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Impacts of El Nino-Southern Oscillation events on China's rice production

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Abstract: This paper aims to demonstrate the relationships between ENSO and rice production of Jiangxi province in order to identify the reason that ENSO might have little effect on Chinese rice production. Using a data set with measures of Jiangxi's climate and rice production, we find the reason that during 1985 and 2004 ENSO's well correlated with rainfall did not promote Chinese rice production. First, the largest effects of ENSO mostly occur in the months when there is no rice in the field. Second, there is almost no temperature effect. Finally, the monthly distribution of rainfall is almost the same in ENSO and neutral years because the largest effects are during months when there is the least rain. In addition, due to the high irrigation share and reliable and effective irrigation facilities of cultivated land, China's rice production is less climate-sensitive.

Keywords: El Niño Southern Oscillation; ENSO; econometric methods; rice production; sea-surface temperature anomaly; China

1 Introduction

Interannual climate variability associated with El Nino-Southern Oscillation (ENSO) events has significant impacts on agricultural production, food prices and rural incomes in many parts of the world (Cane *et al*., 1994; Hansen *et al*., 1998; Phillips *et al*., 1998; Podesta, Messina *et al*., 1999; Kapuscinski 2000). In Indonesia El Nino events—the warm phase of the ENSO cycle as measured by sea surface temperature anomalies (SSTAs) in the Pacific Ocean—typically lead to delayed onset of the monsoon, early season droughts and delayed planting of the main rice crop (Naylor *et al*., 2001; Naylor *et al*., 2002; Falcon *et al*., 2004). Similar effects have been observed in the Philippines (Dawe *et al*., 2008; Roberts *et al*.,

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2009) and a few other regions of Southeast Asia. El Nino events clearly depress rice production in some regions (Indonesia in particular), but in other important producing regions the same events appear to improve conditions for rice agriculture. For instance, in years in which an El Nino (La Nina) leads to lower (higher) than average rainfall in Indonesia, major rice producing and exporting regions in China enjoy higher (lower) rainfall. So, it is cheering if the Indonesian imports are offset by Chinese exports and thus for the world rice market remains relatively steady. However, the statistical evidence on prices presented by FAO (2006) suggests that this is not the case.

Somewhat surprisingly, while it is important to explain this puzzle, there is still not a widely accepted relationship despite the fundamental importance of understanding the relationship between ENSO events and rice production in China. For example, where Tao *et al*. (2004) find little impact of ENSO on rice production, Zhang *et al*. (2008) found that the correlations between rice yields and rainfall and temperature differed between ENSO years and normal years, and Zhang *et al*. (2009) find that there is no clear evidence that the occurrence of anomalous temperature events in winter over southern China is closely linked to ENSO events.

Given China's enormous size and the complexities of its rice economy, trying to address even this one piece of the ENSO/world rice market puzzle is not feasible in a single paper. Therefore, in the rest of the paper we focus on one province of China, Jiangxi, and examine the questions of the relationship between ENSO and rice production in that region. Jiangxi is an appropriate choice both because it is one of the largest rice producing provinces, and because the ENSO-related climate signals in Jiangxi are some of the strongest in China. In other words, if there is any important rice producing region in China where we can measure the effect of El Nino on rice production, it will be Jiangxi (NOAA, 2006).

Empirical correlations between Nino 3.4 SSTA and precipitation (Huffman *et al*., 1997; Wu *et al*., 2003) suggest that ENSO variability is closely linked to variability in wintertime precipitation in Jiangxi. Given these correlations, an examination of the history of ENSO events worldwide suggests that ENSO should have a fairly important influence on Jiangxi's climatic patterns. Between 1950 and 2004 El Nino and La Nina events were not rare. When an El Nino (La Nina) event is defined as a year in which the Nino3.4 SSTA index is at least 0.5℃ above (below) the long run average, over the past 55 years in there have been 13 El Nino years (or 24% of the years) and 17 La Nina years (or 31% of the years).

