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Climatic Effects and Total Factor Productivity in U.S. Dairy Farming: An Empirical Analysis of Northeastern and Midwestern Counties between 1974 and 2012

Salimata Massaly
University of Connecticut - Storrs, salimata.massaly@uconn.edu

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Salimata Massaly

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Presented by

Salimata Massaly, B.S.

Major Advisor______________________________________

Boris Bravo-Ureta

Advisor______________________________________

Eric Njuki

Advisor______________________________________

Nathan Fiala

The University of Connecticut

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Climatic Effects and Total Factor Productivity in U.S. Dairy Farming: An Empirical Analysis of Northeastern and Midwestern Counties between 1974 and 2012

Salimata Massaly, M.S.

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Abstract

Climate change refers to changes in temperature and precipitation patterns as well as increases in the occurrence of extreme events. In recent years, climate change has gained increasing attention from production economists; however, its effects on productivity have been largely ignored in the literature. Our study aims to address these shortcomings by implementing a Total Factor Productivity (TFP) analysis and decomposing TFP into climatic effect, output-oriented technical efficiency, technological progress, and output-oriented scale efficiency indexes. Our study focuses primarily on climatic effects on TFP growth on dairy farming in two traditional US dairy regions. We use U.S. county level data from 1974 to 2012 in the Northeast (NE) and Midwest (MW) to estimate stochastic production frontier models, which provide the basis for measuring TFP and its components. We find that the coefficients for winter and summer temperatures are highly significant and exhibit a positive and negative relationship with output, respectively. In the Northeast, TFP growth is highest in Cayuga County, NY (3.2%), while in the Midwest, Sanilac County in MI exhibits the highest TFP growth (2.6%). Our results also show that on average, per year summer temperatures have a negative contribution to TFP growth per annum while winter

temperatures have a positive contribution to per annum output growth. Precipitation exhibits a mixed effect on TFP growth in both the Northeast and Midwest regions.

Keywords: dairy, total factor productivity, climatic effects, stochastic production frontier, Northeast, Midwest.

Chapter 1

Introduction

The Intergovernmental Panel on Climate Change (IPCC 2014) defines climate change as a change in the state of the climate that can be identified (e.g., by using statistical tests) by variations in the mean and/or the variability of its properties and that persists for an extended period, typically decades or longer. Risks from extreme events related to climate change, such as heat waves, extreme precipitation, and coastal flooding, are already moderate (with high confidence) and become high with a 1°C additional warming (medium confidence) (IPCC, 2014). According to the Environmental Protection Agency (EPA) (2014), earth's average temperature has risen by 1.5°F over the past century, and is projected to rise another 2 to 11.5°F over the next hundred years. Rising temperatures go along with changes in climate and weather, and therefore have various effects through different channels.

Alaska and the Northern and Western regions of the United States have experienced the highest temperature increases, while some parts of the Southeast have experienced little change (EPA, 2014). Though effects are hard to see over a short time span, the National Climate Assessment (NCA), in its 2014 report, predicts that the Southwest and the Southeast will experience increased wildfires and decreased water supplies, while the Northeast and the Northwest will experience heat waves, sea level rise and increasing ocean acidity. According to the same report, in the Midwest, in addition to extreme heat and heavy downpour and flooding, which will affect infrastructure, health and agriculture, climate change will also exacerbate various types of risks in the Great Lakes.

The United States Department of Agriculture (USDA) estimated that agriculture and agriculture-related industries contributed $789 billion to the U.S. Gross Domestic Product (GDP) in 2013, which amounted to 4.7 % of the total output. The overall contribution of the agricultural sector to the GDP is larger than this because sectors related to agriculture—forestry, fishing, and related activities, such as food, beverages, tobacco products, textiles, apparel, leather products, food services and drinking places—rely directly on agricultural inputs and make an important contribution to the economy (USDA, 2015).

Climate disruptions to agricultural production have increased in the past 40 years and are projected to increase further over the next 25 years (NCA, 2014). Projected changes in the frequency and severity of extreme climate events will have more serious consequences for food and forestry production and food insecurity than changes in projected means of temperature and precipitation (high confidence) (IPCC, 2007). This is a global problem and is more significant in developing countries where populations are predominantly smallholder farmers who practice subsistence agriculture. The IPCC, in its 2007 report, estimated that climate change alone would increase the number of undernourished people to between 40 and 170 million. In fact, the Food and Agriculture Organization of the United Nations estimated that between 2003 and 2013, natural hazards and disasters in the developing regions affected more than 1.9 billion people and resulted in estimated damages worth half a trillion US dollars (FAO, 2015). Moreover, climate change is likely to further shift the regional focus of food insecurity to sub-Saharan Africa, where about 75% of all people at risk of hunger are estimated to live by 2080 (IPCC, 2007). Considering only the impacts of major events for a limited number of countries over the 2003–2013 period, estimates of losses were about US$13 billion for the crop sector, mainly due to flooding and storm damage,

and US$11 billion for the livestock sector, mainly attributable to drought. These are only a small fraction of the total costs actually incurred (FAO, 2015).

Though there is a considerable volume of literature predicting that climatic effects would be more significant in developing countries, the United States will also suffer from climate change. Being a large country with diverse agro ecological environments, climatic effects will exhibit different patterns at the regional level. In fact, according to the NCA (2014), climate change poses a major challenge to U.S. agriculture because of the critical dependence of the agricultural system on climate and because of the complex role agriculture plays in rural and national social and economic systems. Beach, Thomson and McCarl (2010) conducted simulation studies for hydrologic unit code regions within the current and potential production range defined for each crop in the United States. Different patterns were found across various regions. For wheat, it is the Dakotas, Lake States, Mid-Atlantic, and Northeast states that tend to have declining simulated yields, with increasing yields predominate throughout the majority of the rest of the U.S. Simulated hay yields tend to be increasing in the western and eastern portions of the production range, except for portions of the Southeast, whereas they tend to be decreasing in much of the Midwest and South-central regions, as well as more southern portions of the Southeast (Beach, Thomson and McCarl, 2010).

Changing climatic conditions affect animal agriculture in four primary ways: 1) feed-grain production, availability, and price; 2) pastures and forage crop production and quality; 3) animal health, growth, and reproduction; and 4) disease and pest distributions (NCA, 2014). Warming temperatures, coupled with higher CO_2 levels, may increase the growth rate and yields for many crops. However, if temperatures exceed the optimums for crops, yield might decrease significantly (EPA, 2014). According to Schlenker and Roberts (2009), yields increase with temperature up to

29° C for corn, 30° C for soybeans, and 32° C for cotton, but temperatures above these thresholds become increasingly harmful. It is expected that as yields decrease, prices will rise for both human and livestock consumption. Climate change multiplies the risks of natural hazards through altered rainfall and temperature patterns, as well as increased frequency and intensity of extreme events such as drought and flooding (IPCC, 2014). Furthermore, higher temperatures coupled with a prevalence of drought can affect grazing livestock drastically by reducing the quantity and quality of forage (EPA, 2014). A current example of a state displaying climate change effects is California. According to the California-Nevada Climate Applications Program (CNAP, 2014), California, which has experienced extremely low precipitation since 2007, hit its record dry year in 2014. Higher temperatures worsen drought by encouraging evaporation from soil and plants, causing more winter precipitation to fall as rain, and causing snow to melt earlier in the year and runoff rather than sustaining crops and water supplies (CNAP, 2014).

Soil erosion is another problem emerging from increased rainfall and evaporation. Simulation studies by Nearing, Pruski and O'Neal (2004) suggest that erosion will increase 1.7% for each 1% change in annual rainfall. An increase in soil erosion would affect livestock and farmers through a reduction in crop yields and higher expenditures in fertilizers and chemicals. In addition, an increase in temperature and CO_2 favors the growth of weeds, insects, and diseases that already have large negative impacts on agricultural production; climate change has the potential to increase these impacts (NCA, 2014). Current estimates of losses in global crop production show that weeds cause the largest losses (34%), followed by insects (18%) and diseases (16%) (Oerke, 2006). Neither plant nor animal diseases are desirable since they reduce yield and cause animal deaths.

Optimum animal core body temperature is often maintained within a 4°F to 5°F range, while deviations from this range can cause animals to become stressed (NCA, 2014). Higher temperatures or an increased number of hot summer days affect animal health by increasing pathogen and parasite related diseases. According to the Research Program on Climate Change, Agriculture and Food Security (CCAFS, 2015), the emergence, spread, and distribution of livestock diseases may all be affected by climate change. For example, higher temperatures affect the rate of development of pathogens or parasites, the distribution of diseases that may impact susceptible animal populations, and the abundance of disease vectors.

The dairy industry is a very important sector of the U.S. economy. In fact the farm value of milk production is second only to beef among livestock industries and is equal to corn (USDA, 2011). Furthermore, in 2014, the largest cash receipts were from cattle production, followed by corn, milk and dairy products, soybeans, broilers, and hogs (USDA). Dairy farming is practiced all over the U.S. with the top 10 producing states in 2011 being: California, Wisconsin, Idaho, New York, Pennsylvania, Texas, Minnesota, Michigan, New Mexico, and Washington (USDA). Traditionally, many small local farmers characterized dairy farming in the U.S. Over the years, this model is disappearing and we are seeing large-scale farms that produce larger quantities of milk at relatively low cost.

MacDonald et al. (2007), in their Economic Research Report for the USDA, found that the number of dairy farms with fewer than 200 cows was shrinking, while the number of very large operations, with 2,000 or more cows, doubled between 2000 and 2006. With consolidation, farmers are able to achieve economies of scale, which were not possible before. Therefore, costs are shrinking, enabling profits to be maximized. Costs per hundredweight of milk produced fall by nearly half as herd size increases from fewer than 50 head to 500 head, and continue to fall, but

less sharply, at even larger herd sizes (Macdonald et al., 2007). Though the Northeast and the Midwest are the traditional dairy regions, dairy farming is now dominated by Western states: California, Idaho, and New Mexico. Dairy operations in Western regions rely more on large operations than the Northeast and the Midwest. Despite the fact that dairy operations in the traditional regions have consolidated over the years, they are still smaller compared to their western counterparts. According to Mosheim and Lovell (2009), in their study of Scale Economies and Inefficiencies of U.S. Dairy Farms, in 2007, California had an average of 824 cows per operation, Idaho had 684 and New Mexico had 814 cows. In contrast, in Wisconsin, New York, and Pennsylvania, the average number of cows per operation in 2007 was 87, 101 and 65 cows, respectively (Mosheim and Lovell, 2009).

