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A Tale of Two Countries

Spatial and Temporal Patterns of Rice Productivity in China and Brazil

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Abstract

This paper looks at differences in spatial and temporal variation of rice yields in China and Brazil. We find that rice yields in China have converged over time and that rice production has become more and more homogeneous. In contrast, rice yields in Brazil have diverged over time, primarily due to variations in upland rice yields. Three hypotheses are put forward to explain the different behaviour of rice yields in Brazil and China: (i) differences in production systems (i.e., irrigated in China versus upland in Brazil); (ii) changes in rainfall patterns and (iii) bias in agricultural R&D favouring irrigated rice. Our empirical analysis provides support to the first two hypotheses by establishing that upland rice is subjected to much greater variation in yields than irrigated rice and that changing rainfall patterns affect mostly upland rice. We also provide evidence of the bias towards irrigated systems by looking at the patterns of varietal release.

Keywords: rice productivity, spatial convergence, technology spillover, China, Brazil

JEL classification: O33, O57, Q16, R12

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Acronyms

CAAS	Chinese Academy of Agricultural Sciences
Embrapa	Empresa Brasileira de Pesquisa Agropecuária (Brazilian Agricultural Research Cooperation)
GE	generalized entropy
HYVs	high-yielding varieties (of rice)
MSV	modern semi-dwarf variety (of rice)

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1 Introduction

Rice is widely produced and consumed in China and Brazil. It is a valued commodity in both countries.[1] Besides being a good caloric[2] source, rice is also a source of employment and income for many farmers. Over the last decades, these two countries have invested significant amount of effort to improve rice productivity and increase production. These efforts have largely paid off in terms of production and yields. So much so that the two countries together have produced roughly one-third of the world's rice production (since 1960). Such high levels of production make these two countries important and influential players in the global rice market.

Increases in rice productivity growth have been the major source of production growth in both Brazil and China. The development and eventual adoption of high-yielding varieties (HYVs) during the green revolution has played an important and significant role in this productivity improvement (Fan et al. 2005; Sanint 2004). Rice yields between 1970 to 2000 have grown, respectively, at 2.5 and 1.5 per cent per year for China and Brazil. This rapid growth in productivity has allowed China and Brazil to meet the growing demand for rice with little increase in the area planted. The impacts of the green revolution on yields, however, were not uniformly distributed across rice-growing areas. In fact, significant variation can be observed across different rice ecologies, agroecological zones, demographic pressures and policy environment (Pingali, Hossain and Gerpacio 1997: 13). Increasing population growth and scarcity of land suitable for rice production suggest that China and Brazil need to increase rice productivity further if they are to continue to meet the increasing demand for food. The search for new sources of productivity growth can be aided by improving our understanding of the spatio-temporal evolution of rice yield (Wood, You and Zhang 2004).

Technology spillovers account for a significant share of agricultural productivity growth, and some studies suggest R&D spillovers might account for half or more of the total productivity growth (Alston 2002). Given the generally available access to agricultural technologies, technology latecomers may readily 'catch up' simply by adopting existing technologies superior to their own (Wood, You and Zhang 2004). This should be the case in particular for countries like China and Brazil where agricultural extension services are relatively strong and effective. If the adoption of new and better technologies is indeed a simple process in China and Brazil, given the widespread dissemination of such technologies (through extension services) and the effects of spillovers, then we would expect crop yields to converge. Indeed, Goeschl and Swanson (2000) show that crop yields in developing countries converged[3] to developed-country levels from 1961 to 1999 for most of the eight crops included in the study (barley, cotton, maize, millet, rice, sorghum, soybean and wheat). Using hybrid rice in India as an example, Zhang, Fan and Cai (2002) show that early successful adopters of HYVs have a large effect on neighbouring farmers, which translates into higher technological adoption by other farmers. However, the impact of agricultural technology is usually

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[1] Brazilians' per capital consumption of white rice is approximately 54 kilos per year (Velásquez, Sanint and Teixeira 1991).

[2] In 2000, rice accounted for 40 per cent of the total calorie intake in China and 12 per cent in Brazil.

[3] The authors found evidence of absolute convergence.

quite location specific. Crop production is subjected to substantial spatial heterogeneity (in soil, terrain and climate), which in turn is an impediment to technological transfer and adoption. Wood, You and Zhang (2004) show that maize, rice and soybean yields in Latin America and the Caribbean did not converge between 1975 and 1998. Given the variability of yields across production systems, crops and regions, and the lack of consensus from previous studies, the issue of crop yield convergence over time and space remains largely an empirical question.

In this paper, we provide an empirical analysis of rice yields for China and Brazil. Our analysis is divided in three steps: (i) panel data analysis is used to document the spatio-temporal changes for rice yields; (ii) tests for yield convergence in the two countries are applied and results suggest convergence for China but no convergence for Brazil; and (iii) given that yields converged for China but not for Brazil, we use the Shorrocks inequality decomposition method and GIS tools to analyse the underlying causes of the differences in the two countries.

Three hypotheses are offered to explain the differences in rice yield convergence in these two countries:

Differences in rice production systems: The majority of rice in China is irrigated while in Brazil rice is produced in both irrigated and upland ecologies. We hypothesize that these differences in production systems contribute to the yield divergence in Brazil.

Impact of climate change and particularly of changing rainfall patterns: Rainfall patterns have changed over the last few decades due to climate change. Increasing rainfall variability has exacerbated yield divergence in rain-fed areas (and thereby affecting rain-fed rice) where consistent rainfall during the growing season is critical.

Agricultural R&D bias towards irrigated areas: International and domestic investments in agricultural R&D over the last few decades have been heavily biased towards irrigated production systems. This bias benefits irrigated rice more than rain-fed rice. We believe that the divergence in yields in Brazil is derived primarily from the variability in upland rice yields.

The remainder of this paper is organized as follows. We first describe the panel dataset and rice production systems in Brazil and China. Next, we analyse temporal and spatial yield variabilities in these two countries. The final section investigates the underlying causes for the differences between the two rice-producing nations. We conclude with a summary and some policy implications.

2 Data and rice production system

We compiled timeseries data of rice production statistics (production, area and yield) at county level for China and at municipality (*município*) level for Brazil.[4] The timeseries runs from 1980 to 2000 for China and from 1975 to 2000 for Brazil. During this period,

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[4] The source for Brazil data is Embrapa—Empresa Brasileira de Pesquisa Agropecuária (Brazilian Agricultural Research Cooperation). The China county data come from the Ministry of Agriculture and Chinese Academy of Agricultural Sciences (CAAS).

rice was produced in approximately 2,300 counties in China and 3,800 municipalities in Brazil, which corresponds to 95 per cent of all Chinese counties and 85 per cent of all Brazilian municipalities. Two GIS boundary files for Chinese counties and Brazil municipalities were linked to the corresponding statistical data. In addition, we calculated average rainfall[5] during the rice growing season for all counties in China from 1980 to 2000 and all municipalities in Brazil from 1975 to 2000. The county/municipality rainfall measures were calculated by averaging rainfall values of all pixels within the counties/municipalities. Annual rainfall measures are averages of monthly rainfall, which take into account changes in the growing seasons across counties (municipalities) in China and Brazil.