Jiangxi is also the third largest rice-producing province, accounting for 11% of China's output (CNBS, 2005). Jiangxi is one of the two largest suppliers of rice to the rest of the country. Consequently, Jiangxi can serve as a convenient laboratory to study the effects of ENSO on rice production. The dependence of Jiangxi's cropping economy on rice is evident in the sown area percentages of its main crops and main cropping patterns. More than 80% of its sown area is cultivated to rice. Most farmers cultivate two rice crops per year. The most common cropping pattern, accounting for nearly 75% of the sown area in Jiangxi, is "early rice" followed by "late rice". Some farmers (13%) plant a single crop of "middle rice". The timing of rice production in Jiangxi spans most of the calendar year, with a three to four month gap when the fields are fallow. Farmers typically begin the seedling beds of the early rice crop in early February, transplant in early March and harvest by late June. As soon as the early rice crop is harvested, farmers immediately prepare the land (by plowing) and transplant the late rice crop (from a seedling bed that was prepared in mid-June). The late rice crop is harvested in October. Middle rice, as the name implies, is planted after the early rice but harvested before the late rice. Given these intensive and complex rice cropping systems, the need for water and precise water control in Jiangxi is high. Fortunately, the province is well endowed with water resources. There are many rivers, streams and tributaries, several large reservoirs, and tens of thousands of small- and medium-sized reservoirs and ponds, most of which are used for irrigation. The prominence of clay soils, which is relatively impermeable and make water easy to store, also leads to rapid runoff rates and low levels of groundwater resources. Of the total irrigated area, provincial officials in the Jiangxi Provincial Bureau of Water Resources estimate that more than 95% of water accessed in Jiangxi is from surface flows (interviews done during preparation of proposal). Officials also estimate that more than 60% of Jiangxi's rice area is irrigated from reservoirs that are either managed by provincial, prefectural or local irrigation districts (IDs) or by villages themselves. Another 30% (or so) is irrigated from run-of-the-river systems or from village-run ponds and small reservoirs.

Given this importance of surface water, understanding variations in Jiangxi rice production requires knowledge of rainfall patterns. Although the large number of reservoirs and river systems make the water flow pathways to rice paddies complex, hydrologically it is simplified by the fact that rainfall is highly correlated with recharge due to the nature of soils and rainfall runoff. There are two major periods of rainfall that recharge the systems—a (potentially) ENSO-affected winter season rainfall period (from November to January) and the higher (and even more important) spring, monsoonal rainfall period (from May to June). These two periods account for more than 80% of Jiangxi's annual rainfall. Since small rivers dry up quickly without rainfall, the amount of water available in the larger reservoirs from both rainfall seasons is critical for supplying enough water for the late rice crop. As might be expected from a system that has been farmed for centuries, average winter rainfall and normal monsoon rainfall supply enough water to the reservoirs to irrigate most of the rice crop (including the late rice crop).

The overall goal of this paper is further to explore how ENSO affects global rice production so that the relationship between ENSO-related climate variability and world rice production can be better understood. We will focus on one major missing piece of the puzzle, the effect of ENSO on China's domestic rice production, and will use two main approaches. Better characterizations of these relationships should improve our understanding of how world rice markets are affected by ENSO events.

The rest of the paper is organized as follows. In the first substantive section we will provide more details of ENSO's effect on weather patterns on China. Since the center of the El Nino signal is on Jiangxi, the next section examines the patterns of rice production across space and over time during each year. The modeling approach is described in section 4 and the results given in section 5. The final section concludes.

2 Data

2.1 Climate data

Long records of weather variables (rainfall and temperature) are available from the Data

Center from the Chinese Academy of Sciences for each of the 16 weather stations interspersing among 15 counties throughout Jiangxi. These county-level records contain daily data of precipitation and temperature and span more than 50 years, starting in 1951. Daily records on precipitation and temperature are aggregated into monthly, seasonal or annual aggregates for different parts of the paper.

Monthly aggregates clearly show the seasonal nature of Jiangxi's rainfall (Table 1), which peaks in June and reaches its lowest point in December. Average monthly temperatures follow roughly the same pattern. Monthly averages, however, disguise variation over the years of our study period. For example, the coefficient of variation of rainfall is 2.91 in December and 1.35 in June, with this variability evident in graphs of the distribution of monthly averages for March, June, September and December. Below we explore the extent to which this variation is related to ENSO.

Table 1 Average rainfall and temperature by month using the data from the 16 weather stations in Jiangxi Province

Month	Average over 1951–2004		Average over 1985–2004	
	Rainfall (0.1 mm)	Temperature (0.1℃)	Rainfall (0.1 mm)	Temperature (0.1℃)
Aug	1360	281	1538	278
Sep	880	243	875	241
Oct	725	188	693	190
Nov	641	130	672	133
Dec	487	75	475	79
Jan	712	54	864	60
Feb	1052	72	1058	80
Mar	1728	113	1851	112
Apr	2227	173	2135	176
May	2546	219	2271	223
Jun	2794	253	2937	255
Jul	1471	287	1665	285

Data sources: China Meteorological Administration

2.2 Rice production data

As with the climate data, rice data in Jiangxi are available on the county level, and include statistics on rice sown area, yields and total production, each disaggregated by rice type (early, middle, or late). Although rice data are available for all counties in the province, our more limited climate data restricts our sample size to 15 counties, for which we have 20 years of data covering 1985–2004. Data on sown area, yields and production from these sources are typically thought to be reliable—especially for use in studies that examine production over time. They have been used in many previous studies, such as, Lin (1992); Fan and Ruttan (1992); and Huang and Rozelle (1995). A basic summary of these data is given in Table 2.