These tendencies should not discourage one from studying climatic effects in the dairy industry in the traditional dairy states. In fact, in these states, dairy farming has also undergone structural changes. According to Macdonald et al. (2007), in addition to Michigan, Ohio and Indiana, farms with upwards of 1,000 head are also appearing in other traditional dairy states in the East and Midwest, either through the expansion of longstanding family operations or through new construction with investor financing. Although milk production and cows are increasingly located in the West, the greatest numbers of dairy farms continue to be in the traditional dairy-producing regions (Lake States, Northeast, and Corn Belt) (Macdonald et al., 2007). According to Njuki and Bravo-Ureta (2015), as a result of productivity increases, counties in the Midwest and the Northeast generated 94% of the country's additional milk in 2013 relative to 2012. Furthermore, the Economic Research Service (ERS) of the USDA calculated percentages of milk production per region and found that the Northeast, the Corn Belt, and the Lake states together made up 45% of the U.S. milk production in 2014; hence, the importance of studying these regions.

Moreover, the Midwest, one of the most intense areas of agriculture in the world, is not only critically important to the economy of the United States, but also for world exports of grain and meat (Hatfield, 2012).

The Northeastern and Midwestern regions, located east of the 100th meridian, the boundary of the region in the U.S., "*where farming is possible without irrigation*" (Schlenker, 2006), make up a great unit of study for climatic effects. Rainfed farming systems in the U.S. are highly productive, economically important, ecologically diverse, and technologically driven (Franzluebbers et al., 2011). Precipitation is critical in these regions because most dairy farmers are dependent on rainfed crops for dairy feed. In fact, harvested forage and pasture, which are almost exclusively rainfed, are significant components of the agricultural landscape in the northeastern U.S., making perennial pasture the single largest agricultural land use system in every state in the region (Franzluebbers et al., 2011). Since most agriculture in this region is rainfed as well, the Midwest is highly vulnerable to summer drought (Andresen et al., 2012). Considering all of the aforementioned factors, the Northeast and the Midwest are great regions to analyze climatic effects on dairy farming.

According to the EPA (2012), in the United States, black and white Holstein cows make up over 90% of dairy herds. This breed has been genetically chosen for milk production and is known for their high ability to produce milk with high protein and fat content (EPA, 2012). Though relatively new, with the first imports of registered Holsteins arriving in the 1880s, the breed has dominated production in the U.S. since the end of World War II, and advances in artificial insemination have increased in popularity in breeding programs around the world, largely owing to their advantage in production over all other breeds (EPA, 2012). In contrast to dairy intensive countries, such as New Zealand, where dairy cows are free ranging in well managed pastures, in

the U.S., most dairy farms raise cows under intensive systems. Large operations tend to confine their milk cows in large barns or in dry lot feed yards, while small operations graze their cows on pasture (Macdonald et al., 2007).

Livestock, especially dairy cows, are very sensitive to extreme temperatures. Climate change has led to an increase in the occurrence of extreme hot days, with a negative effect on livestock production. While severe cold climate conditions (e.g., blizzards, extreme wind-chill) in late fall and winter can be life threatening, high temperature weather patterns often present short-term stressful conditions that find the livestock producer unprepared (Nienaber and Hanh, 2007). Heat stress slows weight gain in animals and, if extreme, can cause animal death. Adams et al. (1998) found a 10% reduction in primary production for cow/calf and dairy enterprises in Appalachia, Southeast, Delta States, Southern Plains, and Texas under a 5.0^{o} C temperature increase. Direct climatic effects on livestock and therefore dairy cows are in the form of heat stress, while indirect effects may be in the form of low quality pastures and increases in bacteria and pathogens. Though not fed exclusively with forage, high producing early lactation cows, need at least 40% of the dry matter in their feed rations to come from roughages (Wheeler, 1993). Low quality forage causes cows to increase their feed intake to get the same nutritional value. This would decrease milk yield and quality, causing a low protein and fat content. For cattle that breed during spring and summer, exposure to high temperatures reduces conception rates (NCA, 2014). According to Jordan (2003), cows under heat stress have reduced duration and intensity of estrus, altered follicular development, and impaired embryonic development. These factors cause long-term losses to farmers who inevitably have to develop techniques to cope with these challenges.

The key objective of this study is to measure Total Factor Productivity (TFP) change using U.S. county level data while accounting for climatic effects. To do so, we develop a suitable dataset

at the county level for dairy farming in the Northeast and Midwest for the period 1974 to 2012. Using this data, we develop different indexes to analyze climatic effects across counties and overtime. This study aims to answer the following research questions: 1) what are the key drivers of TFP growth? and 2) what is the role of climatic effects on TFP growth? The answers to these questions will provide a better understanding of climatic effects and TFP in U.S. dairy farming.

Chapter 2

Literature Review

This chapter aims to review and present some of the previous studies that are closely related to this thesis. It also places the contribution of this study in the context of the existing body of literature. There has been a significant amount of academic work on climatic effects on livestock, including dairy cattle and dairy production (e.g., Thatcher, 1974; Adams et al., 1998; Jordan, 2003; Saint Pierre et al., 2003). Climate change affects dairy cattle directly and indirectly. The direct effects of climate change, e.g., higher temperatures and changing rainfall patterns, can translate into heat stress, the increased spread of existing vector-borne diseases and macro parasites, accompanied by the emergence and circulation of new diseases (IFAD, 2010).

There is literature as early as 1953 (Johnson and Brantox, 1953) addressing climatic effects on livestock and specifically dairy animals. In their attempt to study effects of seasonal climatic changes on physiological reactions of dairy bulls, Johnston and Brantox (1953) observed fourteen dairy bulls consisting of Guernseys, Holsteins, and Jerseys belonging to the Louisiana State University (LSU) Dairy Improvement Center over a 57-week period commencing October 30, 1950, and ending November 30, 1951. The bulls were kept in individual pens and had access to pasture, which was supplemented by hay when necessary. During the experiment, the bulls were confined in a stanchion in the pen at about 1:30 P.M. each day and measurements of respiration rate, pulse rate, and body temperature were made between 2:00 and 4:00 P.M. Semen was collected twice for each bull and examined for quality purposes. Analysis of variance of the data on this basis showed: (a) no significant breed differences in body temperature; (b) significant breed differences in respiration rate only at the 80-85°F temperature range; and (c) significant (40-60°F,

60-70°F, and 70-80°F) or highly significant (80-85°F, 85-90°F, and 90-95°F) breed differences in pulse rate in all temperature ranges (Johnston and Brantox, 1953). In addition, the study reported, coefficients of correlation between fertility and climatic measurements as follows: maximum temperature -0.46; minimum temperature -0.45; and vapor pressure -0.55, all significant at the 1% level. From these coefficients, we conclude that bull fertility is negatively impacted by seasonal climatic changes.

Thatcher (1974), in a study of environmental effects on reproductive performance and benefits of environmental control, found that fertility is inversely related to the maximum environmental temperature the day after insemination and to uterine temperatures both at insemination and the day after insemination. When cows are exposed to extreme temperatures, their bodies take time to adjust, which could adversely affect reproduction. In addition, Thatcher (1974) reported that air conditioning dairy cows for 24 hours per day caused a 9.6% increase in daily yield of 4% fat-corrected milk, and either continued or daytime air conditioning reduced expected summertime decreases in fertility.

Wolfenson, Roth and Meidan (2003) studied the immediate and delayed effects of heat stress on follicular development, dynamics of follicular waves, steroidogenic capacity of theca and granulosa cells, corpus luteum development and function, and secretion of progesterone and gonadotropins. They also briefly reviewed oocyte quality, embryonic development, and uterine function under heat stress. Because most studies report that Luteinizing Hormone (LH) levels are decreased by heat stress, we are drawn to conclude that in the summer, the dominant follicle develops in a low LH environment and this results in reduced estradiol secretion from the dominant follicle, leading to poor expression of estrus, and, hence, reduced fertility (Rensis and Scaramuzzi, 2003). During the summer, dairy cows are more vulnerable to heat stress and, therefore, farmers

incur higher losses due to lower fertility. The use of the timed artificial insemination procedure improves pregnancy rates and reduces the number of days open (Wolfenson, Roth and Meidan, 2003).

West (2003) defined the environmental conditions to which dairy cattle are exposed, examined the effect of heat stress on cattle from a physiologic and productive standpoint, and discussed management options available to the farmer. This study found that continued genetic selection for improved Dry Matter Intake (DMI) and milk yield resulting in cows that are less heat tolerant, coupled with the unknowns associated with global warming in the future, suggests that heat stress could become worse for dairies in the future. Reproduction is a very important part of dairy farming; therefore, multiple studies have been conducted on the effects of heat stress on cow fertility.

Several other recent studies, in addition to those afore-mentioned, have found a negative relationship between climatic effects and dairy reproduction (e.g., Hansen, 2001; Lucy, 2001; Rensis and Scaramuzzi, 2003; Ispierto et al., 2007). In addition to reproduction, milk production is also highly sensitive to climatic conditions. Once cows deliver their calves, they are weaned immediately and the milking process starts after the colostrum is collected. During this stage, it is of utmost importance that the cows get proper nutrition in order to produce the highest amounts of milk possible.

Kendall et al. (2006) conducted experiments to identify if summer conditions in a temperate climate caused perturbations in the vaginal temperature rhythm, which could be used as an indicator of acute, or chronic thermal stress in lactating dairy cows. Holstein cows of similar age and weight in mid lactation were used in this experiment. One group of cows was housed in paddocks with shaded structures (S cows) while the other was in paddocks without shade structures

(NS cows). The result showed that S cows had a higher milk production than NS cows; however, daily milk composition was not affected by shade treatment. Access to shade and a reduced vaginal temperature from 1000 to 1500 h were associated with higher daily milk yield in shaded cows with an overall increase of 0.44 kg/cow/day, equating to a 3% increase in daily milk production (Kendall et al., 2006).

More recently, Lambertz, Sanker and Gauly (2014) studied the effects of the Temperature Humidity Index (THI) on milk production traits for cows raised in 4 different systems: (a) warm loose housing with access to grazing (WG); (b) warm loose housing without access to grazing (WI); (c) cold loose housing with access to grazing (CG); and (d) cold loose housing without access to grazing (CI). The results showed that milk yield and fat and protein percentages decreased with increasing 3-day maximum THI. Here the greatest decreases were calculated for cows raised in WG and WI. Though direct effects are of high importance, indirect effects should not be neglected.