Production systems impact on rice performance. The fundamental differences in plant characteristics and physiology mean that particular types of rice are suitable for different production systems. For example, the modern semi-dwarf, high-yielding varieties developed for the irrigated and the favourable rain-fed lowland systems during green revolution cannot be grown in the upland system. Rice is grown in three different production systems in China and Brazil: irrigated lowlands, rain-fed lowlands, and upland. In China, irrigation is the primary production system for rice, accounting for over 93 per cent of total area sown to rice. Rain-fed lowland rice and upland rice account, respectively, for 5 per cent and 2 per cent of the remaining area. Upland rice is typically found in provinces that have mountainous regions, such as in Yunnan, Guizhou, Guangci and Jiangxi. Rain-fed lowland rice is mainly planted in water-limited areas in the provinces of Hebei, Henan, Shangdong, Shaaxi and Liaoning (see Figure B1 for a map on rice production systems in China). In Brazil, about one-third of the area planted with rice is irrigated. The remaining two-thirds are predominantly cultivated in the uplands and a small percentage in the rain-fed lowlands. As shown in Figure B2, almost all rice in Santa Catarina and Rio Grande do Sul is irrigated. A few other states such as Tocantins, São Paulo and Mato Grosso do Sul produce limited amounts of irrigated rice. Rain-fed lowland rice is grown in only three states: Sergipe, Minas Gerais and Rio de Janeiro

Rice areas in the rain-fed lowland are relatively small in both China and Brazil. Therefore, here we will focus on irrigated and upland rice.

3 Spatial and temporal patterns of rice yield

Figures 1 and 2 show spatial changes of rice yield[6] during the last two decades in China and Brazil. These four maps provide a snapshot of spatial yield variation at the start and end years of the period examined. Two specific patterns emerge from these maps. First, there is significant spatial variation of rice yields in China and Brazil, which suggest that an analysis based on national averages would miss much of the relevant spatial variation in yield performance. For instance, rice yields in China’s northern plains region and in Xingjing province averaged about 3 ton/ha in 2000, while in northeast

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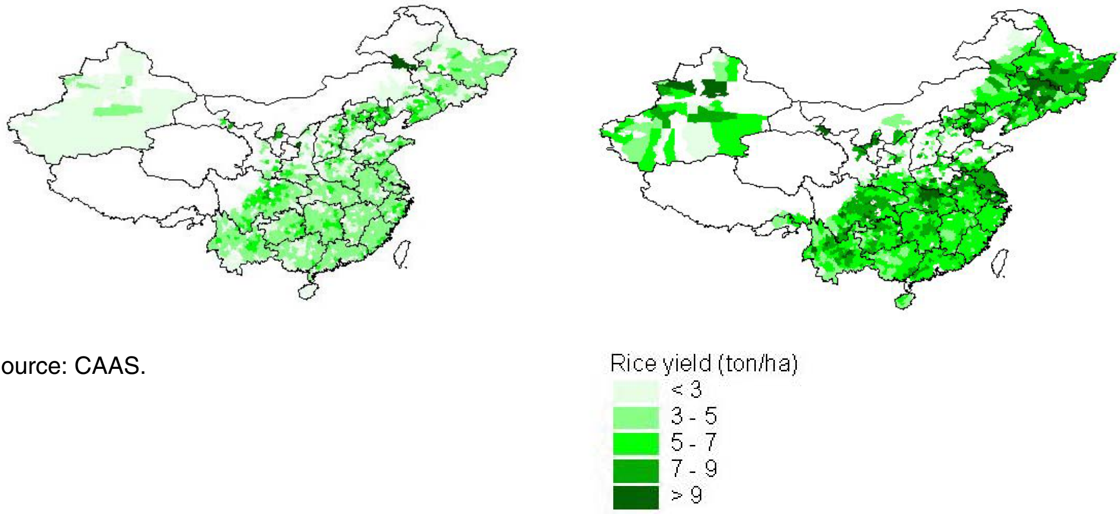
[5] Data for rainfall came from the Climate Research Unit at University of East Anglia (UEA). The dataset used was CRU TS 2.0, which is a 0.5 degree latitude/longitude gridded dataset of monthly rainfall for the whole world for the period 1901-2000 (Mitchell et al. 2006).

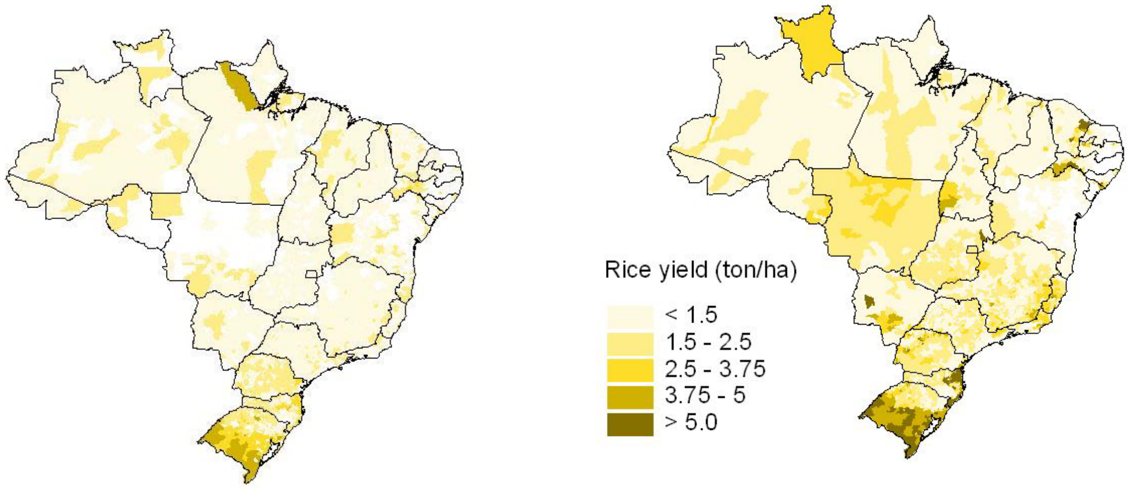
[6] We took three-year averages of yields to avoid atypical years.

Figure 1
Spatial change of rice yields in China, 1980-2000


1980-82 **1998-2000**

Source: CAAS.

Figure 2
Spatial change of rice yields in Brazil, 1974-2000


1975-77 **1998-2000**

Source: Embrapa.

China yields were considerably higher, averaging over 7 ton/ha. Likewise, in Brazil, highly productive states such as Santa Catarina and Rio Grande do Sul managed an average yield of 5 ton/ha, whereas in other states like Amazona and Mato Grosso, performance was considerably poorer, with yields averaging 1.5 ton/ha.

