wide average monthly prices. But only for 1935-40 are disaggregated monthly rural rice prices available, in the form of average prices of paddy, rice, maize (cobs, shelled), fresh cassava and dried cassava chips for the 19 residencies in Java. Urban prices were only collected in a few major cities until the 1930s. However, concerns about food supply led the Office to extend its price monitoring system to cover urban prices in 86 cities and towns in Java, but only the 1934-39 monthly rice prices data have been published.

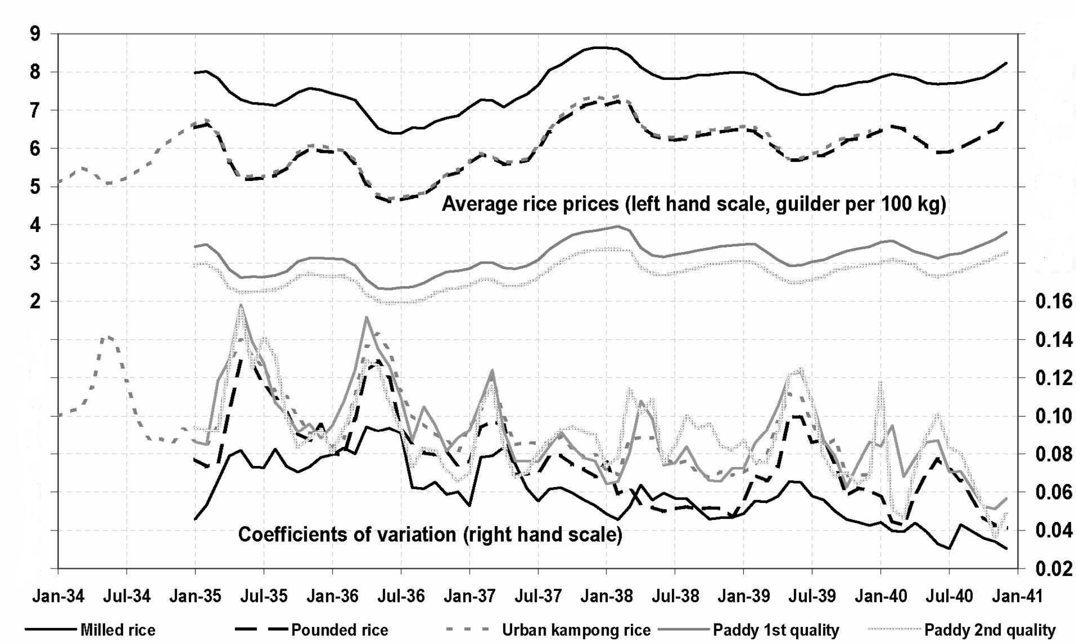
Sources: 1935-40 rural prices *Maandbericht*, *Gegevens Betreffende den Economischen Toestand der Inheemsche Bevolking op Java en Madoera* [Monthly report, data concerning the economic situation of the native population in Java and Madura] (Batavia: Centraal Kantoor voor de Statistiek); 1934-39 urban prices *Maandcijfers Betreffende den Economischen Toestand der Inheemsche Bevolking op Java en Madoera, Deel A* [Monthly figures concerning the economic situation of the native population in Java and Madura, volume A] (Batavia: Centraal Kantoor voor de Statistiek).

Figure 1: Mean Annual Rainfall in Java (millimetres)



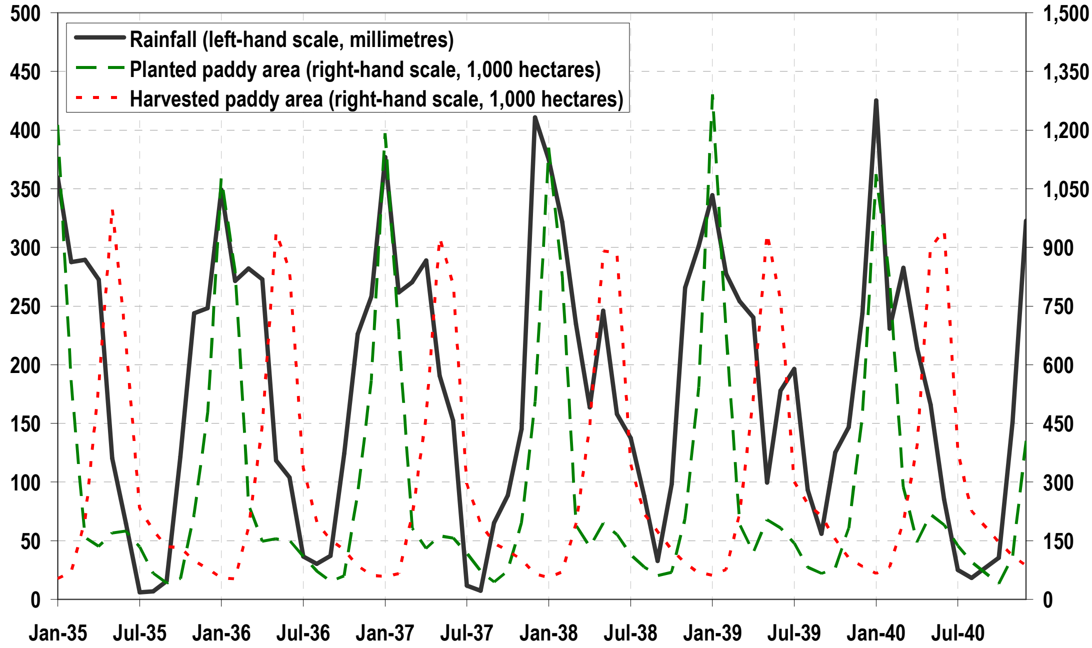
Source: Bakosurtanal, *Indonesia Rata-Rata Curah Hujan Setahun.*

Figure 2: Average Monthly Rural and Urban Rice Prices and Their Coefficients of Variation in Java, 1934-1940



Note: Rural averages are calculated from monthly prices for 19 residencies in Java. The urban average is calculated from monthly prices for 86 cities and towns in Java. Coefficient of variation is the ratio of the standard deviation to the mean.
Sources: See Appendix.

