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Weather events vs food security: an Asian perspective from the supply side

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Extreme weather events are expected to increase. The paper provides a concise overview of climate change as well as issues pertaining to extreme weather events. Several indicators used to quantify climate variability, to assess countries' vulnerability to climate change and extreme weather negative impacts are presented. In Asia rice assumes strategic relevance, thus accounting most of the world production and consumption. This paper aims at expanding the above statement and at investigating the potential effects of weather events on rice supply using a multiple regression analysis. Given its vulnerability to climate change and its limited ability to cope with it, Asia is expected to be severely affected by the adverse impacts of extreme weather conditions, where food security still represents a major concern.

1. Introduction

Since 2007, international commodity markets have experienced a series of dramatic oscillations in prices. During the summer of 2008, in particular, food prices reached their highest levels for over 20 years dropping significantly by mid-2009, and rapidly rising again in the following months. Again, in 2012, food prices peaked sharply before starting a downward trend lasting until December 2014. In future, they are expected to continue experiencing abrupt and marked fluctuations.

Price variability is a common feature of agricultural markets. High and variable food prices are likely to persist in coming years and developing countries are expected to be affected first and hardest (Gilbert, 2010). If, on the one hand, the sharp increase in world food prices has had a modest effect on richer countries, on the other hand, inflation has had a negative impact on the poor's world. In fact, food price spikes are a common feature to many people in developing countries where up to 75 per cent of income is spent on food.

Among the factors affecting food price variability, we can distinguish both demand and supply driven factors. The main explanatory variables concerning demand are income, population trend, changing diet patterns, exchange

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rates and speculation activities. Conversely, production costs, land utilization, productivity, profitability of alternative products, level of stocks, technological changes, public policies and environmental constraints influence supply (Zolin and Andreosso-O'Callaghan, 2012; Brümmer *et al*., 2013).

According to the Food and Agricultural Organization (FAO, 2014), global food demand is expected to increase: people are predicted to get wealthier and, therefore, consume more food and disproportionally more meat. This, in turn, will drive food prices up by 40-50% (Bruinsma, 2009). By 2050, the world will have up to 200 million more food-insecure people.

We have focused this work on the supply side and, in particular, on weather related patterns. Extreme weather events have always been part of agriculture, but they are expected to increase in frequency and intensity on a warming planet (Gillis, 2012), and, a higher percentage of population is foreseen to be living in places at greater climatic risk (Vidal, 2013)[1].

Starting from these premises and with the help of a multiple regression analysis, this paper investigates the explanatory variables influencing rice production in Asia in the period between 1986 and 2011. To this aim, this paper firstly provides a general overview of climate change and of issues relative to extreme weather events. Keeping a focus on the rice market in Asian countries, several indicators used to quantify climate variability and to assess countries' vulnerability to climate change and extreme weather negative impacts are then presented.

Given its vulnerability to climate change, Asia is expected to be severely affected by the adverse impacts of extreme weather, where food security still represents a major concern. Moreover, rice is a staple food for more than half of the world's population and assumes strategic importance among the cereals.

2. Materials and methods

Our objective is identifying the main drivers affecting rice production in Asia over the period of time between 1986 and 2011[2]. To this aim, a multiple regression analysis has been conducted through the Ordinary Least Squares (OLS) method. In our model, the dependent variable is represented by rice[3]

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1 The agricultural sector is not only a potential victim of climate change; it is also a major contributing factor helping to drive extensive deforestation in the tropics, consuming fossil fuels and emitting nitrous oxide, a powerful greenhouse gas, into the air (UN, 2007).

2 The timeframe is conditioned by the availability of OECD producer support estimate data – available starting from 1986.

3 We have selected Thailand white rice "5% Broken".

production in Asia. The independent variables that have been considered to analyze supply include: the extension of area dedicated to rice harvesting and of area equipped for irrigation in Asia, the international price of rice, the international price of grains[4] and the world price of fertilizer, the Standard Oscillation Index, producer single commodity transfers[5] and rice ending stocks in Asia. Yearly data from 1986 until 2011 have been used.

The statistical sources of reference are the Food and Agriculture Organization (FAOSTAT, Food and Nutrition Security Framework programme) and the United States Department of Agriculture (Production, Supply and Distribution) databases, with reference to data on rice production and ending stocks, rice harvested area and area equipped for irrigation. As far as the commodity market is concerned, commodity prices and input costs data are drawn from the World Bank-Global Economic Monitor commodities database. Agriculture support estimates are provided by the Organization for Economic Cooperation and Development (OECD). For weather related data, and specifically the Southern Oscillation Index, we mainly refer to the National Oceanic and Atmospheric Administration (NOAA) and the Centre for Research on the Epidemiology of international Disasters (CRED) databases.

3. Climate change and extreme weather events: a literature review

Climate change and extreme weather events currently represent a complex and particularly relevant environmental, social and political issue.

