Weather and Climate Extremes 12 (2016) 69–79

Contents lists available at ScienceDirect

Weather and Climate Extremes

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

Measuring the effects of extreme weather events on yields

J.P. Powell *, S. Reinhard

LEI, Wageningen University and Research Centre, The Netherlands

ARTICLE INFO

Article history:
Received 6 August 2015
Received in revised form
21 February 2016
Accepted 22 February 2016
Available online 23 February 2016

Keywords:
Extreme climate events
Wheat yields
Panel data
Netherlands

ABSTRACT

Extreme weather events are expected to increase worldwide, therefore, anticipating and calculating their effects on crop yields is important for topics ranging from food security to the economic viability of biomass products. Given the local nature of weather, particularly precipitation, effects are best measured at a local level. This paper analyzes weather events at the level of the farm for a specific crop, winter wheat. Once it has been established that extreme events are expected to continue occurring at historically high levels for farming locations throughout the Netherlands, the effects of those events on wheat yields are estimated while controlling for the other major input factors affecting yields. Econometric techniques are applied to an unbalanced panel data set of 334 farms for a period of up to 12 years. Analyzes show that the number of days with extreme high temperatures in Dutch wheat growing regions has significantly increased since the early 1900s, while the number of extreme low temperature events has fallen over that same period. The effects of weather events on wheat yields were found to be time specific in that the week in which an event occurred determined its effect on yields. High temperature events and precipitation events were found to significantly decrease yields.

1. Introduction

1. 1. Introduction

Weather, whether in terms of averages or events, is an important determinant of yields. Extreme weather events are expected to increase worldwide, therefore, anticipating and calculating their effects on crop yields is important for topics ranging from food security to the economic viability of biomass products. The latest IPCC report, confirming previous findings, attaches high confidence to the probability that extreme weather events will reduce food production (Field et al., 2012; Porter et al., 2014). Extreme events are expected to effect the volatility of yields and are seen as the principle immediate threat to global crop production (Meehl et al., 2000; Rosenzweig et al., 2001; Olesen et al., 2007; Urban et al., 2012; Min et al., 2011; Lobell et al., 2013). A natural question that arises is how to measure their effects on yields. We know from the above and other studies that variations in weather events are geographically specific, thereby implying that effects need to be examined at a correspondingly low level of analysis. An analysis of short-term weather events requires detailed time series data on weather variables at low spatial and temporal levels and corresponding data for all of other primary factors influencing yields. The approach taken in this paper is to examine the effects of uncommon precipitation and temperatures events of short duration on winter wheat yields. By precisely analyzing the effects of observed events over a relatively short time span it become possible to anticipate the effects similar such events will have in the future when their occurrence is expected to increase.

The paper consists of two main threads: first, the increasing occurrence of extreme weather events, formally defined below, is established in order to motivate the relevance of the topic. Daily time series analyses using data from up to 100 years are used to establish and forecast the development of extreme precipitation and temperatures events for over thirty regions in the Netherlands. Once the case has been made that the number of such events is either increasing and will continue to do so into the future, then the potential of extreme weather events to alter wheat yields is calculated using econometric techniques. In order to econometrically ascertain their specific, marginal, effects on yields, it is necessary to include all major inputs needed to produce winter wheat into the econometric model. In short, the specific effects of weather events on yields can only be correctly isolated once the effects of other production factors, including unobserved factors, have been filtered out or controlled for in a model. In this analysis, we combine production input data used of winter wheat, e.g., labor, capital and land, for over three hundred farms in the Netherlands from 2002 to 2013 with daily precipitation, temperature and evapotranspiration (ET) data measured at the local

* Corresponding author.
E-mail addresses: jparkerpowell@gmail.com (J.P. Powell), Stijn.Reinhard@wur.nl (S. Reinhard).

http://dx.doi.org/10.1016/j.wace.2016.02.003

level. We test whether all of these various types of data are necessary in order to isolate the effects of extreme weather events on yields.

1.2. Literature review

The impact of weather on yields has been analyzed in relation to several objectives. Traditionally, crop growth models attempt to simulate average crop growth while econometric approaches are used to link inter-annual variation in weather with yields. For example, inter-annual variation in yields has been estimated using experimental plots resulting from the weather conditions in a particular year (Oskam and Reinhard, 1992). That study included data on weather and nitrogen fertilizer over the period 1948–1964 and divided the Netherlands in five regions based on location and soil type. Other studies have estimated inter-annual variation in yields of winter wheat, sugar beets, and starch potatoes using farm level panel data including nitrogen fertilizer and the acreage planted (Leneman et al., 1999). In that study, weather effects, both direct and indirect, were captured by including year dummies (1975–1996) in the regressions.