Nardone et al. (2010) presented an analysis of some relevant effects of global warming on livestock production and on the forecast of the evolution of major livestock systems. In that same analysis, it was specified that indirect effects of global warming, such as soil infertility, water scarcity, grain yields, and quality and diffusion of pathogens may impair animal production in these systems (industrialized livestock systems) more than the direct effects. Together with economic components, not strictly related to agricultural production systems, climate changes will influence crop production and relative costs, such as irrigation costs, especially for corn production, and pest treatment (Nardone et al., 2010). Corn is the most inexpensive of grains; therefore, it is the most commonly used grain in combination with haylage and silage to feed dairy

cows. As grains become more expensive as a result of climate change, dairy farmers will have to shift to less expensive inputs or incur increases in production cost.

Biologists and animal scientists have done significant work relating to dairy reproduction and milk production. In production economics as well, there has been significant work focusing on dairy farming. In fact, efficiency analysis using stochastic production frontiers has been very popular over the years even though it has not been coupled with climatic variables until recently. Ahmad and Bravo-Ureta (1996) conducted efficiency analysis on an unbalanced panel of 96 Vermont dairy farms using the stochastic production frontier as well as a fixed effect techniques. The fixed effects and truncated one-sided error model yielded very close Technical Efficiency (TE) measures around 77% for both time variant and invariant cases, while the half normal one sided error term models yielded TE measures around 86%. These models revealed that TE could be improved through more agricultural extension efforts designed to improve managerial skills.

Alvarez and Arias (2004) also found that TE in dairy farms improved with farm size. The study was conducted using technical and accounting data from a sample of 196 dairy farms located in Northern Spain for the period of 1993 to 1998. Results showed a positive and significant relationship between technical efficiency and land when controlling for the effects of output prices, input prices, and quasi-fixed inputs. The unconditional relationship between TE and farm size is positive as well; however, it is stronger than the unconditional relationship. Also using a stochastic production frontier model, Cabrera, Solis and Del Corral (2010) evaluated the determinants of technical efficiency among dairy farms in Wisconsin using financial and production information for 273 dairy farms during the 2007 agricultural year. The study aimed to determine the importance of various inputs in dairy production and technical efficiency. Findings suggest that dairy farmers in Wisconsin can improve their productivity and efficiency if they take advantage of more efficient

farm practices, such as using Bovine somatotropin (bST) and more intensive production systems (Cabrera, Solis and Del Corral, 2010).

Climatic variables, which so far have been ignored in the literature, have a strong influence on productivity. Neglecting climatic variables in productivity analysis raises the specter of likely omitted variables bias because farmers' input choices typically respond in part to environmental conditions (Sherlund, Barrett and Adesina, 2002). To avoid bias, Sherlund, Barrett and Adesina (2002) controlled for environmental factors in Cote d'Ivoire, while conducting a study on smallholder rice farmers' technical efficiency. The novelty of this study was incorporating rainfall in the estimation of the production frontier. Findings showed that controlling for measurable environmental production conditions yields significantly lower estimates of technical inefficiency, different output elasticity estimates, and more intuitive and precise estimates of the sources of technical inefficiency.

Mukherjee, Bravo-Ureta and De Vries (2013) analyzed the potential impact of heat stress on milk production efficiency for a sample of dairy farms from the southeastern U.S. In this study, these authors used farm level data from Georgia and Florida, which dominate milk production in the Southeastern U.S. The study relied on a panel data stochastic production frontier model, which incorporated the Temperature Humidity Index (THI) in order to account for heat stress. The results clearly showed an inverse relationship between output and THI irrespective of farm size (Mukherjee, Bravo-Ureta and De Vries, 2013).

Key and Sneeringer (2014a) estimated the relationship between the thermal environment and the technical efficiency of U.S. dairies in order to provide information about the potential implications of climate change for the sector. This particular study contributed to the literature by first including a THI to determine the economic impact of climate change on TE and secondly

forecasting the potential climatic effect on dairy. The authors used a stochastic production frontier to measure the climatic effects on technical efficiency for a livestock production system at the national level. Depending on the climate model used, the results implied that the additional heat stress caused by global warming could reduce milk production for the average U.S. dairy by approximately 0.60% to 1.35% per year in 2030, with somewhat larger declines predicted for dairies in the South (Key and Sneeringer, 2014).

In a different analysis, Key and Sneeringer (2014b) study how the local thermal environment affects U.S. dairies' effectiveness at producing outputs with a given level of inputs. Stressing the importance of heat stress on dairy animals, Key and Sneeringer (2014b) estimated that in 2010, heat stress lowered the value of annual milk production for the average dairy by about $39,000, which equates to $1.2 billion in lost production for the entire dairy sector. In addition, the following losses are projected with an expected annual temperature increase between 1.45 and 2.37^{o}F: (a) lower milk production for the average dairy by 0.60 to 1.35% depending on the climate model used; (b) some production loss to almost all dairies, with 4 to 18% of dairies experiencing a loss greater than 2%; (c) lower total annual production at the State level between 0.05% and 4.4%, with the greatest losses occurring in Southern States; and (d) lower receipts from total annual milk production at the national ranging from $79 to $199 million, at 2010 prices. The study also predicted that additional climate change induced heat stress in 2030 would cause lower consumer and producer welfare.

More recently, Qi, Bravo-Ureta and Cabrera (2015) explored the impact of climatic conditions on milk output in Wisconsin using panel data with alternative stochastic production frontier models. 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 (Qi,

Bravo-Ureta and Cabrera, 2015). This study found that over the 17 years covered by the data used, climate change has had a negative impact on Wisconsin dairy farms, while 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.

Though climatic effects are beginning to be incorporated in frontier analysis, most TFP studies have ignored climatic effects and dealt mostly with the traditional TFP components: technical efficiency, technological progress, scale and allocative efficiency (e.g. Brummer, Glauben and Thijssen, 2002). Brummer, Glauben and Thijssen (2002) used panel data for the period 1991-94 from dairy farms in Germany, Netherlands, and Poland. Findings showed that productivity growth in Germany and Poland was driven by technical change, while in Poland it was driven by allocative efficiency.

Coelli and Rao (2003) aimed to provide up to date information on agricultural TFP for 93 of the world's largest agricultural producing countries from 1980 to 2000. The results show an annual growth in total factor productivity of 2.1%, with technical efficiency change contributing 0.9% per year and technical change providing the other 1.2%. The authors report that the United States had a TFP growth rate of 2.6%, while China experienced the most spectacular growth in TFP with an average annual growth of 6.0% over the study period.

China, where livestock is becoming more important in the domestic agricultural economy (Rae et al., 2006), has been a hot spot for development and productivity studies. In an attempt to better understand productivity factors in this country, Rae et al. (2006) estimated and decomposed TFP into its technical efficiency and technical progress components for four major livestock products. Results indicate that over the 1990s, average growth in TFP was fastest in hog, egg, and beef production, at between 3% and 5% per year, and lowest for milk production, between 0.5%

and 1.3% on average across regions. Technical progress occurred over the 1990s for all livestock sectors; however, growth in technical efficiency has been relatively slow or even negative.

Fuglie (2010) derived TFP growth at the country and regional levels, as well as for the world as a whole for the period between 1961 and 2001. Findings show acceleration in TFP growth in recent decades mainly due to rapid productivity gains in Brazil and China, and more recently to a recovery of agricultural growth in the countries of the former Soviet bloc. Overall, real global agricultural output grew at slightly more than 2% per year since the 1970s due to accelerating TFP growth and decelerating input growth offsetting each other.

In summary, most of the studies mentioned above have neglected climatic effects on productivity growth. Up to recently, we have been aware of only one TFP study in the U.S. that isolated and measured climatic effects on productivity growth. Njuki (2013), analyzed other TFP components, such as technical efficiency, technological progress, and scale efficiency, in addition to climatic effects. The study, which used state level panel data from the USDA, reported a 1.98% per annum growth in U.S. agricultural TFP between 1960 and 2004. Technological progress was the main driver of TFP growth, accounting for 1.93% per annum. The climatic effect, our variable of interest, accounted for a 0.04% reduction in average annual TFP growth. This is the first study on U.S. productivity analysis to include climatic effects.

Our study, building on the work by Njuki (2013), seeks to present a more disaggregated analysis of the link between climatic effects and TFP using county level data. Therefore, this thesis makes two key contributions to the literature: (a) it incorporates the effects of winter and summer temperature and precipitation on TFP and its decomposition, using county level data; and (b) it provides a new analysis of climatic effects, using the stochastic production frontier methods as well as a Proper index to measure and examine the various components of TFP growth.

Chapter 3

Methodology

Several studies have used the Stochastic Production Frontier (SPF) model developed by Aigner et al. (1977) (e.g., Ahmad and Bravo-Ureta, 1996; Abdulai and Tietje, 2007; Cabrera, Solis and Del Corral, 2010). The SPF model is motivated by the theoretical idea that no economic agent can exceed the maximum or "frontier" attainable output and that the deviations from this maximum represent individual inefficiencies (Belotti et al., 2012). Using the SPF model, we will analyze the effect of climatic variables on dairy farming, combining economic with climatic data. The SPF model is very popular amongst agricultural economists. Using this approach, one can use different functional forms, such as Cobb-Douglas (e.g., Ahmad and Bravo-Ureta, 1996, Cabrera, Solis and Del Corral, 2010), translog (Abdulai and Tietje, 2007), or quadratic (Njuki, 2013).

In this study, we utilize the Cobb-Douglas functional form where output and inputs are expressed in logarithmic form. Our general model can be written as:

$$(1) \qquad y_{it} = \sum \beta X_{it} + \sum \gamma C_{it} + \theta_1 T + \theta_2 T^2 + v_{it} - u_{it}$$

where Y_{it} represents the dairy output measured in tons in the ith county in period t; X_{it} represents inputs used in the ith county in period t; C_{it} denotes climatic variables such as rain and precipitation for the ith county in period t; and T denotes the time trend. Finally, β, γ, θ_1 and θ_2 are parameters to be estimated. The term v_{it} represents random errors with a normal distribution $v_{it} \sim N(0, \sigma^2_v)$ and is independent from u_{it}, which represents independent random errors associated with technical inefficiency.