The first scientific debates on comprehending climate change date back to the 19th century; however, in recent decades there has been a growing awareness of the effects of human contribution to global warming and scientific proof has started being collected (Harding, 2007). Nowadays, there is large scientific consensus about serious, large-scale and even abrupt and irreversible disruptions that might occur in ensuing decades due to climate change (Doran *et al.*, 2009; Anderegg *et al.*, 2010). Taking urgent action to combat climate change and its impacts represents one of the Sustainable Development Goals outlined in the 2030 Development Agenda (UN, 2015). A large number of expressions have been used to define climate change and extreme weather events in previous decades (Durwood and Cameron, 1990; Mintzer, 1990; Hutchinson, 1989; Houghton and Woodwell, 1989; Adams *et al.*, 1990). Among the copious definitions available, our analysis takes into consideration those adopted by the Intergovernmental Panel on Climate Change (IPCC), the

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4 Grains include barley, maize, rice, sorghum and wheat.

5 For the rice sector in OECD countries.

leading international body for climate change assessment. According to the IPCC (2013), climate change refers to "a change in the state of the climate that can be identified by changes in the mean and/or the variability of its properties, and that persists for an extended period, typically decades or longer". An extreme weather event is then defined as "an event that is rare at a particular place and time of year – as rare as or rarer than the 10th or 90th percentile of the observed probability density function. When a pattern of extreme weather persists for some time, such as a season, it may be classed as an extreme climate event, especially if it yields an average or total that is itself extreme (e.g., drought or heavy rainfall over a season)" (IPCC AR5 WG I 2013).

As well known, climate variability is heavily influenced by El Niño and the Southern Oscillation (ENSO) ocean-atmosphere phenomena, which are naturally occurring patterns, whose frequency and intensity appear to be altering as a consequence of global climate change (Walker and Sydneysmith, 2008; Roberts *et al.,* 2009; Naylor *et al*., 2007; Huang, 2007). ENSO is a periodic fluctuation of the sea surface temperature (El Niño) and the pressure of the atmosphere (Southern Oscillation) across the equatorial Pacific Ocean. The Southern Oscillation is quantified by the Southern Oscillation Index (SOI), a standardized index based on the differences in observed sea level pressure between Tahiti, French Polynesia and Darwin, Australia[6].

Hence, the SOI measures the large-scale fluctuations in air pressure occurring between the western and eastern tropical Pacific during El Niño and La Niña episodes. Prolonged periods of negative (positive) SOI values coincide with abnormally warm (cold) waters across the eastern tropical Pacific typical of El Niño (La Niña) episodes[7] (Fig. 1).

Globally, El Niño and La Niña are considered the main source of inter-annual climate variability. Warmer and cooler than average air temperatures, as well as severe instances of droughts and floods have been associated to these phenomena. Nevertheless, the effects greatly depend on the location and on the season. In Southeast Asia, El Niño typically results in drier rainfall conditions, especially in the dry season (August-November), while La Niña induces wetter conditions. Within the region, the impact may vary from place to place[8].

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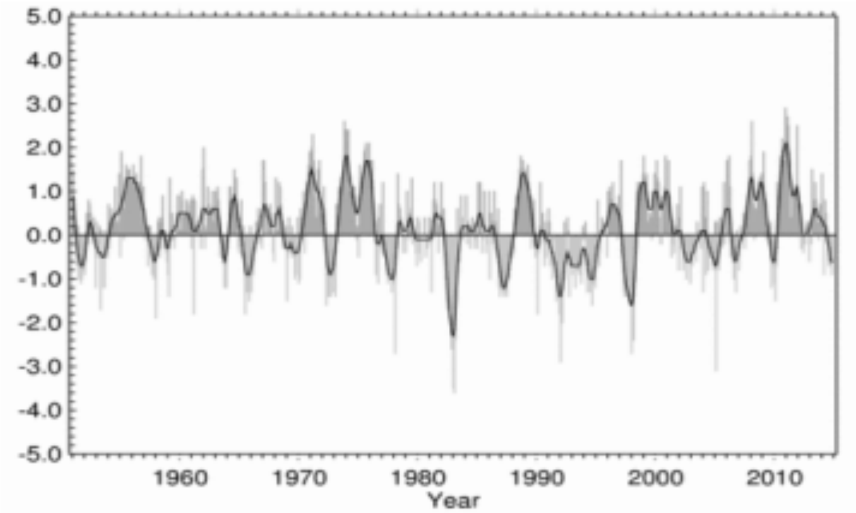
[6] Calculation of SOI: (Standardized Tahiti – Standardized Darwin)/Monthly Standard Deviation.

[7] Historically, notable El Niño episodes occurred in 1982/83, 1991/92, 1993, 1994, 1997/98 where the first and the last are often referred to as extreme El Niño events. More recently, la Niña episodes arose in 1988/89, 1999/2000, 2007/09 with a substantial occurrence in mid-2010, which lasted until early 2012.