The last decade has seen a variety of techniques applied at farm and regional levels which have begun to map the effects of climate change at a local level. A meta-analysis of crop yields for several crops under climate change conditions concluded that the inter-annual variability of mean yields is likely to increase and the consensus in the literature is that yield changes will be negative beginning in 2030 (Challinor et al., 2014). Recent studies of extreme events in Europe point to an increase in the number of warm days and nights, and a decrease of the number of cold days and nights (Porter et al., 2014). Several studies also indicate general increases in the intensity and frequency of extreme precipitation events particularly in winter months during the last four decades, however, inconsistencies between studies, regions and seasons are reported (Hirschi et al., 2011; Vautard et al., 2007; Seneviratne et al., 2010; Berrang-Ford et al., 2014; Yamamoto et al., 2014; Sugiyama et al., 2014; Moriondo et al., 2011; Calzadilla et al., 2013).

The diverse nature of prolonged drought and excess precipitation was found to effect specific aspects of the growth cycle of a given crop and associated field management. Extreme weather events can directly impact the physiological processes of a crop through physical damage, but can also affect the timing and conditions of field operations. Due to differences in growth patterns among crops the impact of warming temperatures and weather extremes is crop dependent (van der Velde et al., 2012). A study at the global level used various weather scenarios to measure the effects of extreme weather events on agricultural regions with diverse crops and found that higher temperatures and events may lead to significant reductions in crop yields (Rosenzweig et al., 2001). Insect, pest, and plant diseases may exacerbate those reductions. Another study used a model based on daily weather data to simulate yields under climate scenarios and concluded that the impact of climate changes on sunflower yields will be larger than that of winter wheat (Moriondo et al., 2011). Similarly, a wheat simulation model combined with local scale climate scenarios predicted that yield losses from drought will fall, but the yield losses due to heat stress will substantially increase (Semenov and Shewry, 2011).

Previous micro-level studies, including crop models, have shown that weather events affect yields. However, few of those models have included a complete set of the most important production factors affecting yields. That qualification aside, the net effects of extreme weather events have been shown to damage most crops, an observation that has most commonly been made in relation to rice yields (Wassmann et al., 2009; Welch et al., 2010). In general, extremely high daytime temperatures are damaging and occasionally lethal to crops (Schlenker and Roberts, 2009; Porter and Gawith, 1999). However, there is debate within the climate change literature in regards to the point at which temperatures begin to negatively affect yields (Porter et al., 2014). For instance, some statistical studies find a positive effect of daytime warming on yields when extremes are infrequently realized (Welch et al., 2010). Rice yields in some regions of China have been found to be positively correlated with higher temperatures, while other regions show negative correlations (Zhang et al., 2010). Another study found that the availability of smaller spatial-scale yield data may allow for improvements in the empirical relation between hot days, precipitation and yields (Hawkins et al., 2013).

The non-inclusion of important variables affecting yields leads to omitted variable bias, an irrecoverable problem affecting all model estimates (Greene, 2012, e.g.,). In addition, the local nature of weather, particularly precipitation, favors low level spatial studies, indeed, there appears to be a trend towards review studies in which conclusions from various micro-level studies are systematically extended to higher levels of aggregation (Porter et al., 2014, Chap. 7). For example, a recent study using a crop model to calculate the effect of multiple weather stress occurrences on wheat yields across fourteen European locations found that for all sites the overall adverse event frequency is much more likely to increase than to decrease (Trnka et al., 2014). Further points of comparison for the current study are briefly reviewed by country of analysis. Articles about the effects of climate change variables on Chinese agricultural production include articles by Tao et al. (2006), Wang et al. (2008) and Chen et al. (2010). The articles are principally phenological studies of the effects of climate change on agriculture production, including winter wheat, and use both panels and data analyzes techniques Tao et al. (2009, 2014). In particular, Tao et al. (2014) regress weather variables to explain wheat growth in China; You et al. (2009) conduct a similar study for China as the one proposed in this paper but at a higher level of aggregation and not specifically focused on extreme weather events. For India, Pathak et al. (2003) use a simulation model to examine the effects of weather variables on rice and wheat yields, however, no other production variables were included in their model. A study by Auffhammer et al. (2012), which analyzes rice yields in India, takes a very similar approach to the current study except that it uses a much higher level of time and spatial aggregation. Kucharik and Serbin (2008) and Lobell et al. (2005) conduct statistical analyses for, respectively, the United States and Mexico, but do not include production variables in their analyzes. Brisson et al. (2010) provides a comprehensive analysis, including time series and simulation models, of the variables that have led to stagnating yields in France, yet at a higher level of aggregation then the one we propose. Licker et al. (2013) use times series weather variables to examine changes in wheat yields in Picardy, France and Rostov, Russia. Gregory and Marshall (2012) using a physiological based model, report potato yield increases for Scotland as a result of warming temperatures. Finally, Ludwig et al. (2009) use a model to show that despite decreasing rainfall in Western Australia, simulated yields based on actual weather data did not fall. This paper contributes to the literature by including a comprehensive set of microeconomic data and weather variables at a very low level of aggregation to examine the marginal effects of weather events on yields.

The remainder of this paper consists of two parts. The first presents the case that extreme weather events have steadily increased in the Netherlands for more than a century. If the argument is accepted that such events are real phenomena that will persist and perhaps increase in the future, then it is worthwhile to establish whether and to what extent they will affect yields. The second part of the paper does so by estimating the net effects of