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From cold to hot: Climatic effects and productivity in Wisconsin dairy farms

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ABSTRACT

This study examined the effects of climatic conditions on dairy farm productivity using panel data for the state of Wisconsin along with alternative stochastic frontier models. A noteworthy feature of this analysis is that Wisconsin is a major dairy-producing area where winters are typically very cold and snowy and summers are hot and humid. Thus, it is an ideal geographical region for examining the effects of a range of climatic factors on dairy production. We identified the effects of temperature and precipitation, both jointly and separately, on milk output. The analysis showed that increasing temperature in summer or in autumn is harmful for dairy production, whereas warmer winters and warmer springs are beneficial. In contrast, more precipitation had a consistent adverse effect on dairy productivity. Overall, the analysis showed that over the past 17 yr, changes in climatic conditions have had a negative effect on Wisconsin dairy farms. Alternative scenarios predict that climate change would lead to a 5 to 11% reduction in dairy production per year between 2020 and 2039 after controlling for other factors.
Key words: climatic effect, dairy production, stochastic production frontiers, Wisconsin

INTRODUCTION

There is increasing concern about the effect of climate change on food security and agricultural sustainability among policy makers and public interest groups. The US Environmental Protection Agency (US EPA, 2013) reports that global surface air temperature over land and oceans has risen steadily over the last 100 yr, and extreme weather events have become routine. Climatic factors, such as temperature and rainfall, have a strong effect on agricultural output (IPCC, 2014), which induces adaptation strategies that can lead to structural changes in farming (Mendelsohn et al., 1994).

Farming, which contributes at least $395 billion to the US economy per year (USDA NASS, 2012), is more sensitive and vulnerable to climate change than other sectors (IPCC, 2014). Livestock production is particularly vulnerable to hot weather, especially in combination with high humidity, which can lead to significant losses in productivity and, in extreme cases, to animal death (Mader, 2003). Besides direct effects on animals, climatic conditions also affect feed supplies by influencing the growth of silage and forage (Hill et al., 2004). Comprehensive analyses of the connection between climatic effects and farm productivity are of increasing importance.

The focus of our paper is dairy farming, which is the fourth largest agricultural subsector in the United States. There is a significant body of animal and dairy science literature, briefly reviewed below, that clearly establishes the susceptibility of dairy cows to extreme weather conditions (IPCC, 2014). The economic literature on this subject remains quite limited; hence, an important motivation for this research is the need to introduce climatic effects into milk production models to evaluate potential economic effects.

In general, research on the connection between climatic variables and livestock has focused on output-related effects. Dairy cattle experience stress when the temperature is out of the thermo-neutral zone (West, 2003; Allen et al., 2013). When heat or cold stress requires the cow to increase the amount of energy used to maintain body temperature, less energy is available for milk production (Collier et al., 2011). The thermo-neutral zone is between 5 and 25°C and depends on many factors, such as age, breed, feed intake, diet, current milk production level, and housing (Roenfeldt, 1998). Under the same housing conditions, the comfort zone of European cattle was found to be between −1.11 and 15.6°C, whereas for Indian cattle this zone was found to be between 10 and 26.7°C. Temperatures outside of the thermo-neutral zone have adverse effects on livestock productivity (Brody, 1956; Kadzere et al., 2002; Nardone et al., 2010).

Heat stress, which is much more likely to occur in lactating cows during hot and humid summer days, is

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not only related to temperature but also to air humidity, and it affects the capacity of the cow to dissipate heat. Heat stress affects feed intake, feed efficiency, milk yield, reproductive efficiency, cow behavior, and disease incidence (Cook et al., 2007; Tucker et al., 2007; Rhoads et al., 2009). It is estimated that the DMI decreases by up to 40% when the ambient temperature is 40°C (NRC, 2001).