[8] In March 2008, La Niña caused a drop in sea surface temperatures over Southeast Asia by 2°C. It also caused heavy rains over Malaysia, the Philippines, and Indonesia (Wu *et al*.,

Fig. 1. The Standardized Southern Oscillation Index between 1951 and 2013



Source: National Climatic Data Centre, National Environmental Satellite, Data, and Information Service (NESDIS), National Oceanic and Atmospheric Administration (NOAA)

To date, the link between global warming and El Niño/La Niña episodes has not been fully explained by scientists. However, a recent study predicts an increase in the frequency of extreme El Niño events in the future in response to greenhouse warming (Cai *et al*., 2014), with potential profound socioeconomic consequences. And, if we add the impacts of El Niño to the extreme weather already being driven by climate change, the amount of potential damage is likely to increase (Carrington *et al*., 2014).

Specific indices have been created to provide a picture of how countries have been or are expected to be affected by the impacts of climate change and extreme weather events. In our work the Global Climate Risk Index (GCRI) and the Climate Change Vulnerability Index (CCVI) are taken into account.

The GCRI[9] analyses to what extent countries have been affected by the impacts of extreme weather events (storms, floods, heat waves etc.), in terms of population affected and economic damages in the 20-year 1993-2012 period (Table 1).

2003). During the last several decades, the number of El Niño events increased, whereas the number of La Niña events decreased (Wittenberg, 2009).

9 Published by the non-governmental organization Germanwatch.

Tab. 1. Global Climate Risk Index 1993-2012[1]: the ten most affected countries between 1993 and 2012

Ranking GCRI 1993-2012	Country	Death toll	Deaths per 100,000 inhabitants	Absolute losses (in million US$ PPP)	Losses per unit GDP in %	Total number of events (1993-2012)
1	Honduras	329.80	4.86	667.26	*2.62*	65
2	Myanmar	7,135.90	13.51	617.79	*1.20*	38
3	Haiti	307.50	3.45	212.01	*1.73*	60
4	Nicaragua	160.45	2.81	224.61	*1.74*	44
5	Bangladesh	816.35	0.56	1,832.70	*1.16*	242
6	Vietnam	419.70	0.52	1,637.50	*0.91*	213
7	Philippines	643.35	0.79	736.31	*0.29*	311
8	Dominican Republic	212.00	2.43	182.01	*0.32*	54
8	Mongolia	12.85	0.52	327.38	*3.68*	25
9	Thailand	160.35	0.26	5410.06	*1.29*	193
10	Guatemala	82.35	0.69	312.23	*0.58*	72

[1] The GCRI 1993-2012 is based on the average values of twenty years
Source: Germanwatch

Noticeably, the majority of the top ten countries are located in Asia. Among them, we can distinguish those which have been continuously affected by extreme weather events from those which rank highly due to exceptional catastrophes. Examples of the latter case are Thailand where, in 2011, floods accounted for 87 per cent of overall damage and Myanmar, where cyclone Nargis in 2008 caused more than 95 per cent of that year's damages.

In 2012, Asian countries experienced the highest number of death tolls and economic damages. The most affected countries were the Philippines and Pakistan which, after having experienced severe flooding in 2010 and 2011, were struck again by a particularly difficult monsoon season in 2012.

The CCVI[10] estimates countries' vulnerability to the effects of climate change over the next 30 years[11] (Table 2).

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[10] Developed by global risks advisory firm Maplecroft to identify climate-related risks to populations, business and governments worldwide.

[11] The CCVI evaluates national vulnerabilities across the following areas: exposure to extreme climate-related events and sea-level rise; the sensitivity of populations in terms of

Tab. 2. Climate Change Vulnerability Index 2014: the ten most vulnerable countries in 2014

Ranking CCVI 2014	Country	Vulnerability category
1	Bangladesh	Extreme
2	Guinea Bissau	Extreme
3	Sierra Leone	Extreme
4	Haiti	Extreme
5	South Sudan	Extreme
6	Nigeria	Extreme
7	DR Congo	Extreme
8	Cambodia	Extreme
9	Philippines	Extreme
10	Ethiopia	Extreme

Source: Maplecroft

According to the 2014 CCVI, the economic impacts of climate change will be most intensely felt in Bangladesh (Maplecroft, 2014). Again, Asian countries appear to be particularly vulnerable. Other important growth markets considered at risk include: India, Pakistan and Vietnam in the "extreme risk" category, in addition to Indonesia, Thailand and China, classified at "high risk". Furthermore, by 2025, 31% of global economic output is foreseen to be based in countries facing "high" or "extreme risks" from the impacts of climate change. "High" and "extreme risk" countries are represented by emerging and developing countries, whose share in world economy is ever increasing: China and India together are expected to total nearly 23% of global economic output by 2025 (Maplecroft, 2014).

4. Agriculture and food security: a focus on Asia

As a consequence of an increasing atmospheric concentration of greenhouse gases, global climate models (IPCC AR3 WGI, 2001; The Royal Society,

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population patterns, development, natural resources, agricultural dependency and conflicts; and, the adaptive capacity of a country's government and infrastructure to combat the impacts of climate change.