3 Methods

Earlier work has documented a close, predictable relationship between August sea surface

Table 2 Rice production—sown area, yield and output—in the 15 counties of Jiangxi Province having weather stations, 1985–2002

Items	Unit	All rice	Early rice	Middle rice	Late rice
Sown Area	Ha	34,345 (29,489)	15,516 (14,082)	2,999 (2,582)	15,830 (13,848)
Yield	Kg/ha	4,955 (679)	4,694 (825)	5,882 (1,466)	5,037 (868)
Output	Tons	169,930 (158,084)	72,363 (72,689)	17,647 (15,029)	80,051 (77,079)

Data source: Data Center, Chinese Academy of Sciences.

temperature anomalies (as measured by the Nino 3.4 SSTA) and subsequent rainfall and rice production patterns in Indonesia (Naylor, Falcon *et al*., 2001; Naylor, Falcon *et al*., 2002; Falcon, Naylor *et al*., 2004). A one-degree Celsius warming (increase in the SSTA) results in about a 1.4 mmt decline in unmilled rice (paddy) production during the September to August crop year that follows. Virtually all of the climate-induced variation in rice production occurs as a consequence of changes in the area harvested rather than in the yield of rice per hectare. Although these effects are highly significant, year-to-year changes can be even more severe. For example, when there is a 5℃ interannual change, rice production can vary as much as 5 mmt on a year-to-year basis, which represents about one-fourth of world rice trade.

To produce the results for Indonesia (and the Philippines—Dawe *et al*., (2006)) the analysts used relatively simple statistical models relating August SSTA directly to seasonal and crop year (Sep/Aug) rice production. Since this approach (henceforth, *Approach 1*) has proved remarkably robust at explaining variability around long-run trends in domestic rice production, we adopt a similar approach here. Since there might be even a stronger relationship between SSTA in later months (when ENSO events often hit their peak) and rice production, we also will examine an alternative set of estimated relationships between ENSO and rice production. In addition, the analysis takes an alternative approach ("*Approach 2*"), which first assesses the relationship between ENSO variation and Jiangxi's climatic variations, and then estimates the effect of variations in rainfall and temperature directly on rice production. In essence, *Approach 2* is seeking to decompose the results from *Approach 1* into its two component parts.

To measure the ENSO effect (in either *Approach 1* or *Approach 2*), we have several choices of variable specification. In order to make our results comparable with the previous work in Indonesia and the Philippines, we have decided to use a measure of the August 3.4 SSTA index directly. We call this variable *Nino3.4anom*. We also measure the effects of *Nino3.4anom* in September-December when the ENSO event moves toward their maximum strength. This index, measured in degrees (Celsius), captures the severity of ENSO events, as reflected in changes in sea surface temperature in the tropical Pacific. In other specifications, we used two dummy variables—one for El Nino (which is equal to 1 if the year was an El Nino event and 0 otherwise) and one La Nina events (measured the same). The signs on the El Nino/La Nina dummy variables and their levels of statistical significance are fully consistent with the results that we will present for the models that use below (results not shown).

In order to isolate the effect of ENSO from other time varying factors, we also include measures of a linear and squared time trend (as do Falcon *et al*., (2004)). These time trend variables pick up any secular rise or fall in the dependent variable (which is especially useful when modeling the rice production variables). Specifically, time trend variables are often included to hold constant factors such as technological change.

In addition, because individual counties could be affected by ENSO events in ways unrelated to the strength of the ENSO signal (through differences in institutional capacity, for example, or accidents of geography), we include a set of 15 county dummy variables in our estimations (dropping one of them and using that county as the base county). These variables account for all non-time varying effects at the county level. As is the tradition in the econometric literature, we call models estimated with the inclusion of the 15 dummy variables our *fixed effects model*.

3.1 Models and strategy

Following the discussion above, we estimate three general sets of models (one for *Approach 1* and two for *Approach 2*). *Approach 1,* which most closely follows the earlier work from Indonesia (Falcon *et al*., 2004), is based on the regression model:

$$\text{Rice\_production}_{it} = a0 + a1*\text{nino3.4anom}_t + a21*\text{time} + a22*\text{time}^2 + \mu + e_{it} \quad (1)$$

where $\text{Rice\_production}_{it}$ is measured in three ways—sown area; yield; total output—in order to account for the different impact pathways of ENSO on overall rice production. For convenience of interpretation, we transform the production variables into log form by taking natural logs, which allows us to interpret the coefficient on the nino3.4anom_t or ENSO dummy variables as percentage changes. The variable nino3.4anom_t and time and time^2 (time-squared) are defined as discussed above and μ represents the 15 county-level dummy variables. The symbols a0, a1, a21 and a22 are parameters to be estimated and e_{it} is the error term.

Because there are three types of rice in Jiangxi—early rice (ER), middle rice (MR) and late rice (LR)—we estimate equation (1) for each type of rice separately. Furthermore, because the effects of ENSO could vary depending on the timing of planting and harvesting, we estimate 11 forms of equation (1) to attempt to capture the multiple pathways through which ENSO could affect production. To simplify discussion in the results section, we present only the a1 coefficients—the *coefficient of interest* for *Approach 1*—in the body of the text.

