Agricultural Systems 148 (2016) 1–11

Contents lists available at ScienceDirect

Agricultural Systems

journal homepage: www.elsevier.com/locate/agsy

Crop selection under price and yield fluctuation: Analysis of agro-economic time series from South Korea

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ARTICLE INFO

Article history:
Received 22 January 2015
Received in revised form 5 June 2016
Accepted 6 June 2016
Available online xxxx

Keywords:
Crop choice
Crop portfolio
Time series analysis
Fluctuation analysis
Singular Spectrum Analysis (SSA)

ABSTRACT

Temporal fluctuations of crop price and yield can have a strong influence on farmers' revenue. Under uncertainty, farmers' crop selection on – what to cultivate and how much of their land to allocate to different crops– is of crucial importance to secure their revenue as well as related ecosystem services. Multi-crop farming can be seen as a strategy to mitigate uncertainties that farmers face. In this study, we used Singular Spectrum Analysis (SSA) to quantify the fluctuations of crop price and yield for single and multiple crop selections in South Korea. Furthermore, risk adjusted revenue of each crop selection was analysed using the Sharpe ratio. We constructed three empirical crop portfolios containing one, three and five crops. For the single crop farming, six main crops in South Korea were analysed, and household data were used to build empirical crop portfolios. Our results showed that revenue from rice farming was the most stable, whereas it fluctuated strongly for pepper. However, growing rice provided the lowest revenue and farmers who cultivate multiple crops might as much as double their revenue compared to rice farming. Diversified crop farming can be a means of enhancing revenue. The biggest part of fluctuations in portfolios with several crops was seasonal, which might be mitigated by planning in advance. The artificial stability of rice price was due to policy intervention. However, it should be noted that the rice policy has been reformed and a high protection for domestic rice farming would no longer last in the future in South Korea. These results might have practical consequences for farmers' decision making on crop selection as well as for agricultural policy.

1. Introduction

Farmers face various types of risks in agricultural production including price fluctuations that can be caused by the dynamics of global economics or climate change (e.g. Janssen and van Ittersum, 2007; Fader et al., 2013; Feola et al., 2015). The tendency of the world prices for agricultural commodities to fluctuate over time makes farmers more vulnerable (FAO et al., 2011). These fluctuations, particularly if large and unexpected, can threaten the stability of the farm household income (FAO et al., 2011) – one of the key indicators to farm well-being (Mishra et al., 2002). Unexpected price volatility and changing environmental conditions can make it harder for farmers to decide what to cultivate and when to harvest it. However, these decisions are of crucial importance to secure their revenue and are tightly related to food security.[1]

Accordingly, substantial efforts are being directed towards reducing risks and ensuring revenue stability on the farm household level (Bradshaw et al., 2004; Harvey et al., 2014; Wood et al., 2014; Feola et al., 2015). Farmers tend to change the type of crops (Wang et al., 2010; Klasen et al., 2013), land management practices (Wood et al., 2014), and the growing season (Olesen et al., 2011), or extend the scope of income by including off-farm income (Bradshaw, 2004; Harvey et al., 2014), for example. Several studies pointed out that decisions on such practices were influenced by socio-economic background of farmers such as age (Potter and Lobley, 1992; van Dusen and Taylor, 2005), education (Below et al., 2012) and income (Awan et al., 2015). As

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[1] "Food security exists when all people, at all times, have physical and economic access to sufficient, safe and nutritious food to meet their dietary needs and food preferences for an active and healthy life" (Rome Declaration on World Food Security and World Food Summit Plan of Action, 1996).

http://dx.doi.org/10.1016/j.agsy.2016.06.003
0308-521X/

farmers are the main actors who promote agricultural adaptation and contribute to food security (Kristensen et al., 2001; Feola et al., 2015), it is important to take account of their socio-economic background in relation to their behaviour. This information could help to understand why some take a certain action to adapt to changes and others omit it (Ilbery, 1978; Cutforth et al., 2001; Fader et al., 2013; Herrero et al., 2014; Feola et al., 2015).

One of the critical decisions that farmers face is crop selection – what to cultivate and how much of their land to allocate to different crops (Rădulescu et al., 2014). As each crop has different trends of price and yield, farmers can reduce risk by cultivating more than one crop. Crop diversity can thus be considered as one of the strategies to mitigate the risk and the uncertainties that farmers face (Heady, 1952; Bhattacharyya, 2008; Rahman, 2009; Pellegrini and Tasciotti, 2014) through the portfolio effect. The portfolio theory (Markowitz, 1952) states that the investor can minimise the risk under uncertainty and stabilise the return by investing in more than one asset. It has been applied in various fields of ecological studies such as biodiversity conservation (Koellner and Schmitz, 2006; Tilman et al., 2006), natural resource management (Halpern et al., 2011) and agriculture (Robison and Brake, 1979; Blank, 1990; Lien and Hardaker, 2001; Di Falco and Perrings, 2005; Rădulescu et al., 2014). Crop diversity can provide farmers with an opportunity to compensate for the loss of revenue caused by the drop of a certain crop price or yield. In view of the variability of price and yield among different crops, crop selection and crop composition in a portfolio is therefore a crucial issue, which has a direct impact on the farm household revenue.