2001) predict a mean global warming between 1.5 to 5.8°C and an increase in mean global precipitation from 5 to 15 per cent by 2100 (Rosenzweig *et al.*, 2001). Relatively small changes in mean temperature can lead to disproportionately large changes in the frequency of extreme meteorological events. In addition, as the magnitudes of warming increase, the likelihood of severe, pervasive and irreversible impacts is higher (National Climate Assessment, 2014).

Major reasons for concern are identified in the IPCC third assessment report (IPCC AR3 Working Group I, 2001), illustrating the consequences of warming and of adaptation limits for people, economies and ecosystems. Over the next few decades, one of the main risks due to high hazards or high vulnerability of the countries involved is the risk of loss of rural livelihoods and income due to reduced agricultural productivity and insufficient water access. A further risk is of food insecurity and the breakdown of food systems due to warming, drought, flooding and torrential rains (IPCC AR5 Working Group II, 2014). This is especially true for the least developed countries, given their limited ability to cope with the situation.

IPCC projections of climate change impacts in the 21st century are estimated to further erode food security and make poverty reduction more difficult (IPCC AR5 WG II, 2014): they are expected to exacerbate poverty in most developing countries and create new poverty pockets in countries with increasing inequality. Thus, food price increases will particularly affect poor wage-labour-dependent households that are food net buyers in regions with high food insecurity and high inequality.

All aspects of food security may be potentially affected by climate change, including food access, utilization and price stability. According to FAO (FAO, 2014), the poorest regions in the world with the highest level of undernourishment will be exposed. Eight of the ten countries most affected by extreme climate in the last decade are developing countries (six of them located in Asia) belonging to the low-income or lower-middle income country group[12] (Kreft and Eckstein, 2013).

Climate change poses a major challenge to the agricultural sector because of the dependence of agriculture on climate and because of the complex role it plays in rural, social and economic contexts (Hatfield *et al.*, 2011). According to FAO (2002), the rising incidence of weather extremes will have increasingly negative impacts on crop productivity, especially if occurring at sensitive stages in crop life cycles (National Climate Assessment, 2014). Nevertheless, agri-

[12] According to World Bank's classification of world's economies based on Gross National Income (GNI) estimates calculated using the World Bank Atlas method. Low-income economies are those with a GNI per capita of $1,045 or less, whereas lower-middle-income economies are those with a GNI per capita of less than $4,125.

cultural production will be affected more by the severity and pace of weather patterns rather than by the gradual trends in climate change.

By mid-century, because of temperature increase and precipitation extremes intensification projections, crop yields and farm profits are expected to decline (Lobell and Gourdiji, 2012), particularly in Southern and South-eastern Asia. Rice yields in South-eastern Asia are projected to fall some 50% by 2100 (ADB, 2009). The International Rice Research Institute has forecast a 20% reduction in rice yields over the Asian region per degree Celsius of temperature rise (IFPRI, 2009), which contradicts production needs of keeping pace with the demand of a growing population (Goldenberg, 2014). Indeed, considering the fact that most of Asian population and economy rely on agriculture as a primary source of income, Asia is expected to be seriously affected by the adverse impacts of extreme weather (Masutomi *et al.*, 2009).

In order to give an idea of the high frequency and magnitude of extreme weather episodes, Table 3 provides a list of the flooding and drought events, in terms of impacts, that occurred in Asia between 1990 and 2014 and the consequences that followed in terms of the population affected and the resultant economic damages.

What is important to stress is that the agricultural sector itself contributes significantly to climate change in that it produces and releases greenhouse gases such as carbon dioxide, methane and nitrous oxide in the atmosphere. Agricultural sector total emissions in 2010 were around 4.3 GtCO2e across all regions, which represents an increase of 13 per cent compared to 1990 levels (Tubiello *et al.*, 2013). During this period, Asia has always been the region with the highest percentage contribution to total emissions[13].

For Asian countries, food security is a major concern. With an increasing population, less arable land available for farming development and with rising and fluctuating food prices, hunger, malnutrition and poverty could be the severe consequences these nations face. Climate change might further threaten food security, social and political stability (FAO, 2012).

According to a recent Asian Development Bank study (ADB, 2013), achieving food security in Asia is made more difficult by its "two different faces", one of progress and prosperity and the other of continued poverty. It was observed that the economy of Asia and the Pacific Region, which accounts for about 60% of global population, grew an average 7.6% a year between 1990 and 2010, compared to a global average of 3.4%. A growing population has continued to drive a greater demand for more protein-rich food and better nu-

[13] In 1990 Asia contributed to 39.8% of total emissions; in 1995 its share increased by more than 10%. Asian contribution to greenhouse gas emissions showed a slight constant increase until 2010, when it reached almost half share (46.5%) of total emissions.