3.2 Approach 2

Approach 2 requires the estimation of two sets of equations. In the first stage, we want to understand whether an ENSO event in the Pacific Ocean that begins in the month of August of a particular year affects the rainfall and temperature in our 16 weather stations in Jiangxi either later in the same year or early in the following year. In the second stage (discussed below), we look at the effect of these ENSO-induced changes in rainfall/temperature on rice production. In an alternative set of estimates we show the results of the impacts of the SSTA for each month of the year on the rainfall for that year.

Stage 1, *Approach 2*

To estimate the relationship between ENSO and Jiangxi's rainfall and temperature, the general form of the model is:

$$\text{Climate\_month } X_{it} = b0 + b1*\text{nino3.4anom}_t + \mu + u_{it} \quad (2)$$

where climate_month X_{it} represents two sets of variables (with each set of variables containing 12 variables). The first set of climate variables includes measures of Jiangxi's rainfall for each county from each year. The second set of climate variables includes measures of Jiangxi's temperature for each county from each year. Within each set of variables, there are 12 specific variables, one for each month (with X being a place holder from 1 to 12). For example, Rainfall_month1_{it} measures the average rainfall during the month of January in county i in year t (in 0.1 mm). Temperature_month6_{it} measures the average temperature during the month of June in county i in year t (in 0.1℃). The dependent variables that we use for the results that we report in the body of the text are in logarithm form. We also include versions of the same equations but using the dependent variable in linear form and find similar results. The main variable of interest—nino3.4$anom_t$—in equation (2) is defined in the same way as it is in equation (1). In equation (2) we do not include time trend variables since rainfall and temperature trends should be mostly stationary over such a short time period (1985 to 2004). Similar to equation (1), however, fixed effects are accounted for by the inclusion of 15 county-level dummy variables which are represented by μ. The symbols b0 and b1 are parameters to be estimated and u_{it} is the error term.

In summary, then, to estimate equation (2) we estimate 24 regression models. The first 12 regressions are designed to measure the effect of El Nino during year t on the rainfall for each month of the year following an ENSO event. Specifically, when we estimate the effect of El Nino on rainfall in August, September, October, November and December, we regress the rainfall in Jiangxi from year t/month X on nino3.4anom for year t. When we estimate the effect of ENSO on rainfall in January, February, March, April, May, June and July, we regress the rainfall in Jiangxi from year t+1/month X on nino3.4anom for year t. The second 12 regressions are designed similarly and are supposed to measure the effect of ENSO during year t on the temperature for each month of the following year.

Stage 2, Approach 2

To estimate the second stage of the relationship between ENSO and rice production, which explores the effect of annual changes in rainfall and temperatures on rice production, the general form of the model is:

$$\text{Rice\_production}_{it} = c0 + c1{*}\text{climate}_{it'} + c21{*}\text{time} + c22{*}\text{time}^2 + \mu + e'_{it} \quad (3)$$

where, as in equation (1), rice production_{it} is measured in three ways—sown area; yield; total output. The variable, $\text{climate}_{it'}$, is a matrix made up of two variables, $\text{rainfall}_{it'}$ and $\text{temperature}_{it'}$, which represents the rainfall/temperature in county i in year t'. The t is given an apostrophe in this equation to draw attention to the fact that it is measuring climate for one of two subperiods of year t. One of the subperiods (henceforth, rainfall_1_{it} and temperature_1_{it}) is measured as the accumulated rainfall/temperature for the two month period that includes September in year t and October in year t. The other subperiod (henceforth, rainfall_2_{it} and temperature_2_{it}) is measured as the accumulated rainfall/temperature for the three month period that includes November in year t, December in year t and January in year t+1. The other control variables, time and time^2 and μ, are the same as in equation (1). The symbols c0, c1, c21 and c22 are parameters to be estimated and e'_{it} is the error term.

As with equation (1), we estimate 11 versions of equation (3) to isolate the various potential seasonal effects of climate variation on rice production. As in other sections, we only report results for our main coefficient of interest (c1).

4 Results

4.1 Results of the estimation by Approach 1

The results of the estimation by *Approach 1* (equation 1) demonstrate clearly that the effect of ENSO on rice production in China is much weaker than that in Indonesia or the Philippines. Indeed, Table 3 shows that it is almost non-existent. In seven of the 11 regressions, there is no measured effect of ENSO on rice production. And somewhat surprisingly, where we do see a mild effect of ENSO, it is of the opposite sign as expected.

