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The impacts of surface ozone pollution on winter wheat productivity in China – An econometric approach

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ABSTRACT

The impact of surface ozone pollution on winter wheat yield is empirically estimated by considering socio-economic and weather determinants. This research is the first to use an economic framework to estimate the ozone impact, and a unique county-level panel is employed to examine the impact of the increasing surface ozone concentration on the productivity of winter wheat in China. In general, the increment of surface ozone concentration during the ozone-sensitive period of winter wheat is determined to be harmful to its yield, and a conservative reduction of ozone pollution could significantly increase China's wheat supply.

1. Introduction

The Chinese government has devoted considerable attention to several factors that can threaten food security, for example, agricultural land loss as a result of urbanization and climate change. However, yield losses driven by air pollution, like surface ozone, have not been recognized by policy makers. Surface ozone concentrations in rural areas are proved to be higher than those in urban areas in China (Wang et al. 2007). Surface ozone had been recognized during the last century as an air pollutant that can adversely affect the growth of crops and induce significant yield losses (Wahid et al. 1995; Benton et al. 2000; Fuhrer and Booker, 2003; Ashmore, 2005; Feng and Kobayashi, 2009).

China may have experienced the same effects of surface ozone pollution. According to the limited data obtained, in the most industrialized areas in China, namely, Beijing–Tianjin region and Yangtze River Delta, for more than 10% of the time, the hourly mean of surface ozone concentration is exceeding the threshold of 60 ppb, which may damage crop growth. The maximum readings for Beijing–Tianjin and Sheshan, near Shanghai, are 170 and 196 ppb, respectively (Wang et al. 2007). Meanwhile, tolerance to ozone concentrations differs among various crops and wheat seems to be one of the most sensitive ones (Jin et al. 2001; Wang et al. 2005). Therefore, measuring the relationship between the elevated surface ozone concentration and wheat yield will warn policy makers the possible damages to food security in China.

To date, the methods of assessing crop yield losses driven by surface ozone pollution could be classified into biological methods and economic models, as remarkably reviewed in the study by Spash (1997). Been estimated using the data generated from laboratories or field experiments, dose-response functions are used to predict crop yield losses in a specific region or nation (Chameides et al. 1994; Tilman et al. 2002). These dose-response functions are also implemented to agricultural economic programming models to estimate the effects of surface ozone pollution on total agricultural supply in a few other studies, where all economic changes are triggered by the reductions of crop yields caused by surface ozone pollution (Howitt et al. 1984; Adams et al. 1985, 1986, 1989). This method has demonstrated an advantage of simplified analysis by the explicit expression between ozone concentrations and crop yields.

Technically, studies on dose-response functions may overestimate the surface ozone shocks to agricultural sector, due to the inconsistency between extremely restricted laboratory requirements and various practical conditions. To understand surface ozone pollution on agriculture, it is important to quantify the direct

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effect of ozone on crop yields in experiments. Regarding economic rationality of farmers, however, they may apply adaptive responses, for example, adjusting management techniques and inputs to offset the adverse effect of surface ozone pollution (Wittig et al. 2007; Feng et al. 2008). According to Spash (1997), on account of cultural and input variations among regions, dose-response functions derived from one area would be inappropriate for other areas. Therefore, applying unique or limited dose-response functions for the prediction of future crop losses in a large country, China as an example, would generate obvious bias.

Econometric approach is a statistical method to estimate the relationship between surface ozone concentration and crop yields, using observed data while controlling socio-economic and other environmental factors. It allows producers to act more flexibly in response to the pollution impacts. It is also useful for policy makers to understand the pure impacts of the elevated ozone concentration on crop productivities in the real world, although it is weak at providing biological knowledge like the way ozone impacts agricultural production, and it may encounter the difficulties of identifying ozone effect from other environmental factors. Limited literature is found using econometric method to estimate the effect of surface ozone exposure on crop yields, and the studies mainly focus on the US and European countries (Rowe and Chestnut, 1985; Westenbarger and Frisvold, 1995; Shankar and Neeliah, 2005; Kaliakatsou et al. 2010). Up to date, this type of research is still thin compared with the biological studies.

This paper uses econometric method and incorporates atmospheric, socio-economic, and biophysical information to identify the effect of surface ozone exposure on winter wheat yield using field observations in China. In the estimation, we expect to examine the adverse effect of ozone exposure on the yield of winter wheat. The interactions between ozone exposure and stress conditions, such as drought and air particles, are also examined.