Tab. 3. Flooding and drought episodes in Asia: number of episodes, total population affected and economic damages[1] between 1990 and 2014

Year	Drought			Flood		
	Number	Population affected	Economic damages Million US$	Number	Population affected	Economic damages Million US$
1990	1	254,282	64,000	24	45,700,469	2,779,968
1991	4	7,500,000	1,000	41	224,772,797	9,399,638
1992	2	12,000,000	53,200	33	18,864,717	6,093,273
1993	2	1,175,000	2,000	33	147,064,006	17,202,363
1994	3	93,690,000	13,855,200	39	127,583,530	8,486,487
1995	1	9,060,000	12,800	45	189,869,107	23,597,094
1996	1	0	542,400	38	181,018,058	23,401,240
1997	3	4,065,000	664,100	36	40,081,046	3,092,346
1998	3	2,605,000	0	35	289,643,494	39,328,844
1999	9	66,129,000	3,622,000	46	144,758,467	10,096,221
2000	13	77,773,000	1,891,165	45	67,542,702	9,922,802
2001	5	17,630,000	0	62	30,189,316	1,683,324
2002	8	371,510,000	2,361,475	59	164,688,275	5,663,967
2003	3	51,015,000	1,000	57	167,117,221	15,742,148
2004	0	0	0	56	115,105,470	9,205,251
2005	5	8,784,000	462,120	84	73,140,845	11,275,697
2006	3	20,100,000	2,910,000	99	27,241,398	5,718,327
2007	2	0	0	93	167,546,642	8,903,174
2008	5	16,080,000	234,000	65	27,718,771	3,722,183
2009	6	62,463,000	3,600,000	52	54,631,514	5,367,408
2010	2	41,482,602	2,370,000	62	179,780,374	31,354,365
2011	2	1,750,000	142,000	62	129,725,095	57,041,619
2012	2	4,800,000	0	62	53,512,306	19,253,923
2013	1	5,000,000	0	66	26,625,664	25,971,888
2014	5	31,500,000	18,000	47	28,462,907	26,733,000
Total	91	906,365,884	32,806,460	1,341	2,722,384,191	381,036,550

[1] Total population affected is the sum of injured, homeless, and affected population. The economic damages correspond to the estimated amount of damages to property, crops and livestock.

Source: Author's elaboration based on World Bank and CRED EM-DAT International Disaster Database trition, which has enormous implications not only for the intensity of production but for increased food consumption in general.

The Intergovernmental Panel on Climate Change, in its fifth assessment report, predicts that climate change will affect food security by mid 21st century, with the largest numbers of food insecure people located in South Asia. Countries in South Asia are expected to lose more than 5% of their growing season, placing an estimated 370 million people at risk due to diminished food security. These regions already contain large populations considered chronically hungry. More than 60% of people suffering from hunger live in Southern and Eastern Asia (FA0, 2014).

The 2030 Agenda for Sustainable Development (UN, 2015) fosters food security achievement through sustainable production and consumption, investments in innovation and infrastructures – with particular interest in ensuring water availability and management – and the engagement in ecosystems protection, and the containment of land degradation and desertification. The experience of three Asian countries, namely China, Vietnam and Thailand has been considered in order to claim and witness the importance of an agriculture-led approach to combat food security (Fan and Polman, 2014).

5. The rice sector in Asia

The 2008 food crisis was a prelude to the current economic crisis, and the rice sector was not sheltered from these world imbalances. The rise of food prices was without precedent; it was highest in the cereals sector and it increased strongly the number of undernourished people (Zolin and Andreosso-O'Callaghan, 2012). As a matter of fact, more than half of the world's population relies on rice as a staple food (FAO, 2012). Even if it is produced and consumed worldwide, rice production and consumption are concentrated in particular in Western and Eastern Asia. As shown in Fig. 3, Asia accounts for almost 90 per cent of the global production and consumption (Fairhurst and Dobermann, 2002) of this grain.

In general, rice production and consumption have followed a constant positive pattern since 1990, both globally and in Asia. Nevertheless, unlike consumption, there was a sudden fall in rice production in 2001, which was mainly caused by adverse weather in several important Asian producing countries (storms, drought and flooding episodes), and changes in public policies[14], thus depleting world rice inventories (Calpe, 2001; FAO, 2005).

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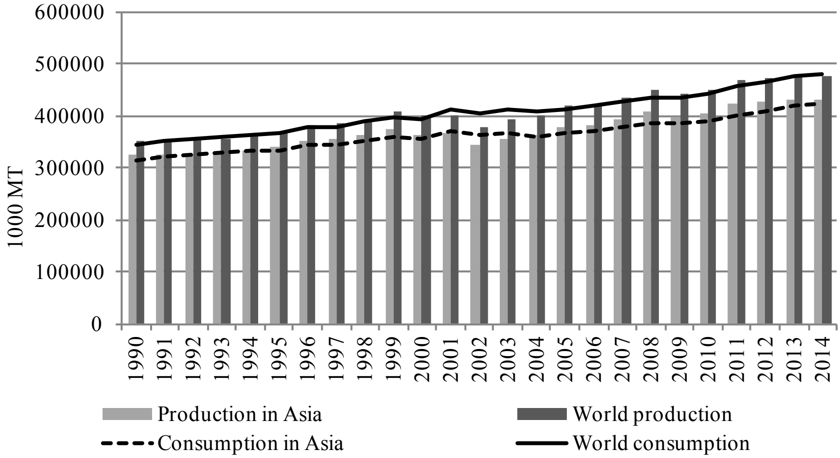
[14] For instance, in China public support to the rice sector was reduced after the country's accession to the World Trade Organization (WTO).