Figure 3: Paddy Production Seasons in Java, 1934-1940 (monthly)



Notes: Unweighted averages of monthly rainfall data for 58 rainfall stations; totals of area (re)planted with paddy and total harvested area in Java.
Sources: See Appendix.

Table 1: Rainfall in Java, 1934-1940

	Average annual rainfall (millimetres)				Rainfall stations with less than Java-average rainfall	
	West Java	Central Java	East Java	Java, total	Number	Share
1934	2,337	2,443	1,856	2,201	24	41%
1935	2,170	2,044	1,932	2,037	36	62%
1936	2,469	2,347	1,609	2,111	34	59%
1937	2,503	2,425	1,942	2,270	15	26%
1938	2,510	2,725	2,041	2,422	13	22%
1939	2,283	2,564	1,915	2,256	19	33%
1940	2,476	1,993	1,581	1,969	46	79%
1934-40 av.	2,393	2,363	1,840	2,181	24	41%

Notes: West Java comprises rainfall stations in residencies 1-5 in the Appendix Table, Central Java residencies 6-12 and East Java residencies 13-19. The total number of rainfall stations is 58.
Sources: See Appendix.

Table 2: Descriptive Statistics and Pair-Wise Correlation Coefficients, 1935-1940

	Mean	SD	1	2	3	4	5	6
1. Price (milled rice, P_t, f)	7.60	0.68	1					
2. Price (pounded rice, P_t, f)	6.00	0.76	0.866	1				
3. Rainfall (R_{t-5}, mm)	184	138	-0.191	-0.259	1			
4. Cropping ratio (C_{t-5})	0.09	0.11	-0.197	-0.274	0.527	1		
5. Harvesting ratio (H_t)	0.08	0.11	-0.198	-0.310	0.481	0.595	1	
6. Rice yield (Y_y, ton/ha)	2.15	0.47	-0.152	-0.034	0.006	-0.002	0.019	1

Notes: N = 1,368, except for C_{t-5} for which it is 1,273 as there are no monthly data for 1934. f = guilder.

Table 3: Estimation Results

Model	1			2		
Dependent variable	Price milled rice (*P*)			Price pounded rice (*P*)		
N	1,273			1,273		
F statistic	F(38, 1234) = 62.84			F(38, 1234) = 77.31		
R^2	0.6593			0.7042		
Adjusted R^2	0.6488			0.6951		
	Coefficient	St.Error	*t*	Coefficient	St.Error	*t*
Rainfall (R_{t-5})	-0.00048***	0.00014	-3.3	-0.00052***	0.00014	-3.5
Cropping ratio (C_{t-5})	-0.240*	0.174	-1.3	-0.367**	0.180	-2.0
Harvesting ratio (H_t)	-0.409**	0.213	-1.9	-1.218***	0.221	-5.5
Rice yield (Y_y)	-0.309***	0.116	-2.6	-0.416***	0.120	-3.4
dBanten	0.365***	0.136	2.6	0.975***	0.141	6.8
dJakarta	0.364***	0.135	2.7	0.812***	0.139	5.8
dBogor	0.860***	0.134	6.3	1.220***	0.139	8.7
dPriangan	0.544***	0.126	4.3	1.005***	0.130	7.6
dCirebon	0.841***	0.132	6.3	0.871***	0.136	6.3
dPekalongan	0.321***	0.138	2.3	0.450***	0.142	3.1
dSemarang	0.654***	0.103	6.3	0.678***	0.106	6.4
dRembang	-0.027	0.085	-0.3	0.450***	0.088	5.1
dBanyumas	-0.202	0.115	-1.7	0.262**	0.119	2.2
dKedu	0.051	0.124	0.0	0.681***	0.128	5.3
dYogyakarta	0.052	0.126	0.4	0.587***	0.130	4.4
dSolo	0.087	0.108	0.8	0.119	0.112	1.0
dSurabaya	0.305**	0.147	2.0	0.490***	0.152	3.2
dBojonegoro	0.086	0.072	1.1	0.309***	0.075	4.1
dMadiun	-0.122	0.095	-1.2	-0.212**	0.098	-2.1
dKediri	0.263**	0.159	1.6	0.768***	0.164	4.6
dMalang	0.014	0.196	0.0	0.594***	0.202	2.9
dBesuki	-0.028	0.249	-0.1	0.665***	0.258	2.5
d1936	-0.525***	0.045	-11.4	-0.445***	0.475	-9.3
d1937	0.406***	0.046	8.8	0.632***	0.475	13.2
d1938	0.769***	0.465	16.5	1.008***	0.480	20.9
d1939	0.329***	0.047	6.9	0.503***	0.487	10.3
d1940	0.530***	0.046	11.4	0.737***	0.481	15.3
Constant	7.859***	0.178	43.9	6.078***	0.184	32.8

Notes: (***) (**) and (*) indicate significant at 1%, 5% and 10% level, respectively. d indicates a dummy variable. The month dummy variables are not shown. dMadura and d1935 were automatically dropped from both models.