Table 3 Summary of the immediate and delayed effects of ENSO (measured as 1℃ rise (fall) in August SSTA) on rice production using a fixed effects estimator in Jiangxi Province, 1985 to 2004

	Sown area	Yield	Output
Late rice (Immediate effect)	n.a.	–	–
Early rice (Delayed effect)	–	–2.9%	–2.3%
Middle rice (Delayed effect)	–	–	–
Late rice (Delayed effect)	–2.2%	–	–2.6%

Note: These results are based on *Approach 1*. The effects shown in the table are the "a1" coefficients estimated from 11 forms of equation (1).

Specifically, we find no immediate effect of ENSO on late rice in the same year (Table 3, row 1). When there is an increase (decrease) in the Nino 3.4-SSTA of one degree (as measured by *Nino3.4anom*) in August of a given year, the warming (cooling) of the ocean has no measureable impact on late rice yields during the same year. Since the sown area for late rice in the contemporary year had already been made, it is not surprising that there also is no measured impact on the output of late rice.

The results also show that there is only a small effect of *Nino3.4anom* on early rice (Table 3, row 2). The coefficient in yield equation suggests that when *Nino3.4anom* increases by 1 degree, yields fall by 2.9% – a somewhat surprising result given the positive relationship between warmer seas surface temperatures and Jiangxi rainfall. Unlike in Indonesia, we find no direct ENSO effect on sown area. As a result the overall effect on output of early rice is similar to that of yield; there is a measured fall in output of only 2.3%. One explanation is that there is no positive relationship because Jiangxi's rice areas are not water constrained—especially during the seasons when there are added ENSO-induced rainfalls. However, it is possible that with additional rainfall there also is an increase in the number of cloudy days (and reduction of sun light), which may lead to slightly lower yields.

The effect of ENSO on late rice output in year t+1, while nearly the same magnitude (–2.6%), is through a different mechanism (Table 3, row 4). The coefficient on the *Nino3.4anom* variable in the yield equation is insignificant. However, there is a measured negative effect of a one degree rise in SSTA on the sown area of late rice in the year following the El Nino event. In fact, we do not know why this is the case. Discussions with those familiar with rice production in Jiangxi (e.g., agronomists in the provincial department of agriculture) were not able to produce an explanation. It is likely that the reduction is so small that it is almost not even noticeable.

Unlike the case of early rice and late rice, there is no measureable effect on middle rice (Table 3, row 3). The coefficients on the ENSO variable in the sown area, yield and output equations are all insignificant.

Taken together, ENSO has only a small effect on rice production in Jiangxi and almost certainly less in all of China (since the ENSO signal appears strongest in Jiangxi). Combining the effects on early, middle, and late rice, we find overall a 2.2% fall in Jiangxi rice production for every degree rise in SST, equaling a 3745 ton production decline. With Jiangxi accounting for around 10% of Chinese rice output, such a decline would represent only a 0.2% or 0.3% production decline for China as a whole.

4.2 Results of the estimation by Approach 2

Estimates by Stage 1

The small apparent effect of ENSO on Jiangxi rice production does not appear to result from a poor ENSO-rainfall relationship in the province. Consistent with expectation, we find significant positive effects of SST warming on ensuing August-December and January-July rainfall (Table 4). Specifically, as can be seen from Panel A in Figure 1, the intensity of ENSO's effect on Jiangxi rainfall rises sharply through the fall and peaks in November, with a one degree warmer SST resulting in a 40% increase in November rainfall. Starting in December, the ENSO effect begins to attenuate—although it is still high in percentage terms in December and January. After January, the measured effect is quite low, never rising above 10%, suggesting that the Spring Monsoons are little affected by ENSO.

Table 4 Summary of the immediate and delayed effects of El Nino (measured as 1℃ rise (fall) in August SSTA by the variable *Nino3.4anom*) on rainfall using a fixed effects estimator in Jiangxi Province, 1951 to 2004

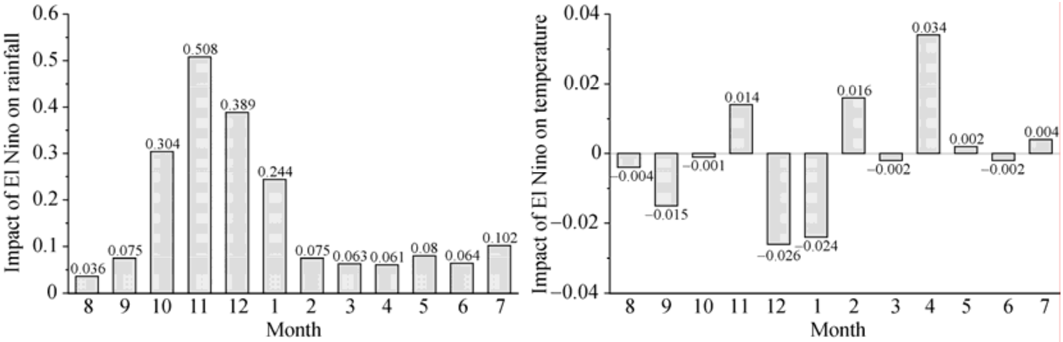
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)
	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Nino3.4 anom	0.245 (8.60)**	0.075 (2.76)**	0.063 (3.43)**	0.061 (3.77)**	0.080 (4.48)**	0.064 (3.10)**	0.104 (2.90)**	–0.168 (4.81)**	0.076 (1.87)	0.305 (6.40)**	0.508 (11.45)**	0.390 (8.70)**
Constant	6.306 (64.65)**	6.877 (73.67)**	7.495 (119.38)**	7.708 (138.68)**	7.913 (129.52)**	7.896 (111.42)**	6.858 (55.53)**	6.920 (58.11)**	6.349 (46.27)**	5.861 (35.95)**	5.960 (39.81)**	5.786 (38.73)**
Observations	759	767	767	767	767	767	767	767	780	764	779	775
R-squared	0.14	0.04	0.08	0.10	0.09	0.11	0.06	0.09	0.08	0.09	0.16	0.10