Fig. 2. Rice Production and Consumption: World and Asia, 1990-2014



Source: Author's elaboration on USDA Production, Supply and Distribution data

Tab. 4. Milled rice in Asia: top five producer and consumer countries, 2014

	Production		Consumption	
	1000 MT	% on World	1000 MT	% on World
China	144,500	*30.39*	148,000	*30.81*
India	102,000	*21.45*	99,000	*20.61*
Indonesia	36,500	*7.68*	39,200	*8.16*
Bangladesh	34,600	*7.28*	35,200	*7.33*
Vietnam	28,250	*5.94*	21,900	*4.56*
Asia	429,742	*90.38*	422,798	*88.02*
World	475,467	*100.00*	480,328	*100.00*

Source: Author's elaboration on USDA Production, Supply and Distribution data

Furthermore, the main rice producers are also the major rice consumers. China and India together account for half of world rice production and consumption (Table 4).

The rice trade in itself is marginal in terms of volume and value if compared to other cereal crops such as wheat and maize, due to a high level of domestic consumption in producing countries (Table 5).

Tab. 5. World rice, maize and wheat trade in terms of volume and value, 2011[1]

	Imports		Exports	
	Quantity (tonnes)	Value (1000 US$)	Quantity (tonnes)	Value (1000 US$)
Rice	355,353	388,392	289,384	405,913
Maize	108,067,148	36,342,489	109,646,045	33,727,471
Wheat	147,205,956	51,184,264	148,270,710	46,847,615

[1] Most recent data available
Source: FAOSTAT

Tab. 6. Rice consumption and percentage of caloric intake in total food consumption in South and East Asia, Europe, World, in 1990-1992 and 2007-2009

Region	1990-1992			2007-2009		
	Average rice consump-tion (kCal/capi-ta/day)	Average total food consump-tion (kCal/capi-ta/day)	Average share of rice in total food consump-tion (%)	Average rice consump-tion (kCal/ capi-ta/day)	Average total food consump-tion (kCal/capi-ta/day)	Average share of rice in total food consump-tion (%)
South-East Asia	1,176	2,177	*54.0*	1,255	2,626	*47.8*
South Asia	772	2,234	*34.6*	736	2,340	*31.4*
East Asia	797	2,568	*31.0*	775	2,955	*26.2*
Europe	44	3,307	*1.3*	54	3,400	*1.6*
World	532	2,613	*20.4*	537	2,816	*19.1*

Source: Asian Development Bank, FAO

Unsurprisingly, it is characterized for being an Intra-Asian trade: the three Asian countries of Thailand, India and Vietnam represent the top three rice exporters, whereas China and the Philippines feature among the top three rice importers.

Rice is mainly cultivated by small farmers in little holdings and is fundamental for rural population food security (Andreosso-O'Callaghan and Zolin, 2010). Because of its strategic importance, rice has been subject to government interventions, becoming one of the most distorted agricultural commodities. Further, rice provides a substantial share of daily caloric intake, particularly in Asia (Table 6).

The average proportion of rice in total food consumption is very high in Asia if compared to the global share and, even more, when compared to the European share. Nevertheless, the share of caloric intake from rice is decreasing in both Asia and the global market. Still, rice remains a major food item for the poor, who spend disproportionately more of their income on rice than the non-poor (Timmer and Dawe, 2012). This is one of the reasons why Asian countries were alarmed by the huge rice price increase during the 2007-08 food crisis (ADB, 2013).

Supply in the rice sector is characterized by the biological nature of the production process (e.g. rice production is highly connected to weather related hazards), by specific water requirements, by the time lag between production and realization, by the law of diminishing returns and by the limited availability of land.

Rice can be grown anywhere, but cultivation is preferable in regions with low labour costs and high rainfall, since it is a labour-intensive crop and requires abundant water. The cultivation of rice also contributes to greenhouse gas emissions: through the burning of rice residues such as straw and husks, an inefficient application of nitrogen fertilizers in rice production systems (which promotes the release of nitrous oxide into the atmosphere) and because of methane emissions from waterlogged and warm rice fields.

Weather threats to rice production are represented by droughts, salinity, irregular rainfall and submergence. Rice crop is vulnerable both to warmer temperatures that could depress yields and to increased salinity linked to rising sea levels (Wassmann *et al.*, 2009). In particular, uncontrolled flooding is increasingly becoming a major production constraint affecting about 20 million hectares of rice fields in South and South-east Asia and causing a loss of up to 1 billion USD every year (Redfern *et al.*, 2012). Indeed, while rice thrives in wet conditions, it cannot survive when submerged for long time periods, at any stage of growth (Mackill *et al.*, 2010). Reduced yields and threats to rice production (and to food insecurity) include other risks like planting and harvesting changes, decreased arable land, and more pests.