2. Materials and methods

2.1. Economic model

The biological nature of agricultural production or the time lags involved between planting and harvesting is viewed as a two-stage process (Houck and Gallagher, 1976; Yu et al. 2012). In the first stage, cropping acreage decisions of farmers are viewed as a function of expected input and output prices, government policies, and other non-economic considerations such as climate conditions, air pollutants, and soil types. In the second stage, after a crop is planted, farmers can decide the amount of inputs for the crop production based on varying conditions such as market and weather. Then the production function for wheat can be written as

$$Q = f_1(L,\ F;\ O,\ W,\ T,\ D), \tag{1}$$

where output of wheat (Q) is a function of input vector (F) that contains J inputs and land area (L) at given surface ozone concentration level (O), weather condition (W), technology changes (T), and regional variables accounting for other effects (D) such as local soil characteristics. Based on the profit maximization goal in the production theory, wheat output can be rewritten as

$$Q = f_2\left(L_0,\ \frac{P^W}{P^{F_j}};\ O,\ W,\ T,\ D\right), \tag{2}$$

where, given land area (L_0) that has been first decided, the optimal levels of inputs for profit maximization are a function of the ratio between wheat price P^W and P^{F_j} that is the price of input $j = 1,\ldots,J$.

Therefore, the wheat yield function can be expressed from Equation (2) as

$$Y = \frac{Q}{L_0} = f_3\left(L_0, \frac{P^W}{P^{F_j}}; O, W, T, D\right). \tag{3}$$

Equation (3) is the basis for the empirical identification of the effect of surface ozone concentration on the yield. This yield function does not explicitly represent the relation between inputs and yield because the information about myriad practices of farmers is not available at a county level. Given that the optimal input use is a function of input and output prices, the ratio between input and output prices would capture the same information as directly using the amount of inputs. The relation between yield Y and P^W/P^{F_j} is expected to be positive. The input and output price ratios have also been used in other studies, such as those by Dixon et al. (1994) and Segerson and Dixon (1999). In addition, at county level, the sign of L_0 is indefinitive. For example, along with the increase of wheat price, both marginal land, which is less productive, and more suitable land from other crops, which has high productivity of wheat, could be incorporated to wheat production.

2.2. Econometric strategy

In the empirical estimation, the key variables used in Equation (3) are elaborately incorporated. To identify the effect of surface ozone on winter wheat yield, county level observations in China in 2006, 2008, and 2010 are used to estimate the empirical model as follows:

$$\text{Ln}Y_{i,t} = \beta_0 + \frac{P^W_{i,t-1}}{P^{F_j}_{i,t-1}}\beta_{1j} + L_{i,t}\beta_2 + O_{i,t}\beta_3 + W_{i,t}\beta_4 + T_t\beta_5 + D_i\beta_6 + \varepsilon_{i,t}, \tag{4}$$

where $Y_{i,t}$ denotes the wheat yield in county i and year t, and β s are parameters to be estimated. Expected output and input prices ($P^W_{i,t-1}$ and $P^{F_j}_{i,t-1}$) are substituted by actual prices in the previous year. As an input vector, from the limited information of input price, fertilizer and labor are chosen as the major inputs for wheat production. Furthermore, other inputs such as pesticide, herbicide, machinery service, and seeds are assumed to be in fixed proportions to planted areas. $L_{i,t}$ is the wheat planted area in county i in year t. $W_{i,t}$ represents weather conditions. Dummy variable T_t represents the hybrid effects such as technology trend and uncontrolled annual shocks. Region-specific characteristics such as soil quality and location are controlled by D_i. $\varepsilon_{i,t}$ is a random error term.

To express ozone exposure ($O_{i,t}$), three widely applied measurements are used as follows:

$$M7(\text{ppb}) = \frac{1}{n}\sum_{i=1}^{n} C^i_{O_3} \text{ for } C^i_{O_3} \text{ measured from } 9:00 \text{ to } 16:00$$

$$M12(\text{ppb}) = \frac{1}{n}\sum_{i=1}^{n} C^i_{O_3} \text{ for } C^i_{O_3} \text{ measured from } 8:00 \text{ to } 20:00$$

$$SUM06(\text{ppbh}) = \sum_{i=1}^{n}\left(C^i_{O_3} - 60\right) \text{ for } C^i_{O_3} \geq 60 \text{ ppb}$$

M7 and M12 are the average values of the hourly mean ozone concentration ($C^i_{O_3}$) during daylight hours (ppb per hour), 9:00 to16:00 and 8:00 to 20:00, respectively. SUM06 is calculated as the