Cold stress is another climatic element that reduces output in some areas. At low temperatures, more dietary energy is needed for cows to maintain body temperature. Cold stress causes animals to consume more feed but to produce less milk, and it also increases milk fat content (Young, 1981). In comparison to heat stress, cold stress is more restricted geographically and can have a significant incidence in the northern United States during winter months.

Climatic conditions have a strong effect on livestock productivity generally and on the dairy sector in particular. A significant negative correlation has been noted between DMI and the temperature-humidity index (**THI**), where the latter is a measure of heat stress often used by animal scientists (Holter et al., 1996; Kadzere et al., 2002). Consequently, a negative correlation exists between THI and milk yield. For example, Key and Sneeringer (2014) and Mukherjee et al. (2013) incorporated annual average THI in production frontier models and found a significant negative effect on milk production. St-Pierre et al. (2003) documented that heat stress affects livestock in all continental US states, although with considerable spatial variation. They estimated that total losses would add up to about \$900 million/yr (\$100/cow per year) even when heat abatement systems were in place. The loss would be as high as \$1.5 billion/yr (\$167/cow per year) without abatement systems. Seo and Mendelsohn (2008) showed that changing livestock species and numbers is one option that farmers have to adapt to climate change.

Dairy production is influenced by temperature and precipitation, and these variables can have divergent effects in different seasons. The literature reveals a variety of methods to measure and incorporate climatic effects in crop and livestock farming (e.g., Mendelsohn et al., 1994; Kelly et al., 2005; Schlenker et al., 2006; Deschenes and Greenstone, 2007; Mukherjee, 2012). These studies usually use temperature, precipitation, and, in some cases, heat degree-days to reflect climatic effects on agricultural production.

Our analysis adopts seasonal averages for temperature and precipitation to capture the climatic effects. Using temperature and precipitation directly, instead of an index such as THI, allows for a clear interpretation of the climatic effects on the dependent variable of interest. In addition, we redefined the length of each season according to the monthly average temperature in the state of Wisconsin.

Wisconsin is one of the largest dairy producing areas in the United States. According to the National Agricultural Statistics Service (http://quickstats.nass.usda.gov/), total milk production in Wisconsin was 27,572 million pounds in 2013, accounting for nearly 14% of the US total milk output. In the same year, the total number of milk cows was 1.271 million.

The general objective of our study was to contribute to the understanding of the effects of climatic variables on dairy farm productivity. The specific objectives were to use alternative stochastic frontier panel data models to analyze the relationship between dairy productivity and climatic effects using data for the state of Wisconsin. The specification of our model makes it possible to calculate a total annual climatic effect as well as partial effects for temperature and precipitation and jointly for all seasons. This specification is a novel contribution to the dairy productivity literature. Based on the estimation results, this study predicts the effects of alternative future climate change scenarios on dairy farms. A noteworthy feature of the current paper is that Wisconsin is a significant dairy producing state in the United States, where winters can be very cold and snowy and summers hot and humid. These extremes are ideal to explore the effects of a range of climatic factors on dairy production.

MATERIALS AND METHODS

Data

The data used for empirical estimation was derived from 2 sources. First, the input-output data contains a total of 9,437 observations for 958 dairy farms scattered around 52 Wisconsin counties over the 17-yr period from 1996 to 2012. These data consist of detailed information of dairy farms participating in the Agricultural Financial Advisor (**AgFA**; http://cdp.wisc.edu/agfa.htm) program at the University of Wisconsin-Madison Center for Dairy Profitability (https://cdp.wisc.edu). The aim of the AgFA program is to collect, analyze, and store high-quality financial and production information for dairy farms in the state of Wisconsin (Cabrera et al., 2010). Second, the temperature and precipitation data were obtained from the Parameter-Elevation Regressions on Independent Slopes Model (PRISM) maps (http://www.prism.oregonstate.edu/recent/). We used Geographic Information System (GIS) techniques to generate monthly mean temperature and precipitation for each county and year. The 2 data sets (input-output