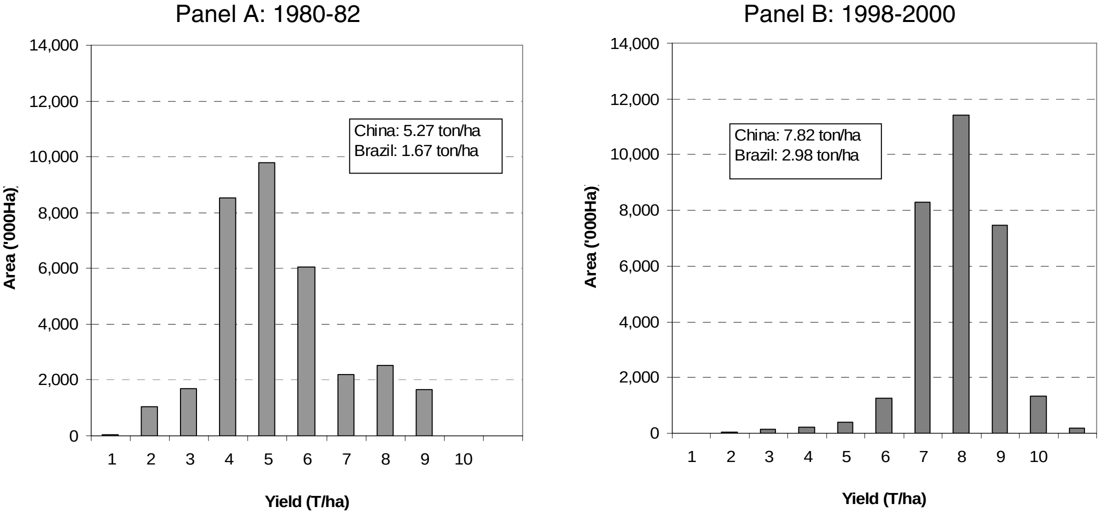
Second, there is a general upward trend in rice yields for Brazil (1975 to 2000) and China (1980 to 2000), albeit with considerable spatial heterogeneity in yield performance. In China, the largest yield gains occur in the northeast region and in the province of Xinjiang, whereas in Brazil, the areas with largest yield increases include states such as Roraima, Mato Grosso, Minas Gerais. Santa Catarina and Rio Grande do Sul have observed limited yield gains during the same period. In comparing both panels in Figure 1, we note an apparent increase in the area sown to rice from 1980 to 2000 in northeast China, Inner Mongolia and Sichuan provinces. Similarly, we note from

Figure 2 the expansion of rice cultivation into the Brazilian savannas or the *cerrados*. Most of the non-productive savannas of the 1970s were growing rice in 2000, particularly in the states of Amazonas, Rondônia, Mato Grosso and Bahia. In the process of exploiting the savannas, upland rice played a crucial role in bringing these areas under cultivation. Low fertility as well as the acidic soils of the region limited the cultivation of crops other than rice (Pinheiro, Castro and Guimarães 2006).

To get a more better sense of quantitative changes in rice yields, Figures 3 and 4 show the yield distribution at the county level (for China) and municipality level (for Brazil). These histograms of yield distribution are plots of the harvested area within each yield class, and represent about 2,300 counties in China and 3,800 municipalities in Brazil. Yield distribution in China (Figure 3) moves to the right and the range becomes narrower from 1980 to 2000, indicating that rice yields are both increasing and converging during this period. On average, Brazilian rice yields also increased from 1.46 ton/ha in 1970s to 2.98 ton/ha in the late 1990s. This is evident from Figure 4B which shows more areas with higher yield ranges than in Figure 4A. Rice yields in Brazil show a bimodal distribution, reflecting the two distinct rice production systems used in the country. The first clustering of rice area in the range of 0.6 to 2.6 ton/ha presumably represents rice grown under the upland system, the second clustering in the 4.6 to 6.2 ton/ha (3.4 to 4.6 ton/ha in Figure 4A range is most likely irrigated rice. The bimodal distribution implies that yields have not grown uniformly across production systems (irrigated and upland) in Brazil. This disparity in growth trends and levels (note the larger yield range in Figure 4B than in Figure 4A suggests that yields have not converged in Brazil as they have in China. In fact, yields have diverged in Brazil.

To further investigate the spatial variability of rice yields and to gain a better understanding of the differences in yield patterns between the two countries, we used the decomposable generalized entropy (GE)[7] class of inequality measures developed by Shorrocks (1980, 1984). The GE index measures the overall spatial variability of yields. This index can also be decomposed into sample groups to assess the contribution of

Figure 3
Rice yield distribution in CHINA, 1980-82 and 1998-2000


Panel A: 1980-82

Panel B: 1998-2000

Source: CAAS.

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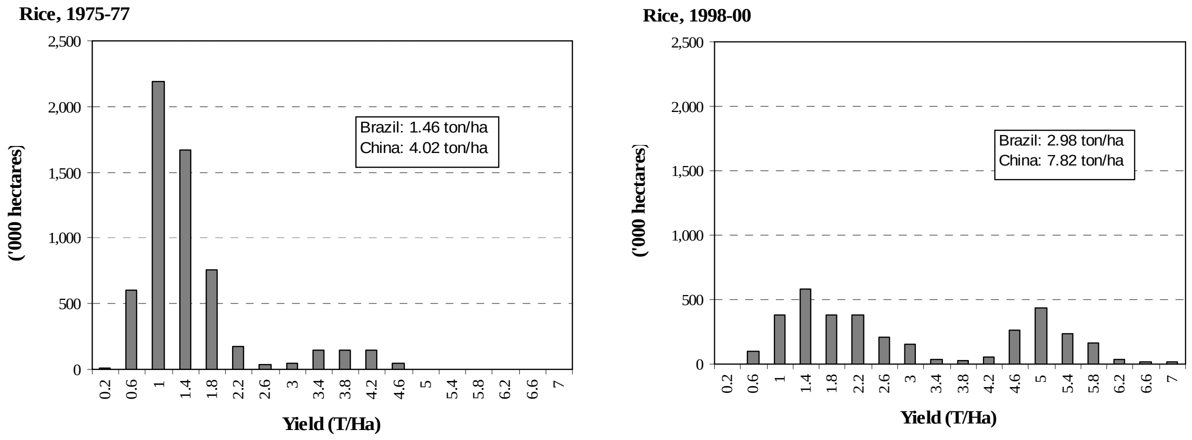
[7] Please see Appendix I for technical details.

individual groups to total variability and the variability within and between groups (Kanbur and Zhang 2005). Figure 5 shows spatial variations of rice yields in both countries from 1975 to 2000, indicating that there is much higher spatial variability in Brazilian yields than in Chinese yields. This difference in the levels of variability is confirmed by the results of the GE analysis. The GE index of rice yields for China shows a gradual decline of 4 per cent per year from 1980 to 2000 with small bumps in 1984 and 1988. On the other hand, GE index for Brazil reflects increases of 4.5 per cent per year from 1975 to1993 but gradually decreases thereafter. These results support our previous findings that rice yields in China have converged from 1980 to 2000 but the same has not happened in Brazil.