Note: These results are based on Stage 1, *Approach 2*. The coefficients for the 15 dummy variables (μ) are not shown. The dependent variables in these regressions are in log form: ln(rainfall) = a + b* nino3.4anom + μ + e. Absolute value of t statistics in parentheses, * significant at 5%; ** significant at 1%.

This timing of ENSO effects on Jiangxi rainfall suggests part of the answer to why the ENSO effects using *Approach 1* were so low. The largest impacts are in November, December and January. When comparing these months with the timing of the planting and harvesting of the different types of rice in China, we find that the largest ENSO effects on rainfall are exactly significant when there is no rice in the ground. Water is stored in reservoir systems for use in subsequent months. Although it was possible that there are still indirect effects later in the year, apparently the carry over of the effects into later months is not very strong.

The effect on temperature is lower (Table 5; Figure 1, Panel B). Unlike the case of ENSO's effect on rainfall, few of the coefficients (only 3 of 12) on the *Nino3anom* variable are significant, and the sizes of the effect are typically small.

Figures 2 and 3, which compare total average precipitation and rainfall in normal years



Panel A Panel B

Figure 1 The coefficients measuring the effects of Nino3.4anom on rainfall and temperature in Jiangxi Province: Panel A: Impact on rainfall (Estimated function: lnRainfall = a + b* nino3.4anom + μ + e); Panel B: Impact on temperature (Estimated function: lnTemp = a + b* nino3.4anom + μ + e)
Note: Coefficients are from Tables 4 and 5.

Table 5 Summary of the immediate and delayed effects of El Nino (measured as 1℃ rise (fall) in August SSTA by the variable Nino3.4anom) on temperature using a fixed effects estimator in Jiangxi Province, 1951 to 2004

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)
	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Nino3.4 anom	–0.031 (1.75)	0.024 (1.27)	–0.003 (0.49)	0.033 (12.52)**	0.011 (1.39)	–0.002 (1.55)	0.003 (2.40)*	0.009 (6.95)**	0.003 (0.25)	0.009 (1.08)	0.023 (2.51)*	0.028 (2.77)**
Constant	4.143 (69.25)**	4.397 (68.91)**	4.832 (221.48)**	5.220 (575.09)**	5.425 (203.73)**	5.556 (1082.80)**	5.664 (1149.99)**	5.638 (1256.17)**	5.519 (156.76)**	5.277 (195.51)**	4.928 (156.37)**	4.418 (127.34)**
Observations	744	757	767	767	767	767	767	767	781	781	781	779
R-squared	0.46	0.37	0.63	0.78	0.21	0.81	0.80	0.84	0.13	0.27	0.35	0.57

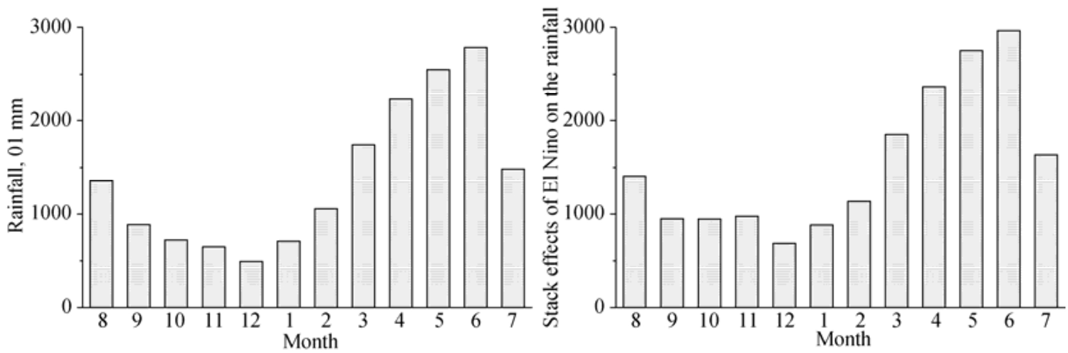
Note: These results are based on Stage 1, *Approach 2*. The coefficients for the 15 dummy variables are not shown. The dependent variables in these regressions are in log form: ln(temperature) = a + b* nino3.4anom + county dummy + e. Absolute value of t statistics in parentheses, * significant at 5%; ** significant at 1%.

versus in El Nino years, illustrate another reason why the effects of ENSO on rice production appear small – namely that the panels look roughly the same. In other words, there is really no large ENSO effect on total rainfall. Why is this? Clearly, the large effect in percentage terms is during the months (October to January) when total rainfall is low, with only small effects in other months.