Our specific model takes the following form:

$$(2) \qquad lnY_{it} = \beta_1 lnX_{1it} + \beta_2 lnX + \beta_3 lnX_{3it} + \beta_4 lnX_{4it} + \beta_5 lnX_{5it} + \theta_1 T + \theta_2 T^2 + \gamma_1 C_{1it} + \gamma_2 C_{2it} + \gamma_3 C_{3it} + \gamma_4 C_{4it} + v_{it} - u_{it}$$

where:

Y_{it} = Dairy output measured in tons for the i^{th} county in period t (tons)

X_{1it}= Number of dairy cows for the i^{th} county in period t (head)

X_{2it} = Machinery and Equipment ($)

X_{3it} = Labor Hours (Hours)

X_{4it} = Commercial Feed (tons)

X_{5it} = Intermediate inputs ($)

C_{1it} = Average summer temperature for the i^{th} county in period t (^{o}F)

C_{2it} = Average winter temperature for the i^{th} county in period t (^{o}F)

C_{3it} = Average summer precipitation for the i^{th} county in period t (mm)

C_{4it} = Average winter precipitation for the i^{th} county in period t (mm)

T = Time trend

v_{it} = Random errors, with a normal distribution vit ~ N (0, σ^2v)

u_{it} = Independent random errors associated with technical inefficiency.

For the purpose of our study, we use a True Random Effects (TRE) specification, with a half normal distribution for u_{it}. Greene (2005) specifies that the random effects model has a tighter parameterization, which allows direct individual specific estimates of the inefficiency term in the

model. Results from the SPF model are used to compute the Total Factor Productivity index (TFPI), which is decomposed into the following elements: Output-oriented Technical Efficiency Index (OTEI); Output-oriented Scale Efficiency Index (OSEI); Technological Change Index (TECPRO); and Climatic Effect Index (CEI).

According to O'Donnell (2010), technological progress or Technological Change mainly refers to expansions in the production possibilities set that comes about through increased knowledge, while technical efficiency improvements refer to increases in output–input ratios. Scale Efficiency is a measure of the potential productivity gains that can be achieved through economies of scale (O'Donnell, 2010). The climatic effects Index (CEI) combines average summer and winter temperatures and precipitations (Hughes et al, 2011).

TFP can be defined in general terms as an output quantity index divided by an input quantity index, which can be expressed as:

(3) $$TFP_{it} = Q_{it}/X_{it}$$

where $Q_{it} \equiv Q\ (q_{it})$ is an aggregate output, $X_{it} \equiv X\ (x_{it})$ is an aggregate input, and Q(.) and X (.) are nonnegative, non-decreasing and linearly homogeneous scalar functions. Using equation (3), we can define a TFP index to measure the productivity of a given county (*k*) in year (*s*) with respect to some other county (*i*) in year *t* and this can be expressed as:

(4) $$TFPI_{ksit} = TFP_{it}/TFP_{ks} = (QI_{it}/XI_{it})/(QI_{ks}/XI_{ks})$$

Here we use the General or Proper Index recently proposed by O'Donnell (2015), which satisfies several important axioms from index number theory (e.g., identity, transitivity, circularity, weak monotonicity, proportionality, and time-space reversal).

Following Njuki (2013), and assuming a Cobb-Douglas functional form, the Proper index can be decomposed into the elements mentioned above as follows:

(5) $$TFPI_{ksit}^{G} = e^{\gamma_1 (g_t - g_s)} \prod_{j=1}^{J} \left(\frac{z_{jit}}{z_{jks}}\right)^{\rho_j} e^{(u_{ks} - u_{it})} \prod_{m=1}^{M} \left(\frac{x_{mit}}{x_{mks}}\right)^{\beta_m - \lambda_m} e^{(v_{ks} - v_{it})}$$

where $\lambda_m = \beta_m / r$ and r represents returns to scale. The first term represents the Technological Progress Index (TECPRO), the second term represents Climatic Effects Index (CEI), the third term is the Output-oriented Technical Efficiency Index (OTEI), and the fourth term is the Output-oriented Scale Efficiency Index (OSEI). The last term accounts for statistical noise, such as unknown factors affecting TFP. Common findings concerning OTEI and OSEI, which have been studied extensively over the years, is that they improve with size (Moshini, 1998; Mishra, 2006; Mosheim and Lovell, 2009).

The CEI, which represents the combined effects of rainfall and temperature variations on output, holding all else constant (Hughes et al, 2011), is a combination of the individual seasonal temperature index and precipitation index for the winter and summer. For the index computations, we have specified Litchfield, CT 1974 and Jo Davies, IL 1974 as the reference points for the Northeast and the Midwest, respectively. Each of the indexes noted above were constructed by dividing the respective input, output and other variables by that of the reference county in the reference year.

Using the CEIs for each county, we can determine if climatic effects have been favorable or not to that county's TFP growth relative to the reference county. Moreover, we decompose the climatic index into four components: Climatic Effects Index for Summer Temperature (CEI_ST), Climatic Effects Index for Winter Temperature (CEI_WT), Climatic Effects Index for Summer

Precipitation (CEI_SP), and Climatic Effects Index for Winter Precipitation (CEI_WP). This decomposition provides a better understanding of climatic effects on TFP growth on a seasonal and county level basis and is similar to the approach used by Qi, Bravo-Ureta and Cabrera (2015).

Data

We utilized county level data from the United States Department of Agriculture (USDA) census. The census data was initially compiled every four years until 1982 and every five years thereafter. The census takes into account farms that generated $1,000 or more in agricultural production (USDA). Many studies have used county level data (e.g., Deschenes and Greenstone, 2007; Njuki, 2013), which is more disaggregated than state level data. In addition, county level data is accessible, available over several years, and covers a wider geographical area in comparison to available farm level data sets.

For the purpose of this study, we used census data from the following years: 1974, 1978, 1982, 1987, 1992, 1997, 2002, 2007 and 2012. The dataset comprises 108 counties spread across 16 states representing the Northeast and Midwest regions of the United States, for a total of 990 observations. Following Njuki and Bravo-Ureta (2015), the "State and County Rankings" volume, published alongside every USDA Agricultural Census Report, was used to select the counties with the highest dairy cow inventories. We also computed the ratio of dairy sales relative to total agricultural sales and added all counties for which dairy sales represented at least 50 percent of total agricultural sales that were not included in the afore mentioned list.

To investigate the effects of climatic variables on dairy output, agriculture production data was coupled with seasonal weather data: winter and summer temperature and precipitation annual averages. The climatic data was obtained from the Parameter-elevation Regressions on

Independent Slopes Model (PRISM) Climate Group. PRISM collects weather observations and develops spatial climatic datasets. The temperature data was converted from Celsius to Fahrenheit while the precipitation data is in millimeters (mm). To provide a better picture of climatic variables, summer and winter temperature and precipitation trends are presented in figure 1 and figure 2.

The census data are comprised of production expenses, market value of products, and operator characteristics (USDA. 2012). The production expenses include feed, fuel and energy, fertilizer and chemicals, and hired and contracted labor. In addition, we have expenses on custom work and leases, depreciation and interest, and the estimated value of machinery and equipment. The dataset also includes the market value of crops and livestock, the value of the livestock inventory including dairy cows, and an inventory of crops.

The dairy output variable was constructed by dividing dairy sales per county by dairy prices received by farmers per hundredweight (cwt) for the state where the county is located as reported by the National Agricultural Statistics Services (NASS). The quantities obtained were then converted to metric tons. The commercial feed variable was constructed by dividing feed expenditures by average state prices for 16 percent concentrate feed for the respective year, obtained from NASS as well. The labor input was constructed in two steps. We first divided expenditures in hired labor, which includes paid family members' wages and contracted labor by wages per hour in the respective states, which we found from the Bureau of Labor Statistics. Then we multiplied the labor input by the respective percentage of dairy sales relative to total agricultural sales All monetary values were converted to current 2015 dollars using the January 2015 Producer Price Index (PPI) from BLS. To construct the machinery and equipment expenses variable, we multiplied the machinery and equipment expenses by the respective percentage of

dairy sales relative to total agricultural sales. Our intermediate input reflects expenses in inputs such as fertilizer, chemicals, gasoline, petroleum, diesel and other natural gases. A summary of the data is presented for the Northeast and the Midwest in Table 1 and Table 2. Figure 1 and Figure 2 show temperature and precipitation trends from 1974 to 2012 in the Northeast and the Midwest.

In summary, we construct a county level dataset for the Northeast and the Midwest using data from the USDA census of agriculture. Using the SPF model, we develop estimates, which we use to construct the General TFP Index. In order to study the link between climatic effects and TFP growth, we decompose the latter into different indices including the Climatic Effect Index.

Chapter 4

Results and Discussion

This Chapter discusses our results from the Northeast, followed by results from the Midwest. We estimated stochastic frontier models which we then used to measure TFP growth and its components. We used the true random effects model to account for unobserved heterogeneity. All estimations were conducted using Stata 12. In both regions, we will first analyze the results from the SPF model then we will conduct a thorough TFP growth analysis.

Northeast

Table 3 presents the results of the estimated econometric coefficients for the Northeast. Consistent with economic theory, the partial output elasticities for the physical inputs are positive and all are significant at the 1% level, except for machinery and equipment and intermediate inputs, which are significant at the 5% level. We note that milk cows is the most important input where a 1% increase causes a 0.84% increase in output. This is a finding that is consistent with the existing literature (e.g., Ahmad and Bravo-Ureta, 1996; Mukherjee, Bravo-Ureta and De Vries, 2013; Key and Sneeringer, 2014; Qi, Bravo-Ureta and Cabrera, 2015). Here, labor is the second most important input.

The model exhibits slightly increasing returns to scale with the sum of the coefficients equaling to 1.02. The temperature coefficients for both the summer and winter seasons are significant at the 1% level; however, the precipitation coefficients for both seasons are not significant. We see a positive relationship between winter temperature and dairy output: warmer winters are beneficial to dairy production. Since cold winters and hot summers characterize the Northeast, warming during the cold periods for temperate areas would likely be beneficial to

livestock production in this area due to reduced feed requirements, increased survival of young, and lower energy cost (Rötter and Van de Geijn, 1999). However, we see a highly significant negative relationship between dairy output and summer temperature. We deduce from this relationship that warmer summers are detrimental to dairy output.