Figure 4
Rice yield distribution in BRAZIL, 1975-77 and 1998-2000

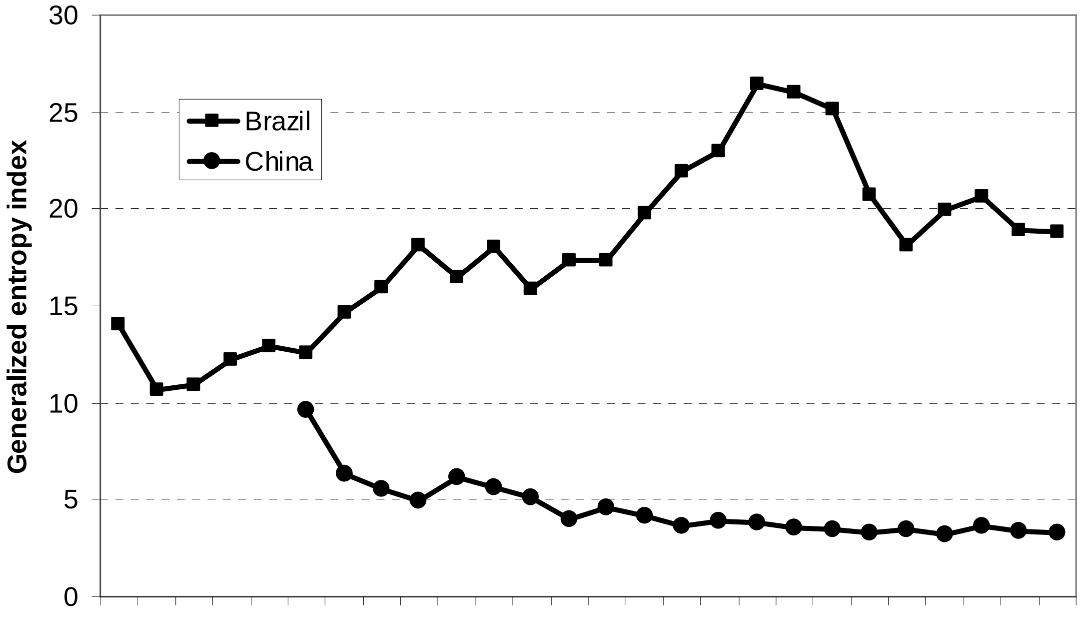


Panel A: 1975-77

Panel B: 1998-2000

Source: Embrapa.

Figure 5
Spatial variability of rice yields in Brazil and China, 1975-2000



Source: Author’s calculations.

Underlying causes

The observed patterns of rice yield variability in Brazil and China seem conflicting, and thus we need to investigate the underlying causes. As outlined in the introduction, we propose three hypotheses to explain the difference of temporal-spatial patterns, which we examine now in detail.

Differences in production systems

Rice yields depend very much on production systems, particularly on their ability to provide access to reliable water supplies. Irrigated rice produces much higher yields because of the continual access to water during the growing season. Upland rice, on the other hand, which relies on rainfall may suffer crop damage if the required rainfall is lacking during the critical growing period. The average upland rice yield in Brazil is only 25 per cent of the average yield observed in 2000 for irrigated rice. In addition, most irrigated rice plots in both countries have more favourable biophysical (soil) and socioeconomic conditions (e.g., market access) than the upland rice plots. These differences in conditions (whether biophysical or socioeconomic) help to account for the fact that irrigated rice in comparison to upland rice not only has a much higher yield but also a more homogeneous pattern of yield growth. In China over 90 per cent of the rice is irrigated while almost two-thirds of the rice grown in Brazil is in the upland regime. We hypothesize that the spatial variability of rice yields in Brazil mainly reflects the variability in upland rice. To confirm this hypothesis, we applied Shorrocks' decomposition method to quantify the relative contributions of upland rice and irrigated rice to the overall spatial variability. Table 1 and Figure 6 show the spatial variations for both Chinese and Brazilian rice yields. The table shows generalized entropy indices for total rice, irrigated rice, upland rice, between irrigated and upland rice, and the polarization index (see Appendix I for definitions). In China, the spatial variability of yields drop from 1980 to 2000 primarily because of the decreasing variability of irrigated rice; upland rice reflects an overall decreasing trend with considerable yearly fluctuations while the variability between upland and irrigated rice remains small and similar (around 0.08). The polarization index is increasing from 1 per cent in 1980 to over 2 per cent in 2000 because the total variation index declines over the period (Table 1: Part A). This trend is clearly shown in Figure 6A. Because rice is dominantly irrigated in China and spatial variability of irrigated rice has been declining, the fluctuating variation of upland rice and increasing polarization between irrigated and upland rice have little impact on the country's total rice variation.

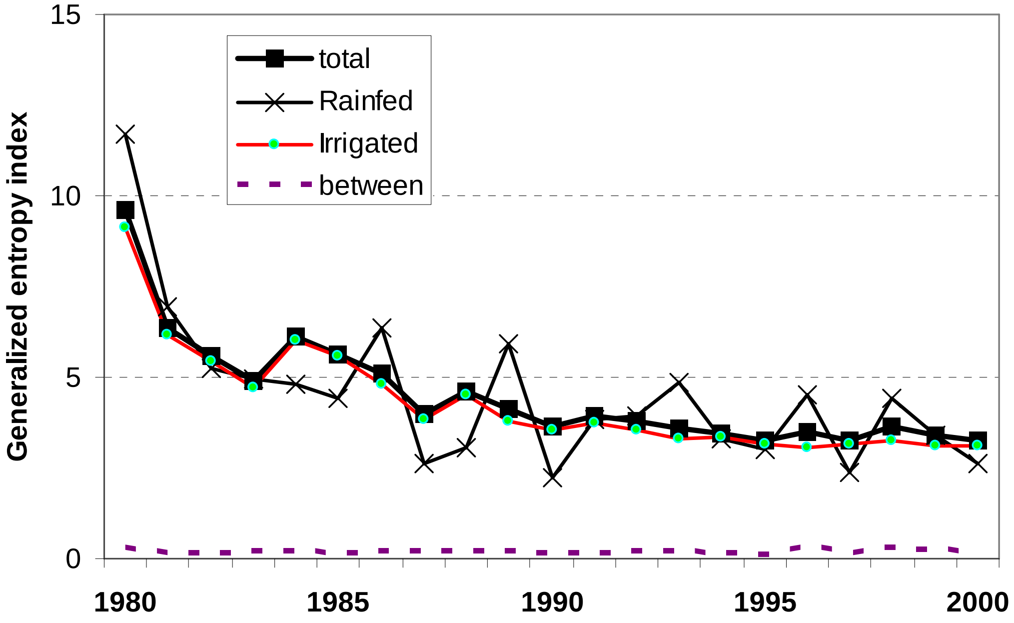
In contrast to the declining yield variation in China, GE index of rice yields in Brazil increased from 14.05 in 1975 to almost 18.80 in 2000, an increase of 36 per cent. The widening total variability comes mainly from the added variability of upland rice (from 7.94 in 1975 to 11.84 in 2000) and the increasing difference between irrigated and upland rice (from 5.56 in 1975 to 9.67 in 2000), representing 51 and 75 per cent increases, respectively. Spatial variability of irrigated rice in Brazil fluctuated between 12 and 14 from 1975 to 1983 but decreased between 1984 and 2000 (Table 1: Part B; Figure 6B). GE index of irrigated rice in Brazil decreased 70 per cent over the 1975-2000 period. These results show that the growing divergence in Brazil's rice yields is mainly due to increasing yield variability of upland rice and the expanding polarization between irrigated and upland rice.