In sum, then, there are three explanations for ENSO's small measured effect on rice. First, the largest effects of ENSO are almost all in the months when there is no rice in the field. Second, there is almost no temperature effect. Finally, because the largest effects are during months when there is the least rain, the monthly distribution of rainfall is almost the same in El Nino and non-El Nino years.

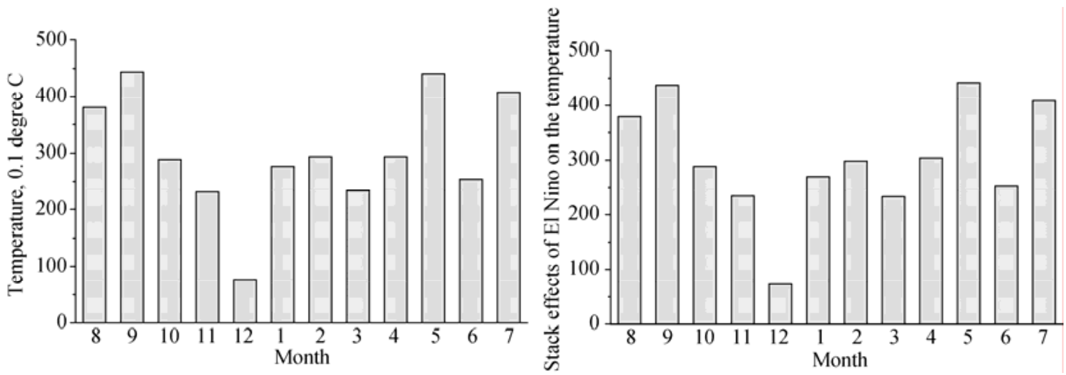
Estimates by Stage 2

The results from Stage 2 of *Approach 2* provide another insight into our key question about the effect of ENSO on rice production. In this part of our analysis, we focus on the results of the regression analysis that examines the *direct* effect of rainfall and temperature on rice production in Jiangxi. As seen from the summary table (Table 6), we find little effect of rainfall and temperature variations on rice production. In the 22 regression models (11 for rainfall and 11 for temperature), there are only three significant coefficients. All of the ef-



Panel A Panel B

Figure 2 Comparing the effect of El Nino (measured as Nino3.4anom) on month by month rainfall in Jiangxi Province, 1951 to 2004, rainfall by month in normal year (Panel A) and stack effects of El Nino on the rainfall by month (Panel B)



Panel A Panel B

Figure 3 Comparing the effect of El Nino (measured as Nino3.4anom) on month by month temperature in Jiangxi Province, 1951 to 2004, temperature by month in normal year (Panel A) and stack effects of El Nino on temperature by month (Panel B)

fects are relatively small. In fact, in the case of the effect of ENSO induced temperature change, there is less than ½ percent (–0.4%) impact on late rice yields. In the case of the effect of ENSO-induced changes in rainfall on early rice yields and outputs, the changes are only around minus two percent (–1.8% on yields and –2.3 % on output). Importantly, these small negative effects are consistent with (and help us identify) the mechanism underlying the findings from *Approach A1* (Table 3); in both *Approach 1* and *Approach 2*, we find that there is a similar small and negative significant effect of El Nino on the yields/output of early rice.

What are the implications of this? One is that even though there might be a case that Jiangxi is vulnerable to shifts in rainfall and temperature, this vulnerability does not appear to extend to late fall and winter rainfall and temperature shifts. Perhaps Jiangxi is well enough endowed with dams, reservoirs, canals and weirs and natural springs that it can withstand variations in climate in September/October (climate_1) and in November, December and January (climate_2). With little observed role of ENSO in the variation of potentially more relevant climate variables, such as spring monsoon rainfall (Stage 1 of *Approach 2*), it is unsurprising that *Approach 1* found little overall effect of ENSO on rice production.

