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RESEARCH ARTICLE

Estimating the average treatment effect of adopting stress tolerant variety on rice yield in China

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Abstract
Climate extremes, characterized by droughts and floods, have become one of the major constraints to sustainable improvement of rice productivity. Variety choice, considered as one of the main adaptation measures, could help farmers reduce yield loss resulting from these extremes. Based on a three-year panel survey of 1 080 Chinese rice farms in major rice producing provinces, we assume Hicksian neutral technology and employ an IV regression to estimate the average treatment effect (ATE) on rice yield for adopting stress tolerant variety, and find that farmers who adopted the stress tolerant variety on average increased rice yield by 15.5% in comparison to the non-adopters.

Keywords: climate extremes, rice, stress tolerant variety, yield, ATE, endogeneity

1. Introduction

Climate extremes, characterized by drought and flood, have significant adverse effects on agricultural production (Liu and Chen 2000; Wang *et al*. 2007; Long *et al*. 2011) and have become a major challenge to sustainable development of agriculture (Lin 1997; Stern 2006; Mendelsohn and Dinar 2009; Pan 2011; De Salvo *et al*. 2013; Chen 2015; Schwan and Yu 2017). The frequency of the extremes is predicted to increase and the challenge to agriculture and international food security has been pronounced (World Bank 2013). The total area suffering from drought globally will increase between 15–44% in the future (IPCC 2014). In China, the annual average crop area suffering from drought has more than doubled since the 1950s, followed by flood (MWR 2014). Ju *et al*. (2007) report that the direct economic losses due to meteorological disaster amount to 100 billion CNY each year, accounting for an estimated 3–6% of GDP, and the areas affected by drought and flood respectively account for 17.6 and 8.1% of the total grain acreage, while the proportions for each province respectively are about 5–19% and 2–10%. Drought and flood are the most severe weather events faced by China's rice producers (Huang *et al*. 2015), especially with the frequent occurrence of climate extremes, even if the irrigation condition has been improved under current technical level, the losses of wheat, corn and rice yields are expected to be 3–7%, 1–11% and 5–12%, respectively (Ju *et al*. 2007). Rice is the main staple food in China, which produces nearly 30% of the world's total rice output (FAO 2014), but it is particularly vulnerable to climate extremes. It was found that a 1°C rise in average temperature during the growth period in South China

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would decrease paddy rice yields by 2.5–3.5% (Zhou *et al*. 2010). The rising temperatures, especially extremely high temperatures during the ripening period, could accelerate rice growth, shorten the growth period, lead to milky white grains and immature grains, and ultimately result in a decline in rice yields (Zhou *et al*. 2010; Kawasaki and Uchida 2016). Historical record datasets also show that rice yield loss caused by drought increased at a rate of 4.6% over the period of 1951–2010, while the rice yield loss resulting from flood grew at a rate of 3.8% (NBSC 2012). Hence we especially shed light on rice production in this study.

Overcoming the challenge to food security caused by increasing climate extremes has drawn much attention from researchers. Recent studies have identified a variety of effective adaptation measures being taken by farmers to cope with climate change, such as diversifying crop varieties (Bradshwa *et al*. 2004; Bryan *et al*. 2009; Chen *et al*. 2014; Bai *et al*. 2015), adjusting the timing of sowing and harvesting (Smit and Skinner 2002; Challinor *et al*. 2007; Tubiello *et al*. 2007; Deressa *et al*. 2009), increasing input use and changing plant densities (Cuculeanu *et al*. 1999; Smit and Skinner 2002; Meza *et al*. 2008; Seo and Mendelsohn 2008). Particularly, farmers appear to undertake two main types of adaptation measures, including physical measures and non-physical measures, to cope with climate extremes, such as investment in engineering adaptation measures in irrigation infrastructure (Wang 2005; Wu and Liu 2015) and farm management or other measures demanding less investment (Wang *et al*. 2014; Huang *et al*. 2015). However, most studies focused on the determinants of adaptation decisions, the effectiveness of adaptation practices has not been well evaluated. For example, Deressa *et al*. (2009) find that household characteristics and access to extensions influence farmers' adaptation decisions in Ethiopia. Similarly, Chen *et al*. (2014) indicate that farm characteristics and local government policies influence farmers' adaptation decisions in China. Though some studies have analyzed the impact of adaptation on crop yield (Yesuf *et al*. 2008; Di Falco *et al*. 2011; Pan 2011; Chen 2015; Huang *et al*. 2015), yet to what degree these adaptation measures can help mitigate the impact of climate extremes remains unclear.

Variety choice is a major adaptation strategy. In other words, farmers can adopt new variety with strong resistance to reduce risks from climate extremes (Selvaraj and Ramasamy 2006). Given that the stress tolerant varieties are of shorter duration, and have ability to withstand high heat, drought, flood and other unfavorable weather conditions, crop breeding for stress-tolerance variety has attracted considerable research attention in the recent past (Lybbert and Bell 2010; Bai *et al*. 2015). In the case of rice, it has been reported to have a yield advantage of 5–28% over the existing varieties (Virk and Witcombe 2007; Pray *et al*. 2011; IRRI 2013). The adoption of excellent variety with strong tolerance is a main adaptation measure of farmers, which can mitigate the harmful effects of climate change on rice (Wu and Zhou 2004; Wang 2005). Besides, several studies have examined the factors affecting farmers' choice of seed varieties. Meng *et al*. (2005) indicated that yield potential was the top concern when farmers in Guangxi Zhuang Autonomous Region make a decision of seed purchase, which could help maximize the profit. Yuan and Yan (2009) found that farmers' maize seed choice behavior was heavily motivated by increasing high yield, other factors including labor, marketing, local cultivation knowledge, livelihood strategy and the awareness of risk and so on. Similarly, Cao (2011) indicated that yield potential was a major driver for adoption behavior in China, significantly related to labor force and the age of household head. These studies, however, did not make clear that to what extend farmers' adoption behavior is affected by climate change, particularly, the increasing trend of climate extremes.

Given the increasing severity of climate extremes and the potential role of stress tolerant variety in mitigating climate risks, it is important to identify the factors influencing farmers' adoption of stress tolerant variety, and to evaluate whether their adoption can really reduce rice yield loss. The adoption of stress tolerant variety responding to extreme climate events can be considered as an effective adaptation strategy to climate extremes, an issue which is only studied in a limited way in the current literature. Particularly, the adoption behavior could be endogenous, but it has not been well examined in the literature. Except for the study by Huang *et al*. (2015), in which they investigated how rice farmers adjust their farm management practices in response to extreme weather events and determine whether their adjustments affect the mean, risk, and downside risk of rice yield. Different from Huang *et al*. (2015) who use an endogenous switching model, we assume the technical innovation for adoption is Hicksian neutral and we also take endogenous adoption into account to estimate the average treatment effect (ATE) of stress-tolerant variety adoption by an instrumental variables (IV) regression.

Empirically, we shed light on the impact of adoption of stress tolerant varieties on rice yield in China by using a three-year panel dataset collected from 1 080 Chinese rice farmers in four major rice producing provinces in China: Zhejiang and Jiangsu in the coastal area of eastern China, Sichuan in Southwest China, and Hunan in Central China. We are particularly interested in identifying factors influencing farmers' adoption behavior and evaluating whether their adoptions can reduce rice yield loss. The nature of panel data enables us to compare the adoption behaviors in different years in respond to different weather

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