Table 1
Spatial variability of rice yield

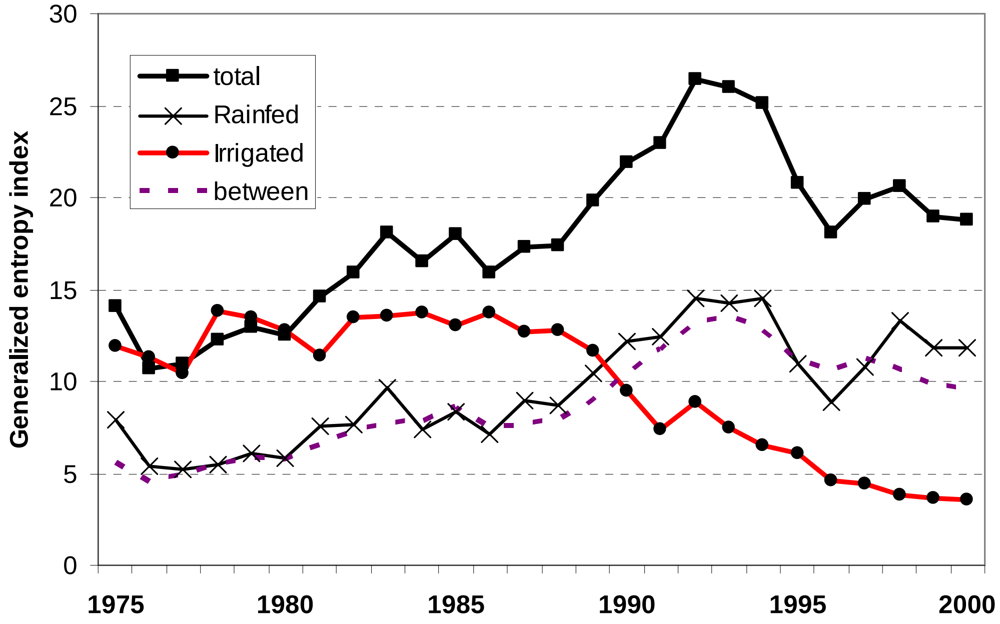
	Generalized entropy index				
	Total	Upland	Irrigated	Between	Polarization index (%)
	Panel A: China, 1980-2000				
1980	9.15	11.70	9.15	0.09	1.01
1981	6.20	6.96	6.14	0.06	0.91
1982	5.49	5.23	5.44	0.05	0.88
1983	4.78	4.95	4.72	0.06	1.23
1984	6.10	4.80	6.04	0.06	0.97
1985	5.62	4.40	5.58	0.05	0.86
1986	4.87	6.34	4.79	0.07	1.45
1987	3.91	2.61	3.85	0.07	1.67
1988	4.58	3.04	4.52	0.07	1.56
1989	3.88	5.90	3.81	0.06	1.63
1990	3.61	2.22	3.56	0.05	1.50
1991	3.80	3.82	3.75	0.05	1.40
1992	3.63	3.95	3.56	0.07	1.81
1993	3.38	4.86	3.32	0.06	1.77
1994	3.37	3.28	3.33	0.04	1.26
1995	3.19	3.00	3.15	0.04	1.17
1996	3.24	4.50	3.08	0.11	3.39
1997	3.19	2.38	3.14	0.05	1.51
1998	3.30	4.40	3.27	0.10	3.03
1999	3.20	3.40	3.13	0.08	2.50
2000	3.10	2.60	3.10	0.07	2.26
	Panel B: Brazil, 1975-2000				
1975	14.05	7.94	11.93	5.56	39.59
1976	10.68	5.35	11.34	4.55	42.64
1977	10.92	5.21	10.40	4.97	45.52
1978	12.22	5.50	13.83	5.46	44.67
1979	12.94	6.10	13.45	5.79	44.72
1980	12.55	5.84	12.79	5.71	45.53
1981	14.64	7.53	11.37	6.53	44.65
1982	15.92	7.65	13.45	7.32	46.00
1983	18.09	9.63	13.57	7.71	42.64
1984	16.49	7.42	13.75	7.80	47.32
1985	18.00	8.38	13.06	8.59	47.71
1986	15.87	7.11	13.75	7.46	46.99
1987	17.33	8.92	12.66	7.68	44.30
1988	17.37	8.67	12.80	7.88	45.35
1989	19.79	10.46	11.63	9.08	45.87
1990	21.95	12.15	9.46	10.42	47.46
1991	22.98	12.40	7.39	11.77	51.23
1992	26.41	14.50	8.85	13.25	50.16
1993	26.03	14.29	7.44	13.55	52.05
1994	25.16	14.52	6.51	12.75	50.67
1995	20.75	10.92	6.08	11.12	53.60
1996	18.10	8.89	4.59	10.58	58.44
1997	19.90	10.74	4.43	11.22	56.37
1998	20.63	13.31	3.82	10.57	51.24
1999	18.93	11.80	3.63	9.75	51.51
2000	18.80	11.84	3.54	9.67	51.45

Figure 6
Spatial variability of rice yield in China and Brazil

Panel A: China, 1980-2000



Panel B: Brazil, 1975-2000

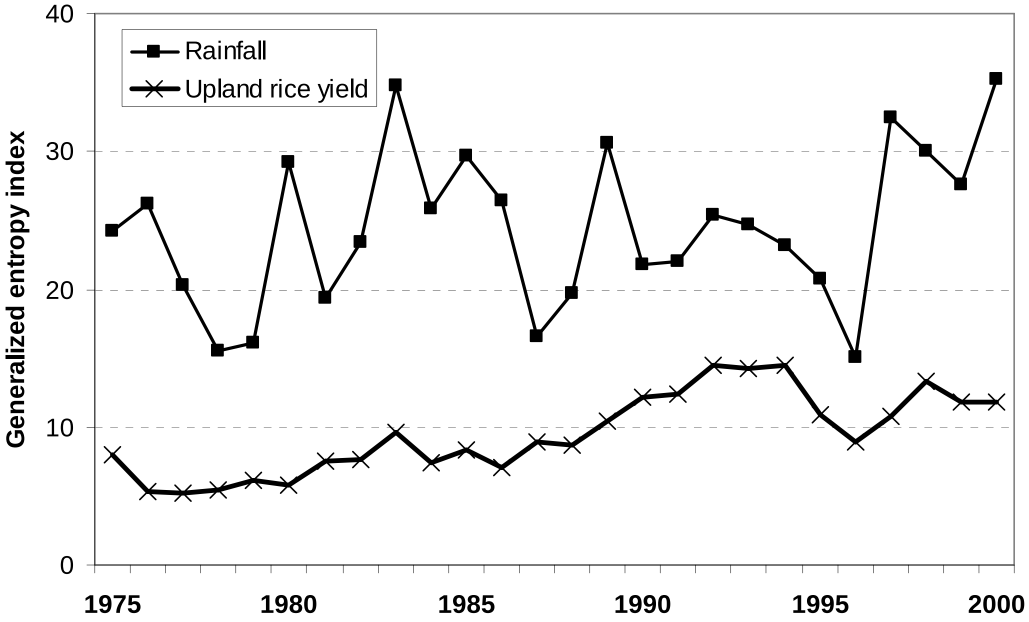


Source: Author’s calculations.