Table 6 Summary of the effects of changes in rainfall and temperature due to ENSO on rice production using a fixed effects estimator in Jiangxi Province, 1985 to 2004 (percentage)

	Rise (fall)	Sown area	Yield	Output
Late rice (Using Climate_1)	Rainfall	n.a.	–	–
	Temperature	n.a.	–	–0.4%
Early rice (Using Climate_2)	Rainfall	–	–1.8%	–2.3%
	Temperature	–	–	–
Middle rice (Using Climate_2)	Rainfall	–	–	–
	Temperature	–	–	–
Late rice (Using Climate_2)	Rainfall	–	–	–
	Temperature	–	–	–

Note: These results are based on Stage 2, *Approach 2*. In the same way that we needed to estimate 11 versions of the equation (1) in Table 4, we also estimate 11 versions of equation (3) in this table. In our analysis rainfall_1/temperature_1 are measured as the average rainfall/temperature in September and October in year t. In our analysis rainfall_2/temperature_2 are measured as the average rainfall/temperature in November and December in year t and January in year t+1. These sets of variables will allow us to estimate the immediate effects of rainfall_1 and temperature_1 in year t on late rice yields and output in year t (row 1). It also allows us to estimate the delayed effects of rainfall_2 and temperature_2 in year t (and January in year t+1) on sown area, yields and output of early rice in year t+1 (row 2); on sown area, yields and output of middle rice in year t+1 (row 3); and on sown area, yields and output of late rice in year t+1 (row 4). Since our coefficient of interest is c1, in this table we only report this coefficient.

4.3 Evidence from survey data

In addition to using data collected by the meteorological stations (rainfall and temperature data) and statistical bureaus (rice production data), we also executed a primary survey. Specifically, we randomly chose seven counties in Jiangxi Province and six villages in each county, in total visiting 40 villages (7*6 = 42–2 villages that did not provide complete data). In these villages, our enumerator staffs (who were all Ph.D. students or research fellows from the Chinese Academy of Sciences in Beijing) conducted face-to-face interviews with a three person team in teach village: the party secretary, the village leader and the village accountant. We asked each team whether they believed the above (below) average rainfall in the months of November, December, January and/or February has had any effect on either yield, area sown, or production of rice.

The evidence from our survey data, in fact, supports the findings of the regression results from both *Approach 1* and *Approach 2*. In none of the 7 counties did more than 8% of the leader say that there was evidence of any impact of ENSO on rice production. In other words, on average, 94% of village leadership team respondents said there has not been any noticeable effect. In the villages in which the leaders stated there was some effect, in only one of them did they say the impact was moderate or severe. In the others, the effect has been minimal in most parts of the province.

Discussions with the village leader respondents as well as with officials during interviews by the authors in 2007 revealed the reasons that they did not believe there was any effect. We were told that rainfall in the winter months, when there was no rice in the field, did not matter. In addition, leaders often told us that below or above average rainfall in winter was almost always be erased by the monsoon rains (which were not affected by ENSO events and not correlated—at least in the minds of village leaders—with rainfall during the winter months (November to February).

5 Conclusions

The findings of this study have contributed to solving a puzzle about why there is a significant effect of ENSO on international rice prices. ENSO events lead to climate shifts in Indonesia and the Philippines and contribute to rice production shortfalls and higher domestic prices. Facing higher prices (or the prospects of higher prices), the Indonesian and Filipino governments both are known to increase rice imports during the year immediate following an El Nino event. When they go into (the relatively thin) world markets for additional rice purchases, the world rice price rises. If China, which has rainfall shifts that are in the opposite direction of those in Indonesia and the Philippines, experienced higher than normal production and began to export more in El Nino years, it is possible that the upward pressure on prices in world markets could be abated. However, as our results show, there is no observed offsetting effect.

Our analysis has identified a number of reasons that ENSO might have little effect on Chinese rice production, despite being well correlated with rainfall. First, the largest effects of ENSO are almost all in the months when there is no rice in the field. Second, there is almost no temperature effect. Finally, because the largest effects are during months when there is the least rain, the monthly distribution of rainfall is almost the same in ENSO years and neutral years. In addition, it could be that China's agriculture (at least compared to that in Indonesia and the Philippines) is less climate-sensitive because of the higher share of cultivated land that is irrigated in China and because the irrigation facilities in China are more reliable and effective.

So are there any policy implications of our findings beyond those already raised in the previous work by Falcon *et al*. (2004)? For countries that typically import rice, our results bolster the conclusion that during an El Nino year, governments and private sector actors should expect higher than average rice prices, and should be prepared to take action if domestic price stabilization is a policy goal (Yin *et al*., 2009). This will be doubly true for countries such as Indonesia, who will face simultaneous production shortfalls and world price increases. Furthermore, because there are not natural offsetting supplies in China that are exported in order to keep prices down, it does not mean that there can not be policy induced (or commercially-induced) response that anticipates ENSO-related price movements. If it is known as early as August in the previous year that an El Nino event will likely lead to higher world prices during the next year, governments and/or commercial interests in either Vietnam or Thailand (counties with a weaker ENSO signal) could take action to ramp up production in order to take advantage of what will likely be higher prices. Were they to do this, the price spikes typically accompanying large ENSO events could be mitigated.

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