Our study's primary objective is to incorporate a CEI into TFPI in order to analyze climatic effects on productivity growth. To do so, we use the SPF coefficients to construct and decompose a Total Factor Productivity Index (TFPI) into Output-oriented Technical Efficiency Index (OTEI), Output-oriented Scale Efficiency Index (OSEI), Technological Progress Index (TECPRO), and the Climatic Effect Index (CEI) (Table 4). To pursue the stated objective we rely on the General or proper index introduced by O'Donnell (2015).

The term ΔCEI represents the change in annual aggregate climatic effects on TFP growth for each county. In order to detect seasonal heterogeneity, we further decompose the ΔCEI term into the following effects: Summer Temperature (ΔCEI_ST); Winter Temperature (ΔCEI_WT); Summer Precipitation (ΔCEI_SP); and Winter Precipitation (ΔCEI_WP). Table 5 presents the estimates for all these effects.

In the Northeast, we observe that Saratoga, NY, experiences the highest annual average TFP growth equal to 3.22%, followed by Lebanon, PA (2.94%), and Cayuga, NY (2.82%). From the available level of inputs, the above-mentioned counties are the most productive relative to the Reference County. Among all counties in the Northeast, Sussex, NJ has the lowest TFP growth (0.13%). On average at the regional level, the Northeast experiences TFP growth of 1.5%. From Figure 3, we observe that TFP grew steadily between 1974 and 2002. From the period of 2002 to 2007, there is a sharp decline in TFP. In 2007, the Northeast starts experiencing growth at the end of our period of study. Figure 4 and 5 respectively show TFP trends in Saratoga, NY and Sussex,

NJ. In this case we observed a steady growth in TFP from 1974 to 2012. In Sussex, NJ declines in TFP were observed in different periods: 1974-1978, 1992-1997 and 2002-2012.

Our key objective is to find the effect of climatic variables on TFP growth. The average overall CEI change per county is reported in Table 4 and indexes from the decomposition of CEI change are exhibited in Table 5. From our analysis, we observe that CEI on average at the regional level contributes 0.0016% per annum to TFP growth. However, we observe greater variations at the county level. CEI, on average, has an overall negative joint effect on TFP growth per annum in Lancaster, Franklin, and Lebanon counties in Pennsylvania, and Rockingham County in Virginia. CEI had an overall average positive joint effect with TFP growth for the remaining counties. After decomposition (Table 5), we observe negative CEI changes for all counties in the summer season. In fact, in Saratoga, NY, CEI on average contributes -0.0002% to TFP growth. We deduce from this relationship that TFP growth has a negative relationship with warmer summer temperatures for the winter season, in all counties, with the exception of Franklin and Lancaster, PA, CEI contributes positively to TFP growth; therefore, warmer winters are beneficial to output. Precipitation, contrary to temperature, does not show a particular pattern. Over the study period, in 18 out of the 52 counties, on average, summer precipitation has a negative effect on per annum TFP growth; moreover, for the winter, in 91% of the counties in the Northeast, on average, precipitation has a negative effect on TFP growth. For counties that exhibited the highest and lowest TFP growth, Saratoga, NY and Sussex, NJ, summer precipitation had a positive contribution to TFP growth, while declining winter precipitation reduced TFP growth per annum. The opposite is valid for some other counties, which shows a great level of heterogeneity at the county level.

Although farmers in the northeastern U.S. have not specialized to the extent of other parts of the country, they have adopted similar technology and management, thus productivity and efficiency have increased (Franzluebbers et al., 2011). However, we see that OSEI on average has been decreasing annually for 99% of the counties in our sample. In cases where it is increasing, it is at a very minimal rate. This is not surprising given that we have seen a great decrease in agricultural land due to urbanization in the Northeast. According to Franzluebbers et al. (2011), agriculture in the northeastern U.S. has shrunk considerably; for example, cropland in Maryland declined from 1.5 to 0.8 Mha, and in Maine from 1.4 to 0.6 Mha. Due to higher costs of production, but also higher costs of energy and other inputs (Franzluebbers et al., 2011), in these regions, farmers experienced declining economies of scale.

Midwest

Similar to the Northeast, all inputs exhibit a positive relationship with dairy, and are all highly significant at the 1% level, except for the intermediate inputs coefficient, which is significant at the 5% level (Table 3). The most important input is milk cows, where a 1% increase in this input results in a 0.43% increase in dairy output. The second most important input is machinery and equipment, followed by labor. The model exhibits slightly increasing returns to scale with the sum of the partial elasticities being 1.02. The temperature coefficients, similar to those for the Northeast, are highly significant at the 1% level. The precipitation coefficients on the other hand are significant at the 10% level for the winter season and are not significant for the summer season. We observe that a 1^{o}F increase in temperature in the summer causes a 0.1% decrease in output (Table 3). Winter temperature on the other hand exhibits a strong positive relationship with output. A 1^{o}F increase in winter temperature causes a 0.5% increase in output (Table 3). Winters being very cold in the Midwest, farmers could gain from increases in

temperature. These findings are consistent with the most recent literature in Wisconsin by Qi, Bravo-Ureta and Cabrera (2015), who found a 4.52% reduction in output in the summer and 1.8% increase in output in winter with a one-unit increase in temperature (1 C°). Winter precipitation exhibits a modest negative relationship with a slight reduction in output of 0.5% with a 1mm increase in rainfall. Summer precipitation in this case exhibits a positive relationship with dairy output.

Table 6 shows the estimated annual average percentage changes in TFP and its components in the Midwest from 1974 to 2012. Sanilac, MI, Richland, WI, and Sheboygan, WI exhibit the highest TFP growth: 2.64%, 2.49% and 2.41%, respectively. On the other hand, Wright, MN exhibits the lowest TFP growth of 0.85%. For the following periods, 1982-1997 and 2007-2012 we observe instances of TFP growth, while for the remaining periods, we observe declines of TFP. Figure 7 illustrates TFP and its components for Sanilac, MI, the best performing county in the Midwest in terms of TFP growth. For this county, TFP declined over the periods 1974-1978, 1987-1992, and 2002-2007, but increased over the remaining years. In Wright, MN, which is illustrated in Figure 8, we see a similar but more pronounced pattern in TFP reductions, which occurred at an impressive rate during the remaining portion of the study.

On average, CEI has a positive overall joint effect on TFP growth per annum in all counties except Wayne, OH (Table 6). At the regional level, CE contributes 0.006% to output growth. This finding is consistent with Njuki (2013) who found that CEI contributed 0.04% to reductions in annual TFP growth, which averaged 2.21% between 1960 and 2004. In all counties, summer temperature has a negative effect on output growth. This shows that higher summer temperatures are detrimental to dairy cows. In contrast, on average per annum, winter temperatures has a positive contribution to TFP growth in all counties except for Wayne, OH. In 12 out of the 52 counties

selected, summer precipitation contributes positively to TFP growth. In contrast, we observe that in 27 out of 52 counties, winter precipitation negatively affects TFP growth.

OSEI increases on average per annum for 30% of the counties studied. In the Midwest, scale efficiencies have on average a negative overall joint effect on TFP growth. Between 1974 and 2012, Kewaunee, WI shows the largest growth in scale efficiency (0.03%), while the lowest growth happens in Carver, MN (-0.03%). Technological progress in our model was estimated assuming a linear time trend; therefore, it remains the same and contributes 0.05% to TFP growth.

To summarize, this chapter presented the results of an analysis of climatic effects on dairy production using both the SPF model and TFP analysis. In our SPF model for both regions, all inputs exhibit a positive relationship with dairy output. We also note a positive relationship between winter temperature and output and a negative relationship between summer temperature and output. Warmer winters are beneficial while hotter summers are detrimental to dairy output. Precipitation displays a mixed pattern both in the SPF and the subsequent TFP analysis. On average, we find a positive CEI at the regional level; however, we emphasize that winter temperatures have a positive effect on dairy while summer temperatures have a negative effect on dairy.

Chapter 5

Summary and Conclusions

Climate change is a global phenomenon, which requires a lot of attention as it manifests itself by increases in temperature, changes in precipitation, and an increase in the prevalence of extreme events. The dairy sector is a very important part of the U.S. agricultural economy, especially in the Northeast and the Midwest, which traditionally have been dairy intensive regions. As climatic effects get more pronounced, dairy farming will also have to deal with its consequences. Climate change is gradual; hence, farmers have time to adapt to increasing temperatures by investing in cooling techniques, newer more efficient ways to keep dairy cows from experiencing heat stress, genetic improvements in the dairy herd, among other options.

This study contributes to the literature by using estimates from an SPF model to decompose a TFP index that explicitly isolates and accounts for the role of climatic effects, as well as technical efficiency, scale efficiency, and technological progress in the Northeast and Midwest dairy sector of the United States. The results show highly significant relationships between temperature and output in the summer as well as in the winter in the Northeast and the Midwest. We found that warmer summers are detrimental to milk output while warmer winters are beneficial. The coefficients for precipitation, regardless of season, were not significant in our model.

We also developed a TFP index, which we used to estimate TFP growth. We found that Saratoga, NY experiences the highest growth on average in TFP per annum in the Northeast, while Sanilac, MI exhibits the highest TFP growth in the Midwest. The lowest TFP growth was observed in Sussex, NJ and Wright, MN. On average per annum, TFP grew 2.02% in the Northeast and 1.55% in the Midwest.

Two of the key contributions of our study are our inclusion of climatic effects into our TFP growth analysis and our decomposition of the CEI into four components for summer and winter temperatures and precipitation. Our key findings show that, in both the Northeast and the Midwest, higher summer temperatures had a negative contribution in TFP growth while warmer winter temperature had a positive contribution to output growth. In the Northeast, on average, TFP per annum was impacted positively by higher summer precipitation. TFP growth fell in the same region due to variations in winter precipitation. On average, in the Midwest, higher summer precipitation contributed negatively to average annual TFP growth while higher winter precipitation had on average a positive effect on TFP growth.