The impact of climate change and particularly changing rainfall patterns

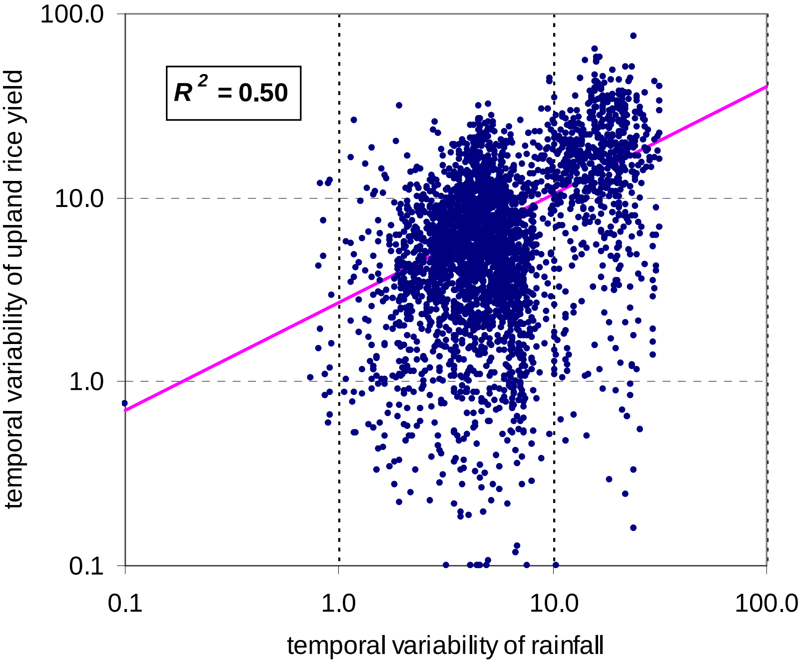
Crop production is intrinsically location specific. This suggests that differences in local resource endowments contribute to the spatial divergence in crop yields. There is significant climate variance in large countries such as China and Brazil, and this may be a factor affecting crop yield variability. Indeed, many case studies show that crop yields are affected by both increasing climate variations and global warming, which are the consequences of climate change.[8] Rainfall is the most important climate factor for rice production, particularly for non-irrigated rice. Thus, we examine whether the changing rainfall patterns in the last few decades have had an impact on the temporal-spatial pattern of rice yields in the countries under review.

Figure 7
Spatial variability in rainfall and upland rice yield in Brazil



Source: University of East Anglia and Embrapa.

Figure 8
Temporal variability in rainfall and upland rice yield in Brazil



Source: Author's calculations.

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[8] See, for example, Nichalls (1997); Carter and Zhang (1998); Naylor et al. (2002); Lobell and Asner (2003); Peng et al. (2004); Wang and You (2004); You et al. (2005).

Not surprisingly, annual rainfall during the growing season has a negligible impact on irrigated rice yields because irrigation compensates for possible shortfalls in rainfall.[9] This is true for both China and Brazil. However, changes in rainfall patterns do affect upland rice yields. Figure 7 plots the spatial variability of rainfall and upland rice yields in Brazil.[10] Three facts are worth noting. First, spatial variability of rainfall is 2-3 times higher than that affecting upland rice yields, and yearly variation of rainfall is also higher than that of the corresponding rice yields. Second, there is a small but statistically significant upward trend in rainfall variability (a slope of 0.21 per year for rainfall GE indices, with *t*-value -3.57). This upward trend in rainfall is smaller than the corresponding upward trend in upland rice yield variability (a slope of 0.31 with *t*-value -4.57). Third, we observe some parallel movement between upland rice yield indices and rainfall indices. For instance, both rainfall and rice yield indices increase from 1987 to 1989 and drop suddenly in 1996. This supports our hypothesis that changing rainfall patterns may have contributed to the increasing divergence in the yields of upland rice production. Indeed, there is growing evidence that there has been an increase in rainfall variability and extreme events such as drought and floods in the last few decades (Dai, Fung and Genio 1997; Dai et al. 2004; Chen et al. 2004).

We now look at the covariate patterns of temporal variability of rainfall and rice yield for Brazil. To do so, we have calculated the temporal variability in upland rice yields and average rainfall for the municipalities of Brazil. Figure 8 shows the temporal variation in rainfall and upland rice yield in the country. The figure shows an apparent correlation between the variability of rainfall upland rice yields, with a R^2 value of 0.5. This correlation of temporal variability suggests that increasing rainfall variability from 1975 to 2000 is a contributing factor to the widening divergence of upland rice yields in Brazil.

Agricultural R&D bias towards irrigated areas

There are two aspects to this bias: first, there is the much higher investment in breeding and extension services for irrigated rice varieties; and second, the potential for technological spillovers is greater for the relatively more homogenous irrigated areas than for the agro-ecologically heterogeneous upland areas (Wood, You and Zhang 2004). High yielding varieties developed during the green revolution are targeted towards tropical and subtropical regions with good irrigation systems or regular rainfall (Evenson and Gollin 2003). Sanint and Wood (1998) show that almost 90 per cent of new rice varieties released in Latin American and Caribbean since the 1970s were targeted to irrigated and rain-fed wetland production environments.

China's rice breeding programmes work almost exclusively with irrigated rice varieties, which has resulted in these varieties being highly popular.[11] Most varieties used in

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[9] Rainfall affects availability of irrigation water, especially under extreme climate conditions such as drought.

[10] China has limited upland rice production, and the observations available were too few for meaningful spatial variability estimation.

[11] China has also pioneered the development of hybrid rice varieties and was the first country to commercially use them. Hybrid rice alone accounted for over 60 per cent of total rice production in 1990s (Fan et al. 2005).

upland rice and rain-fed lowland rice ecosystems are varieties introduced from other countries with little local breeding work (Zhu 2000).