Several methods and practices are being adopted to face the challenges posed by climate change. Production systems, for instance, have been adapted through the alteration of planting dates, cropping patterns and farm management techniques. Further, embankments have been built to protect from floods and new varieties of drought, flood and salinity tolerant rice varieties have been produced and distributed.

Measuring the impacts of climate change on production is extremely difficult. In fact, the effects of climate change are foreseen to be highly heterogeneous in their localization, with some regions even gaining even if the overall effect is negative. As a matter of fact, we find it important to point out that projected impacts are likely to vary across regions and food crops, as ample literature suggests (IPCC AR4 WGII, 2007; Turral *et al.*, 2011; White *et al.*, 2011; IPCC AR5 WGII, 2014).

Predictions on climate change in South Asia foresee a substantial reduction in aggregate crop production by the end of the century. Rice yields are also expected to decline (ADB, 2013), with the most vulnerable regions being the southern part of the Indochinese peninsula and the northern part of Southern Asia (IPCC AR5 WGII, 2014).

Despite these shared premises, our work has selected the SOI index as an explanatory variable of rice production in Asia between 1986 and 2011. The index has many advantages such as the availability of data, frequent use by the literature, the possibility of being included in the regression as independent variable. Aware that to capture the impact of climate change or extreme weather events, the localization ought to be, perhaps, more restricted than a continent and more indices can be processed and used, the results represent a first step of a broader research.

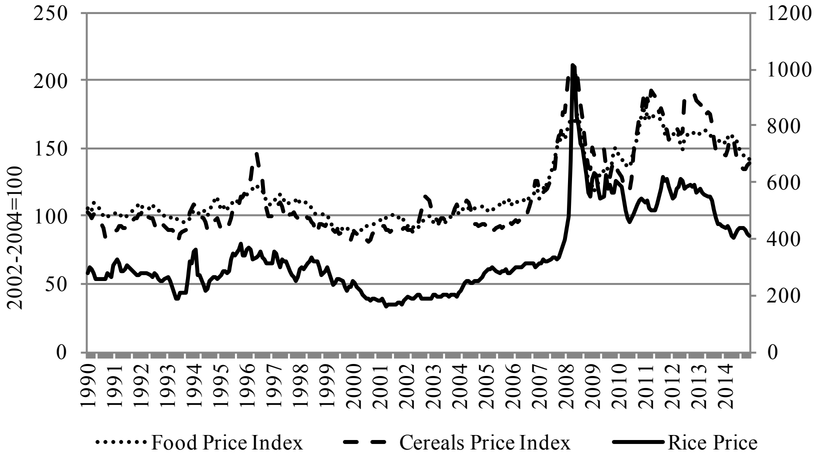
6. Results

As previously mentioned, price variability is a common feature of commodity markets and rice does not constitute an exception. The overall pattern of international rice prices between 1990 and 2014 reflects food and cereals price index trends. In particular, after the 2007-2008 crisis, rice prices experienced a dramatic peak reaching unprecedented levels. Since 2012 the level of rice price has been gradually declining (Fig. 3).

As well known, price variability is influenced by several factors, ascribable both to demand and supply; our work is focused on the supply side – and specifically on rice production. Important factors influencing rice production include land and water availability, the international price of rice and cereals, the cost of inputs, rice ending stocks, public support and climate variability.

In order to identify the main drivers affecting rice production in Asia, a multiple regression analysis has been used by combining yearly data over the period of time between 1986 and 2011. In our regression analysis, conducted through the Ordinary Least Squares (OLS) method, the dependent variable is the logarithmic transformation of rice production in Asia. The variables with potential explanatory power are the logarithm of the extension of the area dedicated to rice harvesting and of the area equipped for irrigation in Asia,

Fig. 3. Monthly Real Food Price Index, Cereals Price Index and World Rice Price between 1990 and 2014



Source: Author's elaboration based on FAO and Indexmundi database

the international price of rice[15], the international price of grains[16] and the world price of fertilizers[17], rice ending stocks in Asia, producer single commodity transfers and the Standard Oscillation Index.

After running the regression analysis, we obtain the following results: ending stocks, world rice price, fertilizers price and single commodity transfers are not significant[18] independent variables in explaining rice production variability in Asia between 1986 and 2011. For this reason, the explanatory variables that lack statistical significance, specifically, ending stocks, rice price, fertilizers price and single commodity transfers are excluded from the analysis.

This leaves four statistically significant variables which in order of importance are: the rice harvest area in Asia, the international price of grains and, finally, the hectares of area equipped for irrigation in Asia and the Southern Oscillation Index. The results are given in Table 7.

The adjusted R-squared shows that more than 99 per cent of the variation of rice production in Asia is explained by multiple regression analysis conferring a good explicative power to the model.