The influences of crop selection and crop portfolio choice on farm household have been studied by several authors. For single crop farming, Klasen et al. (2013), for example, analysed the income dynamics caused by crop choice between coffee and cocoa production. Di Falco and Perrings (2003) studied the effect of crop diversity on mean and variance of income in multiple crop farming. They found that crop diversity increased the mean of income and decreased its variance. Guvele (2001) analysed how multiple crop combinations affect the income variability in Sudan using the mean-variance model. Pellegrini and Tasciotti (2014) revealed the positive effect of crop diversification on income by regression analysis. However, most studies do not pass beyond the mean and variance. Other studies reported the effects of crop diversity on yield, however, the results were not conclusive. Smale et al. (1998), for instance, used a Just-Pope production function (Just and Pope, 1978) to test the relationship between biotic diversity variables and the mean and variance of yield. They found that genealogical variables increased the mean of yield and reduced its variance. Crop diversity also reduced the variance of crop production in Italy (Di Falco and Chavas, 2006) and in Ethiopia (Di Falco et al., 2010) especially when rainfall was low. Di Falco et al. (2010) emphasised that crop diversity was crucial under challenging conditions such as low precipitation. In contrast, Carew et al. (2009), who used the same Just-Pope approach, stated that spatial and temporal diversity had a negative effect on mean yield. Most of the published studies that examined the impact of crop diversity on yield ignored the temporal fluctuations and concentrated on the mean and the variance. To our knowledge, only few studies considered the temporal structure of the data explicitly, except for the use of dummy variables (Smale et al., 1998; Carew et al., 2009). However, the temporal aspect is crucial for the stability of farmers' revenue.

Detecting and quantifying fluctuations over time in data is the domain of time series analysis. It has been applied in various fields of research such as in finance (Liu et al., 1999; Gopikrishnan et al., 2001; Thomakos et al., 2002; Kiyono et al., 2006), meteorology (Allen and Smith, 1994; Talkner and Weber, 2000) and oceanography (Vianna and Menezes, 2006). However, to our knowledge, applications to agro-economic time series are rare in the literature. Singular Spectrum Analysis is a model-free method to decompose time series into trend, periodicities and noise (Golyandina et al., 2001). Therefore, it allows consideration of different components of a time series. Its data-adaptive character gives it a particular strength compared to classical methods like Fourier analysis and makes it suitable to analyse non-linear dynamics (Elsner and Tsonis, 1996). Most applications of Singular Spectrum Analysis to economic data focus on forecasting (e.g. Hassani and Thomakos, 2010). In contrast, our goal is the analysis of different components.

Motivated by aforementioned approaches, we aim to quantify the temporal fluctuation of crop price and yield for different choices of crops by using Singular Spectrum Analysis. We apply the crop portfolio theory to farmers' crop selection as a strategy to cope with uncertainties originated from the market (price uncertainty) and from environmental conditions (yield uncertainty). Our goal is to examine the impact of crop selection and composition in portfolios on the farm household revenue. The case study was based on household data collected from the Gangwon Province of South Korea and the nation-wide statistical data. We structured our study into three parts. First, we investigate a farm household survey of farmers' socio-economic background to understand their crop selection decision and to identify empirical crop portfolios based on crops frequently chosen by farmers. This step allows to compare different crop selections in the study region. Second, we use Singular Spectrum Analysis to quantify fluctuations in crop price (1996–2011) and yield data (1980–2011 for most crops, 1965–2011 for rice). In this step, we quantify the fluctuations of each single crop and how their trends differ from each other. Third, we finally compare the fluctuations of single crops with those of different empirical crop portfolios constructed in the first step to investigate whether crop diversity might stabilise farm revenue.

2. Material and methods

2.1. Study area

The study was conducted in the Gangwon Province of South Korea located in the mid-eastern part of the Korean Peninsula (Supplementary Fig. SF1). Eighty-one percent of the total province area is covered with forests and only 10% is agricultural land. The latter is managed as dry fields (64%) and rice paddies (36%) (Gangwon Province, 2016). The annual average temperature is 116 °C (averaged from 1973 to 2009), and the annual average precipitation is 1373 mm. More than half of the annual precipitation falls during the monsoon period, which starts in late June and continues for 30 days on average (Kang et al., 2010).

Because the environmental conditions vary from the coastal areas to the mountain regions, the agricultural practices differ across the province. In the north-western part, for example, rice farming and livestock production such as pigs and chickens dominate. As it is close to Seoul, the capital of South Korea, green house farming is also popular. The regions in the North and South-East are close to the coast and visited by many tourists (Gangwon-do Agricultural Research and Extensions Services, 2016). This leads to the development of agritourism, where farmers provide the visitors with an opportunity to experience farming activities (Hong et al., 2003). This can potentially be an income source for farmers. In the south-western part of the province, exporting crop production and off-season fruit farming are the main agricultural activities. In contrast, in the mountainous area with higher altitudes, dry fields (primarily radish and cabbage), fruit production and rice cultivation dominate (Kim et al., 2007).

Due to climate change, the regional distribution of major crops is changing. Apple farming, for example, moved northward from the Gyeongbook Province (in the southern part of South Korea) to the Gangwon Province (Kim et al., 2010). Many farmers try new strategies such as different crop selection to cope with changing farming conditions (Schaefer, 2013). This adjustment might continue with increasing climate change.