Brazil, on the other hand, has a vast upland rice area. It also established the Upland Rice and Bean Research Centre (CNPAF) in 1974 and has released a total of 35 new varieties over the period 1976-2000 (Pardey et al. 2006). Despite the interest of the institute for upland rice, the adoption of modern upland rice varieties is still low. Table 2 shows the changes in area and yield for rice by seed varieties from 1975 to 1997.[12] Modern semi-dwarf irrigated rice varieties increased from zero in 1975 to almost 1.2 million hectares in 1997. By 1997, over 96 per cent of the irrigated rice planted in Brazil originated from HYVs. The adoption rates of HYV for upland rice, although considerably lower than irrigated, were still significant. In 1997 approximately 21 per cent of the area planted with upland rice was sown to HYVs. While the HYV adoption rates may be lower than for irrigated, the change in their usage over time has been quite impressive, from nearly zero in 1975 to almost 500,000 hectares in 1997. This difference in HYV adoption rates between irrigated and upland is reflected in yield performance, as was established

Table 2
Rice production by seed varieties in irrigated and upland areas in Brazil

	Areas under modern semi-dwarf varieties				Rice yield (ton/ha)			
	Upland		Irrigated		Upland		Irrigated	
	(1000ha)	(%)(a		(%)(a	Traditional(b	MSV(b	Traditional	MSV
1975	0.0	0.0	0.0	0.0	1.26		3.60	
1976	0.0	0.0	10.9	2.0	1.27		3.60	4.30
1977	0.0	0.0	22.5	4.0	1.27		3.70	4.30
1978	101.8	2.0	37.4	7.0	1.02	1.50	3.80	4.50
1979	246.5	5.0	41.8	8.0	1.11	1.50	3.85	4.50
1980	395.5	7.0	53.4	9.0	1.30	1.50	3.90	4.70
1981	439.4	8.0	61.0	10.0	1.06	1.00	3.90	5.23
1982	443.2	8.2	248.1	40.0	1.28	1.70	3.90	4.70
1983	375.8	8.4	380.4	60.0	1.06	1.70	3.90	4.70
1984	393.6	8.5	468.7	65.0	1.22	1.70	3.90	4.70
1985	363.1	9.0	576.3	80.0	1.38	1.90	3.90	4.70
1986	418.3	9.3	994.3	91.0	1.10	1.90	3.90	4.75
1987	456.7	9.4	1050.6	92.0	0.95	1.90	4.00	4.75
1988	461.5	9.8	1157.9	92.5	1.18	2.00	4.00	4.75
1989	420.2	10.2	1156.0	93.0	1.10	2.30	4.30	4.87
1990	368.8	12.0	1024.7	93.2	0.42	2.30	4.00	5.00
1991	397.6	13.0	1094.3	93.4	1.02	2.50	4.00	5.00
1992	483.2	14.0	1149.9	93.6	0.93	2.30	4.20	5.00
1993	484.5	15.0	1257.9	93.8	0.82	2.30	4.20	5.10
1994	535.0	17.0	1217.3	94.0	1.05	2.30	4.20	5.10
1995	497.3	16.1	1192.0	92.2	0.95	2.30	4.30	5.20
1996	555.3	20.0	1083.8	95.0	1.32	2.10	4.30	5.20
1997	494.6	21.0	1193.3	96.0	1.09	2.00	4.20	5.10

Notes: (a per cent area planted to modern semi-dwarf variety (MSV), which is equivalent to the high yielding varieties.
(b Rice yield using traditional or MSV seeds.
Source: Embrapa.

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[12] 1997 is the latest year we have data.

earlier. The benefits of HYVs, however, go well beyond higher productivity. They may also reduce yield variability and be tailored to combat pests and environmental elements more successfully through, say, drought-resistant genes, among others. These diverging performance levels of irrigated rice versus upland rice and the adoption of HYVs, as well as the differences in the Brazilian and Chinese production explain why yields in Brazil have not converged as they have in China.

4 Conclusion

We have examined and compared the spatial and temporal patterns of rice yield variability in China and Brazil. Our analysis shows that rice yields in China have converged while those in Brazil have diverged over time. We then explored some possible underlying causes for the differences in yield variability between the two countries. The reasons for such dramatic differences are: (i) different system of production (particularly the fact that upland rice production is dominant in Brazil); (ii) the changing rainfall patterns, and (iii) the technology bias towards irrigated rice production environments.

The different rice production systems of China and Brazil play a significant role in the observed variations in their rice yield patterns. Irrigation reduces much of the yield variability in areas where supplemented water replaces rain-fed production. China’s primarily irrigated rice production, along with the bias toward generating technologies applicable for the more favoured production systems and the wide adoption of modern high-yield varieties, has contributed to the convergence of overall rice yields over the last few decades. On the other hand, the mixed production system in Brazil, with one-third irrigated rice and two-thirds upland rice, accounts for the divergence in rice yields over time. As in China, irrigated rice yields in Brazil have been converging over the last few decades. However, upland rice yields have diverged and the polarization between irrigated rice and upland rice has increased. The increasing spatial variability of upland rice in Brazil has been affected by recent changes in rainfall patterns. The statistically significant correlation between temporal variability of upland rice yields and that of rainfall suggests that changing climate regimes affect the performance patterns of upland rice yields. The agricultural R&D bias against upland rice further contributes to the widening divergence in upland rice yields.

The difference in convergence or divergence of yield trends in Brazil and China provides us some valuable lessons. Agricultural R&D investments in China and Brazil, as in the rest of the world, have focused on the more favoured areas. Irrigated rice has received considerably more attention and effort from researchers than upland rice. Production with systematic irrigation is considerably more expensive and requires greater investment than production under rainfall-dependent systems. Thus, the research focused on irrigated rice as opposed to upland also has a distributional effect, as it favours financially-better placed farmers, most likely with better lands. If this is the case, we can evaluate the differences between irrigated and upland rice systems in the context of favoured versus less-favoured areas. In recent years, researchers have looked at the impact of investment in less-favoured areas and have found that (rates of economic) returns can be quite high and also have the additional benefit of poverty reduction (Fan and Hazell 1999). Anecdotal evidence also suggests the existence of a possible reduction in resource- and environmental degradation in addition to economic growth and poverty reduction. Thus, more investment in technologies, infrastructure and institutions targeting the less-favoured areas such as those planted with upland rice has the potential to achieve not only higher yields, but also high rates of return. Our empirical finding is also relevant to the ongoing debate on the impact of climate change on food security. Crop productivity in the less-favoured regions, such as the upland rice areas in Brazil, is significantly correlated with climate change and global warming. Less-favoured lands will bear the brunt of the adverse consequences from climate change. Improving food security and reducing poverty in these areas, where the capacity to adapt to global change is also weakest, still remains a challenge.

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Appendix I: A generalized entropy index of spatial yield variability[13]

The generalized entropy (GE) measure (Shorrocks 1980 and 1984) can be written as:

$$I(y)=\begin{cases} \sum_{i=1}^{K} f(y_i)\left\{\left(\frac{y_i}{\mu}\right)^c - 1\right\} & c \neq 0,1 \\ \sum_{i=1}^{K} f(y_i)\left(\frac{y_i}{\mu}\right)\log\left(\frac{y_i}{\mu}\right) & c = 1 \\ \sum_{i=1}^{K} f(y_i)\log\left(\frac{\mu}{y_i}\right) & c = 0 \end{cases} \qquad (1)$$

In the above equation, y_i is yield in the i^{th} region, μ is the total sample mean, $f(y_i)$ is the area share of the i^{th} region in the total planting area and K is the number of regions. Here the region is either a county in China or a municipality in Brazil.