15 Thailand, 5%, $/mt, real 2010$
16 2010=100, real 2010$
17 2000=100, constant 2000$
18 At the 5% level

Tab. 7. Multiple regression analysis results

Dependent Variable: LOG_PROD
Method: Least Squares
Sample: 1986 - 2011
Included observations: 26
Newey-West HAC Standard Errors & Covariance

	Coefficient	Std. Error	t-Statistic	Prob.
LOG_AREA	1.820430	0.158731	11.46866	0.0000
LOG_IRRIG_AREA	0.445138	0.039612	11.23743	0.0000
SOI	-0.011074	0.004067	-2.722751	0.0127
LOG_GRAINS_PRICE	0.051106	0.009921	5.151217	0.0000
C	-19.63851	2.563228	-7.661630	0.0000
R-squared	0.992554			
Adjusted R-squared	0.991136			

The coefficients of the rice harvested area and area equipped for irrigation in Asia are positive, implying a direct relationship existing between these two variables and rice production pattern. As expected, arable land dedicated to rice harvesting and a wider area equipped for irrigation available to farmers favour rice cultivation, particularly if we consider the greater need for water rice requires in the growing period compared to other crops like wheat and beans. Predictably, although the value of the coefficient is low, the price of grains had an overall positive effect on rice production in Asia between 1986 and 2011.

The independent variable relating to climate variability has some explicative power for rice production in Asia. Nevertheless, climate patterns associated with El Niño and La Niña episodes exert a very limited negative influence on rice production in Asia, being the SOI coefficient very close to zero. Generally, low SOI values result in wetter conditions in Asia, which are particularly desirable for rice cultivation.

7. Concluding remarks

Climate change is expected to affect the frequency and magnitude of extreme weather events thus influencing the availability of agricultural resources and the sustainability of food security. In addition to affecting crop location, timing and productivity, extreme weather events may also alter the stability of food supplies, affecting the quantity of produce available for domestic consumption and trade as well as food prices. This is especially significant as the world will try to feed nine billion people by 2050. Asia, where food security represents a major concern and rice assumes strategic relevance, is expected to be severely hit by the adverse impacts of extreme weather, given its vulnerability to climate change and its limited ability to cope with these phenomena.

The multiple regression analysis conducted for this study aims at assessing the extent to which specific variables affect rice production in Asia. The main independent variables that result in explaining the pattern of rice production in Asia between 1986 and 2011 are, in order of relevance, the size of the area dedicated to rice harvesting, the portions of arable area equipped for irrigation, the international price of grains and the Standard Oscillation Index, though with respect to others, the SOI has weaker explanatory power.

As expected, an increase in the area dedicated to rice harvesting and in the area equipped for irrigation positively impacts rice production. However, there are particular production constraints, such as limited availability and the degradation of land and water as well as underdeveloped irrigation systems, that need to be overcome in some parts of the Asian regions, in compliance with 2030 Sustainable Development Agenda's goals and targets (UN, 2015).

Recently, improvements in water management systems have been made and new high yielding rice varieties have been adopted. This will probably facilitate farmers in accessing the necessary resources allowing them to deal with the consequences of extreme weather patterns and thus sustain rice production. For instance, over the last decade private investments in groundwater pumping in Bangladesh have been made and smarter water management, combined with short-duration, high-yielding rice varieties, has allowed farmers to grow multiple crops per year.

As expected, the price of grains also positively affects rice production even if the value of the regression coefficient is very low. After all rice is one of the cereals considered in price formulation. For Asian farm households, which produce mainly for their own consumption or for local markets insulated from price fluctuations in international markets, impacts on crop production is generally mitigated. Further analysis, also taking into account the price of rice and/or grains in national and/or regional markets, may be considered.

Climate variability exerts a largely insignificant negative influence on rice production, the SOI coefficient being very close to zero. Even though the Southern Oscillation Index does not play a relevant role in explaining the production pattern in Asia between 1986 and 2011, we have to consider the wide extension of the Asian continent and therefore the variety of ecosystems, and climatic, economic and social conditions cohabiting it. Further research might proceed with a selection of Asian countries such as the ones overlooking the Pacific

Ocean where the effects of El Niño and La Niña events are more intensely felt. A deeper analysis on inland Asian countries may consider further weather-related indicators, such as rainfall and temperatures amounts and patters.

The effects of climate change on agricultural commodity markets need to be considered along with other evolving factors that affect agricultural production, such as changes and innovation in farming, practices and technology. Recently, high-yielding varieties of rice are being distributed, including submergence and salinity-tolerant varieties[19]. The menace of global climate change is going to affect the poor and vulnerable populations in developing countries, including the Asian populations, the most. The cumulative impacts of weather patterns will ultimately depend on the changing global market conditions as well as responses to local climate stressors, including policy makers, farmer's mitigation, and adaptive actions where international organizations and national governments play a fundamental role. Food reduction affect food prices and food shortages may lead to humanitarian crises, political instability and security concerns. Investments in Asia and in developing countries in general are currently more focused on recovery from extreme weather events rather than on the creation of adaptive capability, thus leading to a vicious circle of debt burden on these countries. To date much effort has been concentrated on mitigation, and much still needs be done for adaptation, given the fact that global warming cannot be avoided. A long-term sustainable development planning needs to be enacted by developing countries governments, with a particular focus on assessing countries' vulnerability to extreme weather events, disaster risk management and adaptation.

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