Our study showed that at the regional level, combined climatic effects of summer and winter temperature and precipitation, had an overall positive joint effect on TFP growth. This relationship could be due to increasing investments in adaptation strategies at the farm level. However, considering the IPCC (2014) and NCA (2014) predictions, these relationships could potentially become negative in the future, as farmers' abilities to adapt may be exhausted or reach diminishing returns. To better understand climatic effects on TFP growth, further studies using scenario analysis should be conducted across the United States and throughout the world. The United States is a country with diverse climatic patterns; thus, further studies could estimate climatic effects of temperature and precipitation in all seasons. Given the importance of the Western Region for dairy production, it would be beneficial to conduct TFP analyses to understand the main productivity drivers in these areas using county and farm level data. Considering that climate change is a slow process that takes decades, future climate studies that use a TFP framework might benefit from data covering a longer time span.

Tables and Figures

Table 1: Descriptive statistics for counties in the Northeast

Variable	Mean	Std. Dev.	Min	Max
Output/county per year				
Milk equivalent, metric ton	123,196	113,694	6,191	964,272
Conventional inputs/farm per year				
Cows, head	19,067	16,070	750	110,805
Machinery and Equipment, $	47,401	32,676	2,197	184,668
Labor, hours	557,647	460,133	21,268	4,703,343
Intermediate Inputs, $	11,160	11,342	519	74,426
Commercial Feed, metric tons	95,622	182,397	1,612	1,467,129
T	19.33	12.46	1	39
Climatic variables				
Summer temperature, F°	65.77	3.29	58.57	75.03
Winter temperature, F°	23.36	5.76	11.8	38.09
Summer precipitation, cm	98.54	18.22	56.86	159.07
Winter precipitation, cm	73.2	17.96	24.52	131.99

Table 2: Descriptive statistics for counties in the Midwest

Variable	Mean	Std. Dev.	Min	Max
Output/county per year				
Milk equivalent[1], metric ton	202,063	101,793	3,805	617,902
Conventional inputs/farm per year				
Cows, head	31,861	14,768	653	80,911
Machinery and Equipment, $	97,411	46,013	1,647	267,893
Labor, hours	603,271	391,390	4,321	2,236,989
Commercial Feed, metric tons	101,623	79,036	7,106	1,108,239
Intermediate Inputs, $	27,849	19,316	7,582	224,825
T	19.33	12.46	1	39
Climatic variables				
Summer temperature, F°	68.35	2.48	61.16	73.52
Winter temperature, F°	20.49	5.45	3.57	32.98
Summer precipitation, cm	103.38	31.89	44.75	210.32
Winter precipitation, cm	30.9	12.32	7.75	78.81

Table 3: Parameter estimates for stochastic production frontier model for the Northeast and Midwest

Variable	Northeast	Midwest
ln(Cow)	0.8399***	0.428***
	(0.0193)	(0.0304)
Ln(Machinery)	0.0318**	0.2577***
	(0.0145)	(0.0298)
ln(Labor)	0.0900***	0.2081***
	(0.0128)	(0.0223)
ln(Commercial Feed)	0.0274***	0.0784***
	(0.0098)	(0.0184)
ln(Intermediate inputs)	0.0326**	0.0442**
	(0.0135)	(0.0185)
Time trend	0.0104***	0.0057***
	(0.0006)	(0.0014)
Time trend squared	-0.0001***	-0.0000058
	(0.00001)	(0.00003)
Summer temperature	-0.0037***	-0.0017***
	(0.0004)	(0.0004)
Winter temperature	0.0039***	0.0048***
	(0.0008)	(0.0008)
Summer precipitation	-0.0001	0.00002
	(0.0001)	(0.0001)
Winter precipitation	0.0002	-.0005*
	(0.0001)	(0.0003)

Level of Significance: ***1%, **5%, *10%

Table 4: Estimated Average Annual Percentage Rates of Growth in TFP in the Northeast, 1974-2012

County	ΔTFPI	ΔOTEI	ΔOSEI	ΔTECPRO	ΔCEI	ΔSNI
Northeast	**2.0206**	**0.0061**	**-0.0204**	**0.0978**	**0.0016**	**1.8729**
Litchfield, CT	1.1914	0.0068	-0.0597	0.0978	0.0004	1.1293
Tolland, CT	0.8620	-0.0524	-0.0221	0.0978	0.0002	0.8340
Franklin, ME[1]	1.7235	0.0533	-0.0571	0.0978	0.0019	1.5111
Penobscot, ME[1]	2.2407	0.0538	-0.0093	0.0978	0.0005	1.9846
Piscataquis, ME	2.0771	0.0922	-0.0391	0.0978	0.0007	1.8974
Somerset, ME	1.6676	0.0493	-0.0116	0.0978	0.0008	1.4520
Frederick, MD	1.0764	0.0091	-0.0459	0.0978	0.0000	0.9939
Berkshire, MA	1.1565	0.0197	-0.0494	0.0978	0.0015	1.0601
Coos, NH[1]	2.2534	0.0120	-0.0375	0.0978	0.0020	2.1423
Grafton, NH[2]	-0.9855	-0.0330	0.0122	0.0978	0.0023	-0.0003
Sullivan, NH	1.7400	-0.0027	-0.0176	0.0978	0.0010	1.6133
Sussex, NJ	0.1277	0.0348	-0.0862	0.0978	0.0001	0.0829
Cattaraugus, NY	2.4925	0.1334	-0.0323	0.0978	0.0003	2.1242
Cayuga, NY	2.8154	-0.0105	0.0284	0.0978	0.0039	2.5741
Chautauqua, NY	2.1980	-0.0327	-0.0220	0.0978	0.0008	2.1209
Chenango, NY	1.6615	0.0044	-0.0464	0.0978	0.0006	1.5730
Cortland, NY	2.1673	-0.0153	-0.0409	0.0978	0.0003	2.0945
Delaware, NY	1.5619	0.0095	-0.0709	0.0978	0.0017	1.5054
Dutchess, NY[1]	0.8100	0.0127	-0.0835	0.0978	0.0008	0.8437
Franklin, NY	2.5663	-0.0214	-0.0135	0.0978	0.0024	2.4411
Genesse, NY	2.0765	0.0325	0.0317	0.0978	0.0051	1.7875
Herkimer, NY	1.7928	-0.0334	-0.0379	0.0978	0.0030	1.7467
Jefferson, NY	2.5593	-0.0111	-0.0151	0.0978	0.0050	2.4121
Lewis, NY	2.2568	0.0206	-0.0087	0.0978	0.0054	2.0486
Livingston, NY	2.3825	0.0032	0.0144	0.0978	0.0006	2.1669
Madison, NY	1.8543	0.0231	-0.0206	0.0978	0.0047	1.6803
Oneida, NY	2.0065	-0.0131	-0.0397	0.0978	0.0054	1.9215
Ontario, NY	2.5251	-0.0812	0.0271	0.0978	0.0007	2.4440
Otsego, NY	1.2742	-0.0134	-0.0592	0.0978	0.0017	1.2378
Saratoga, NY	3.2211	0.0069	-0.0156	0.0978	0.0012	3.0247
St Lawrence, NY	2.7695	-0.0410	0.0020	0.0978	0.0057	2.5675
Steuben, NY	2.6180	0.0630	-0.0199	0.0978	0.0011	2.3439
Washington, NY	1.8654	-.0140	-0.0129	0.0978	0.0024	1.7438
Wyoming, NY	2.4198	-0.1942	0.0177	0.0978	0.0002	2.5939
Berks, PA	2.3137	0.0211	-0.0029	0.0978	0.0000	2.1012
Bradford, PA	2.2265	-0.0233	-0.0463	0.0978	0.0005	2.1773
Chester, PA	2.5694	-0.0332	-0.0150	0.0978	0.0008	2.4735
Franklin, PA	2.6840	0.0571	0.0138	0.0978	-0.0009	2.3561
Lancaster, PA	2.2590	-0.0543	0.0249	0.0978	-0.0011	2.1385

Lebanon, PA	2.9430	-0.0453	0.0173	0.0978	-0.0003	2.8004
Tioga, PA	1.9932	0.0782	-0.0408	0.0978	0.0008	1.7635
Addison, VT	2.2659	0.0013	-0.0004	0.0978	0.0020	2.0831
Bennington, VT	1.4842	0.0995	-0.0350	0.0978	0.0022	1.2384
Caledonia, VT	2.4479	0.0220	-0.0260	0.0978	0.0028	2.2664
Chittenden, VT	1.5275	0.0100	-0.0509	0.0978	0.0017	1.4385
Essex, VT	2.5305	-0.0263	-0.0210	0.0978	0.0024	2.4304
Franklin, VT	2.4237	0.0106	-0.0001	0.0978	0.0022	2.2167
Grand Isle, VT	1.8904	0.0231	-0.0093	0.0978	0.0017	1.7011
Lamoille, VT	1.8055	0.0122	-0.0538	0.0978	0.0018	1.7117
Orange, VT	1.9293	0.0759	-0.0190	0.0978	0.0010	1.6695
Orleans, VT	2.2770	0.0496	-0.0071	0.0978	0.0020	2.0198
Rutland, VT	1.0262	-0.0163	-0.0564	0.0978	0.0015	0.9925
Washington, VT	2.1542	0.0364	-0.0313	0.0978	0.0021	1.9690
Windham, VT	2.1091	-0.1088	-0.0244	0.0978	0.0027	2.1768
Windsor, VT	1.3445	0.0371	-0.0469	0.0978	0.0017	1.2138
Rockingham, VA	1.6991	0.1513	0.0252	0.0978	-0.0003	1.2764

[1] 2012 data not available ΔTFPI, ΔOTEI, ΔOSEI and ΔSNI were calculated from 1974 to 2007

[2] 2012, 2007 data not available ΔTFPI, ΔOTEI, ΔOSEI and ΔSNI were calculated from 1974 to 2002

Table 5: Estimated Average Annual Climatic Effects (Percentage) in the Northeast, 1974-2012