The valuable feature of the GE measure is that it is additively decomposable. For rice production systems indexed by g, the overall GE measure can be expressed as:

$$I(y) = \sum_{g}^{K} w_g I_g + I(\mu_1 e_1, \ldots, \mu_K e_K) \qquad (2)$$

where $w_g = \begin{cases} f_g\left(\frac{\mu_g}{\mu}\right)^c & c \neq 0,1 \\ f_g\left(\frac{\mu_g}{\mu}\right) & c = 1 \\ f_g & c = 0 \end{cases}$

where I_g is inequality in the g^{th} rice production system (e.g., irrigated rice), μ_g is the mean of the g^{th} rice production system and e_g is a vector of 1's of length n_g, where n_g is the planting area of the g^{th} rice production system. If n is the total planting area of a country, then $f_g = \frac{n_g}{n}$ represents the area share of the g^{th} production system in the country. The first term on the right side of (2) represents the within-group inequality. $\frac{w_g I_g}{I(y)} * 100$ is the g^{th} group's contribution to total inequality. The second term is the between-group (or inter-group) component of total inequality.

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[13] This section is largely taken from Wood, You and Zhang (2004).

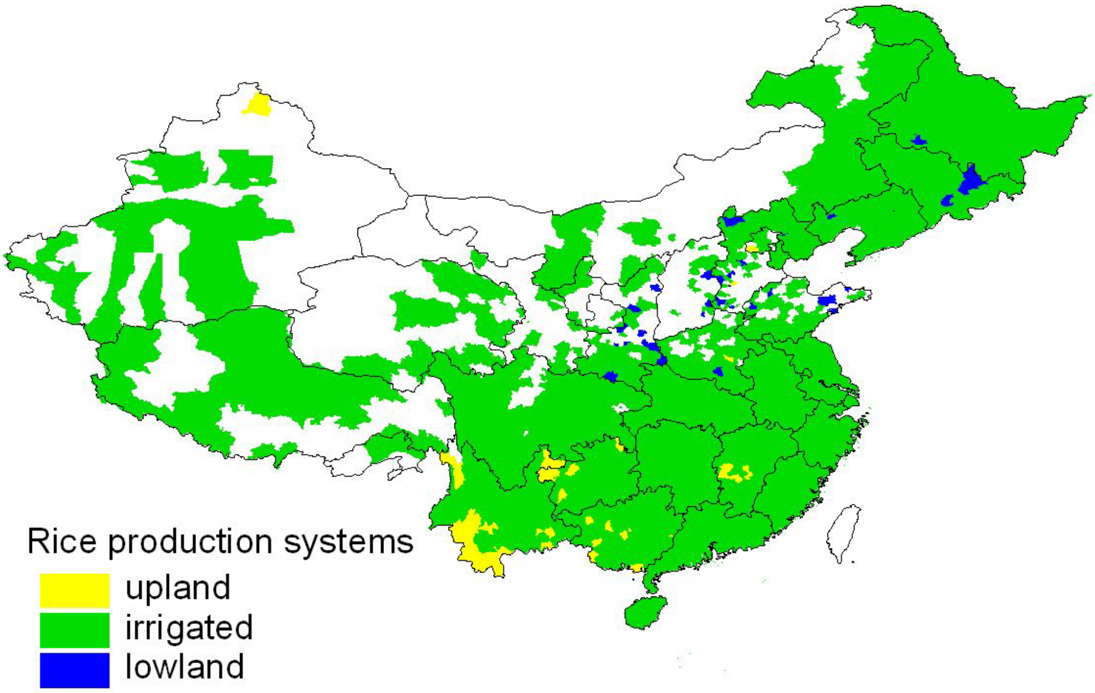
Following Zhang and Kanbur (2001), we define the polarization index, P, as:

$$P = \textit{between-group inequality/total inequality} \tag{3}$$

The parameter c in the GE index represents the weight given to distances between regions or between production systems. For simplicity, we present results in this paper only for $c=0$.

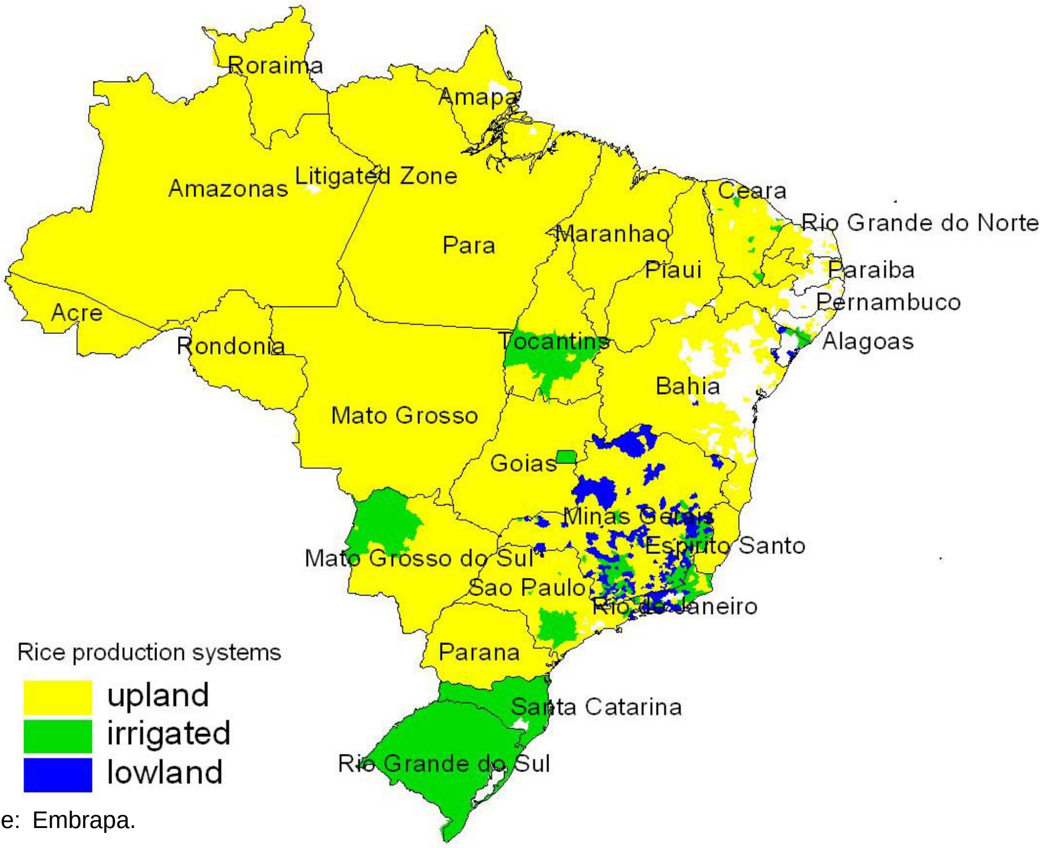
Appendix II: Rice production systems in China and Brazil

Map B1
Rice production systems in China



Source: CASS.

Map B2
Rice production systems in Brazil



Source: Embrapa.