County	ΔCEI	ΔCEI_ST	ΔCEI_WT	ΔCEI_SP	ΔCEI_WP
Northeast	**0.001636**	**-0.000322**	**0.002147**	**0.000031**	**-0.000219**
Litchfield, CT	0.000375	-0.000354	0.001080	-0.000011	-0.000341
Tolland, CT	0.000169	-0.000340	0.000953	-0.000068	-0.000376
Franklin, ME	0.001923	-0.000395	0.002846	-0.000105	-0.000422
Piscataquis, ME	0.000709	-0.000308	0.001396	-0.000101	-0.000278
Penobscot, ME	0.000485	-0.000272	0.001057	-0.000051	-0.000248
Somerset, ME	0.000847	-0.000353	0.001653	-0.000117	-0.000336
Frederick, MD	-0.000035	-0.000282	0.000551	-0.000058	-0.000246
Berkshire, MA	0.001501	-0.000351	0.002043	0.000104	-0.000294
Coos, NH	0.002001	-0.000322	0.002727	-0.000055	-0.000349
Grafton, NH	0.002287	-0.000279	0.002927	-0.000032	-0.000328
Sullivan, NH	0.001004	-0.000356	0.001753	-0.000058	-0.000334
Sussex, NJ	0.000112	-0.000403	0.000720	0.000091	-0.000296
Dutchess, NY	0.000847	-0.000231	0.001401	-0.000013	-0.000309
Saratoga, NY	0.001233	-0.000200	0.001609	0.000088	-0.000263
Cayuga, NY	0.003902	-0.000349	0.004138	0.000138	-0.000024
St Lawrence, NY	0.005744	-0.000357	0.006180	0.000081	-0.000160
Steuben, NY	0.001051	-0.000386	0.001540	-0.000002	-0.000101
Franklin, NY	0.002360	-0.000209	0.002556	0.000102	-0.000089
Jefferson, NY	0.004979	-0.000365	0.005328	0.000056	-0.000039
Ontario, NY	0.000707	-0.000341	0.001012	0.000050	-0.000014
Cattaraugus, NY	0.000347	-0.000389	0.000567	0.000020	0.000150
Wyoming, NY	0.000195	-0.000263	0.000382	-0.000029	0.000106
Livingston, NY	0.000638	-0.000352	0.000972	-0.000017	0.000035
Lewis, NY	0.005426	-0.000349	0.005758	0.000127	-0.000110
Chautauqua, NY	0.000824	-0.000296	0.000936	0.000009	0.000175
Cortland, NY	0.000311	-0.000243	0.000657	0.000032	-0.000135
Genesse, NY	0.005062	-0.000372	0.005356	0.000061	0.000018
Oneida, NY	0.005359	-0.000306	0.005706	0.000164	-0.000204
Washington, NY	0.002353	-0.000212	0.002814	0.000087	-0.000335
Madison, NY	0.004732	-0.000317	0.005100	0.000111	-0.000161
Herkimer, NY	0.002970	-0.000301	0.003330	0.000118	-0.000177
Chenango, NY	0.000614	-0.000281	0.001093	0.000025	-0.000223
Delaware, NY	0.001740	-0.000265	0.002252	0.000094	-0.000340
Otsego, NY	0.001699	-0.000213	0.002026	0.000113	-0.000226
Lebanon, PA	-0.000284	-0.000346	0.000295	0.000018	-0.000250
Franklin, PA	-0.000901	-0.000395	-0.000306	-0.000051	-0.000148
Chester, PA	0.000767	-0.000380	0.001398	0.000007	-0.000257
Berks, PA	0.000044	-0.000425	0.000762	0.000012	-0.000304
Lancaster, PA	-0.001053	-0.000383	-0.000342	-0.000034	-0.000293

Bradford, PA	0.000534	-0.000313	0.001112	0.000007	-0.000273
Tioga, PA	0.000758	-0.000414	0.001296	0.000029	-0.000153
Essex, VT	0.002353	-0.000336	0.003021	-0.000015	-0.000317
Caledonia, VT	0.002785	-0.000274	0.003339	0.000049	-0.000328
Franklin, VT	0.002235	-0.000387	0.002701	0.000087	-0.000165
Orleans, VT	0.001968	-0.000304	0.002437	0.000067	-0.000231
Addison, VT	0.001984	-0.000348	0.002681	0.000041	-0.000389
Washington, VT	0.002058	-0.000177	0.002522	0.000008	-0.000295
Windham, VT	0.002742	-0.000331	0.003271	0.000048	-0.000246
Orange, VT	0.000963	-0.000181	0.001523	0.000002	-0.000380
Grand Isle, VT	0.001675	-0.000324	0.002190	0.000089	-0.000280
Lamoille, VT	0.001753	-0.000229	0.002124	0.000062	-0.000204
Chittenden, VT	0.001730	-0.000358	0.002319	0.000041	-0.000272
Bennington, VT	0.002155	-0.000282	0.002555	0.000121	-0.000239
Windsor, VT	0.001672	-0.000418	0.002381	0.000062	-0.000353
Rutland, VT	0.001536	-0.000290	0.002083	0.000113	-0.000369
Rockingham, VA	-0.000307	-0.000518	0.000437	-0.000005	-0.000222

Table 6: Estimated Average Annual Percentage Rates of Growth in TFP in the Midwest, 1974-2012

County	ΔTFPI	ΔOTEI	ΔOSEI	ΔTECPRO	ΔCEI	ΔSNI
Midwest	**1.5788**	**-0.0169**	**-0.0059**	**0.0540**	**0.0060**	**1.5170**
Jo Daviess, IL	1.4282	-0.0336	-0.0222	0.0540	0.0042	1.4260
Stephenson, IL	1.2997	-0.0342	-0.0239	0.0540	0.0028	1.3032
Clayton, IA	1.3113	-0.0179	-0.0272	0.0540	0.0039	1.2932
Dubuque, IA	1.3528	-0.0244	-0.0089	0.0540	0.0032	1.3177
Winneshiek, IA	1.4135	-0.0177	-0.0057	0.0540	0.0049	1.3599
Sanilac, MI	2.6451	0.0315	-0.0113	0.0540	0.0055	2.4872
Carver, MN	0.9680	-0.0440	-0.0348	0.0540	0.0059	0.9958
Chippewa, MN	-0.0247	-0.1136	-0.0416	0.0495	0.0087	0.0767
Fillmore, MN	1.5336	-0.0163	-0.0206	0.0540	0.0047	1.5002
Goodhue, MN	1.4762	-0.0206	-0.0149	0.0540	0.0060	1.4388
Morrison, MN	2.3114	0.0034	-0.0010	0.0540	0.0077	2.1920
Otter Tail, MN	1.0823	-0.0442	-0.0337	0.0540	0.0100	1.1038
Stearns, MN	1.7895	-0.0137	0.0046	0.0540	0.0078	1.7019
Todd, MN	1.8468	-0.0037	-0.0245	0.0540	0.0088	1.7891
Winona, MN	2.1545	0.0069	0.0047	0.0540	0.0034	2.0305
Wright, MN	0.8514	-0.0480	-0.0288	0.0540	0.0063	0.8750
Wayne, OH	2.2214	0.0115	0.0120	0.0540	-0.0010	2.0819
Barron, WI	1.3176	-0.0235	-0.0162	0.0540	0.0065	1.2874
Brown, WI	2.3687	0.0182	0.0131	0.0540	0.0079	2.1937
Buffalo, WI	1.5675	-0.0143	-0.0097	0.0540	0.0042	1.5138
Calumet, WI	1.5453	-0.0140	0.0123	0.0540	0.0084	1.4502
Chippewa, WI	1.4399	-0.0216	-0.0115	0.0540	0.0052	1.4004
Clark, WI	1.8043	-0.0062	0.0126	0.0540	0.0051	1.6952
Columbia, WI	1.7269	-0.0035	-0.0107	0.0540	0.0077	1.6492
Dane, WI	1.2920	-0.0427	0.0000	0.0540	0.0080	1.2646
Dodge, WI	1.3710	-0.0258	-0.0106	0.0540	0.0076	1.3337
Dunn, WI	1.4976	-0.0116	-0.0160	0.0540	0.0045	1.4501
Fond Du Lac, WI	1.5591	-0.0146	0.0191	0.0540	0.0085	1.4539
Grant, WI	1.3715	-0.0452	0.0040	0.0540	0.0046	1.3464
Green, WI	0.9913	-0.0599	-0.0112	0.0540	0.0029	1.0128
Iowa, WI	1.2128	-0.0555	-0.0105	0.0540	0.0048	1.2253
Kewaunee, WI	2.0788	0.0054	0.0275	0.0540	0.0077	1.9119
Lafayette, WI	1.1396	-0.0571	0.0032	0.0540	0.0045	1.1348
Manitowoc, WI	1.7698	-0.0030	0.0174	0.0540	0.0072	1.6450
Marathon, WI	1.3350	-0.0255	0.0033	0.0540	0.0096	1.2736
Monroe, WI	1.3001	-0.0398	-0.0062	0.0540	0.0033	1.2845
Oconto, WI	1.4210	-0.0059	-0.0005	0.0540	0.0084	1.3358
Outagamie, WI	1.3506	-0.0300	0.0027	0.0540	0.0080	1.2992
Pierce, WI	1.5383	-0.0156	-0.0090	0.0540	0.0051	1.4847

Polk, WI	2.0728	0.0218	-0.0075	0.0540	0.0070	1.9398
Richland, WI	2.4968	0.0310	-0.0018	0.0540	0.0039	2.3293
Rock, WI	2.2212	0.0201	-0.0001	0.0540	0.0024	2.0819
St Croix, WI	1.2770	-0.0237	0.0046	0.0540	0.0083	1.2139
Sauk, WI	1.5645	-0.0079	0.0009	0.0540	0.0086	1.4770
Shawano, WI	2.4128	-0.0427	-0.0101	0.0540	0.0081	2.3965
Sheboygan, WI	1.1241	0.0114	-0.0035	0.0540	0.0055	1.0293
Taylor, WI	1.3706	-0.0272	-0.0128	0.0540	0.0056	1.3419
Trempealeau, WI	1.7435	-0.0020	-0.0121	0.0540	0.0053	1.6693
Vernon, WI	1.1545	-0.0372	-0.0142	0.0540	0.0038	1.1467
Waupaca, WI	1.6060	-0.0096	-0.0026	0.0540	0.0087	1.5257
Winnebago, WI	1.2113	-0.0210	-0.0033	0.0540	0.0085	1.1565
Wood, WI	1.5629	-0.0247	-0.0047	0.0540	0.0069	1.5138

[2] 2012, 2007 data not available ΔTFPI, ΔOTEI, ΔOSEI and ΔSNI were calculated from 1974 to 2002

Table 7: Estimated Average Annual Climatic Effects (Percentage) in the Midwest, 1974-2012

County	ΔCEI	ΔCEI_ST	ΔCEI_WT	ΔCEI_SP	ΔCEI_WP
Midwest	**0.006044**	**-0.000211**	**0.006177**	**-0.000018**	**0.000095**
Jo Daviess, IL	0.004224	-0.000221	0.003780	-0.000058	0.000722
Stephenson, IL	0.002773	-0.000237	0.002398	-0.000045	0.000658
Clayton, IA	0.003941	-0.000246	0.004489	-0.000064	-0.000238
Dubuque, IA	0.003158	-0.000200	0.003248	-0.000055	0.000165
Winneshiek, IA	0.004941	-0.000244	0.005250	-0.000036	-0.000028
Sanilac, MI	0.005531	-0.000103	0.005116	0.000012	0.000505
Carver, MN	0.005944	-0.000192	0.006720	0.000003	-0.000586
Chippewa, MN	0.007968	-0.000169	0.008164	-0.000017	-0.000009
Fillmore, MN	0.004668	-0.000197	0.005029	-0.000025	-0.000139
Goodhue, MN	0.006045	-0.000150	0.006755	0.000036	-0.000594
Morrison, MN	0.007717	-0.000146	0.007753	0.000001	0.000108
Otter Tail, MN	0.010006	-0.000141	0.010086	-0.000001	0.000062
Stearns, MN	0.007802	-0.000134	0.007607	-0.000007	0.000336
Todd, MN	0.008751	-0.000104	0.008501	-0.000006	0.000360
Winona, MN	0.003380	-0.000234	0.003813	-0.000021	-0.000177
Wright, MN	0.006290	-0.000146	0.006622	-0.000002	-0.000184
Wayne, OH	-0.001037	-0.000166	-0.000470	-0.000020	-0.000380
Barron, WI	0.006540	-0.000176	0.007258	-0.000002	-0.000537
Brown, WI	0.007939	-0.000232	0.007447	0.000001	0.000721
Buffalo, WI	0.004199	-0.000265	0.004894	0.000001	-0.000430
Calumet, WI	0.008434	-0.000197	0.007870	-0.000002	0.000761
Chippewa, WI	0.005249	-0.000196	0.005934	0.000004	-0.000491
Clark, WI	0.005059	-0.000223	0.005664	-0.000003	-0.000378
Columbia, WI	0.007651	-0.000254	0.007603	-0.000036	0.000337
Dane, WI	0.008032	-0.000271	0.007994	-0.000035	0.000343
Dodge, WI	0.007607	-0.000227	0.007367	-0.000042	0.000509
Dunn, WI	0.004506	-0.000147	0.005275	0.000005	-0.000626
Fond Du Lac, WI	0.008505	-0.000237	0.008040	-0.000033	0.000734
Grant, WI	0.004602	-0.000283	0.004963	-0.000061	-0.000016
Green, WI	0.002879	-0.000302	0.002815	-0.000041	0.000407
Iowa, WI	0.004772	-0.000288	0.004952	-0.000045	0.000154
Kewaunee, WI	0.007741	-0.000262	0.007097	-0.000006	0.000910
Lafayette, WI	0.004488	-0.000273	0.004389	-0.000059	0.000431
Manitowoc, WI	0.007192	-0.000197	0.006374	0.000003	0.001011
Marathon, WI	0.009576	-0.000235	0.010094	-0.000009	-0.000271
Monroe, WI	0.003334	-0.000199	0.003778	-0.000028	-0.000217
Oconto, WI	0.008382	-0.000186	0.008292	-0.000017	0.000292
Outagamie, WI	0.008047	-0.000237	0.007764	-0.000008	0.000528
Pierce, WI	0.005075	-0.000105	0.005737	0.000027	-0.000582
Polk, WI	0.006972	-0.000189	0.007394	-0.000005	-0.000227

Richland, WI	0.003854	-0.000263	0.004340	-0.000029	-0.000193
Rock, WI	0.002376	-0.000224	0.002077	-0.000035	0.000558
Sauk, WI	0.008255	-0.000269	0.008380	-0.000032	0.000176
Shawano, WI	0.008577	-0.000213	0.008755	-0.000011	0.000047
Sheboygan, WI	0.008146	-0.000207	0.007467	-0.000024	0.000908
St Croix, WI	0.005492	-0.000110	0.006008	0.000009	-0.000414
Taylor, WI	0.005578	-0.000226	0.006245	0.000001	-0.000439
Trempealeau, WI	0.005252	-0.000259	0.005781	-0.000012	-0.000257
Vernon, WI	0.003780	-0.000264	0.004398	-0.000025	-0.000329
Waupaca, WI	0.008679	-0.000211	0.008530	-0.000019	0.000378
Winnebago, WI	0.008532	-0.000253	0.008147	-0.000024	0.000660
Wood, WI	0.006875	-0.000250	0.007222	-0.000022	-0.000074

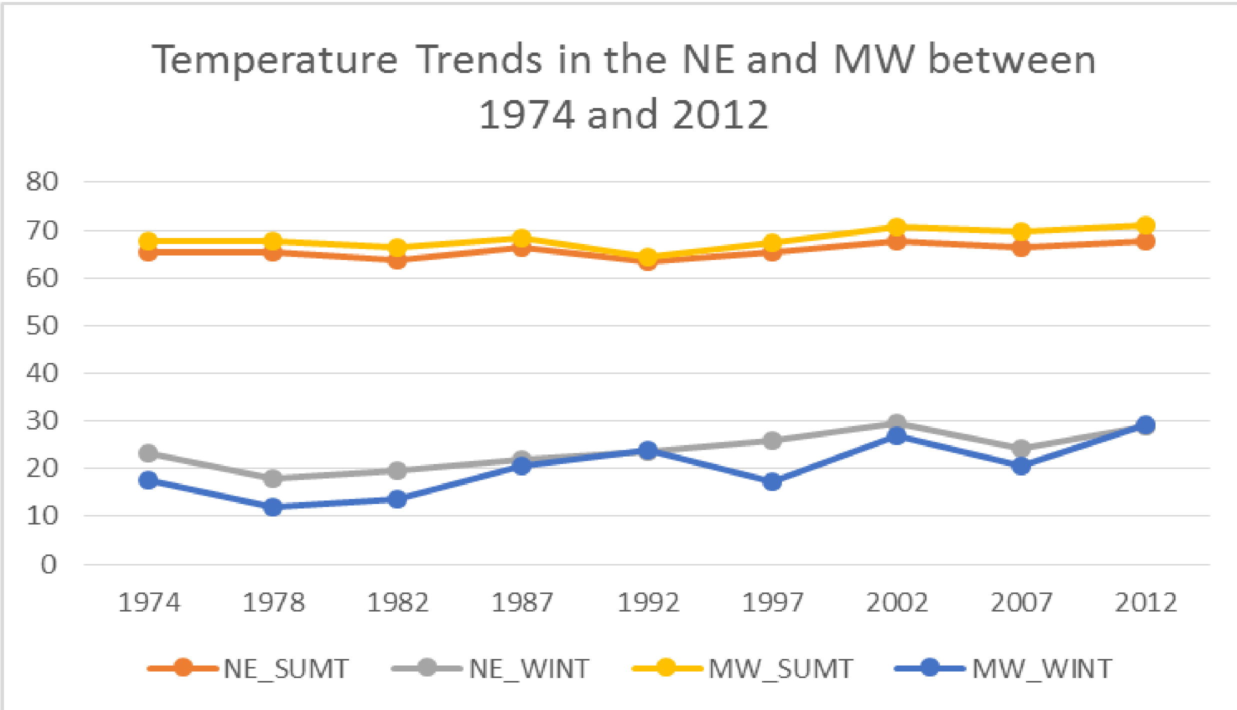

Figure 1: Temperature Trends in the Northeast and Midwest between 1974 and 2012

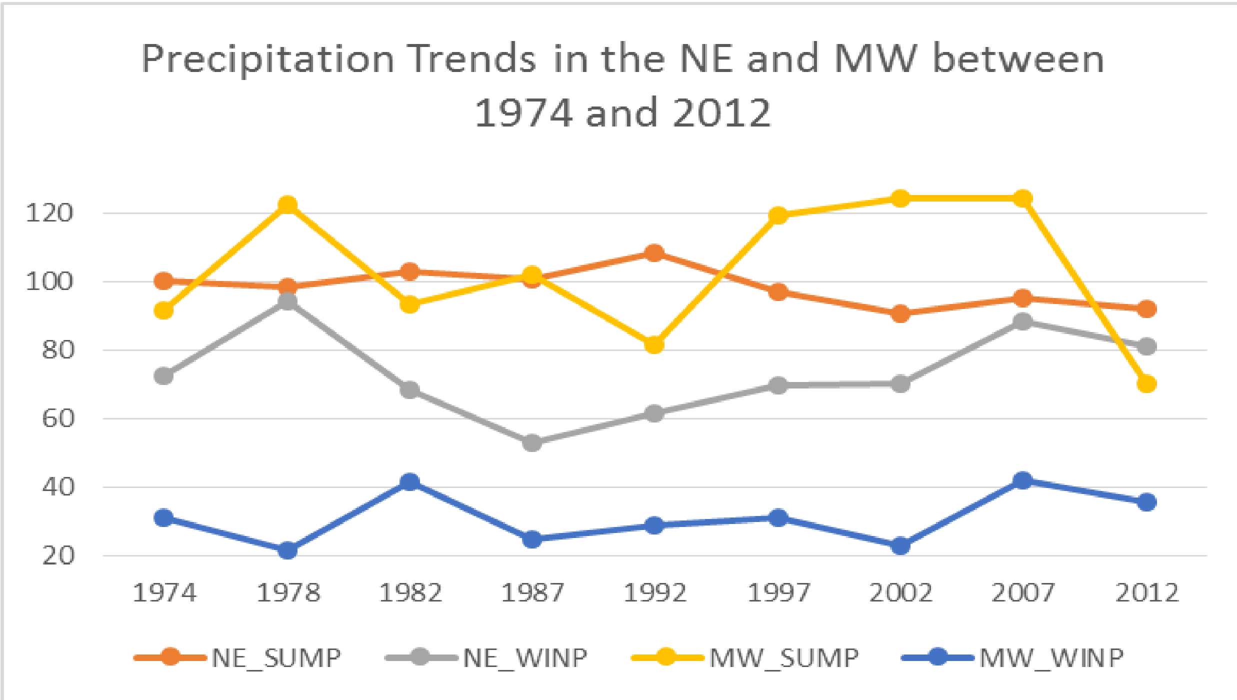

Figure 2: Precipitation Trends in the Northeast and Midwest between 1974 and 2012

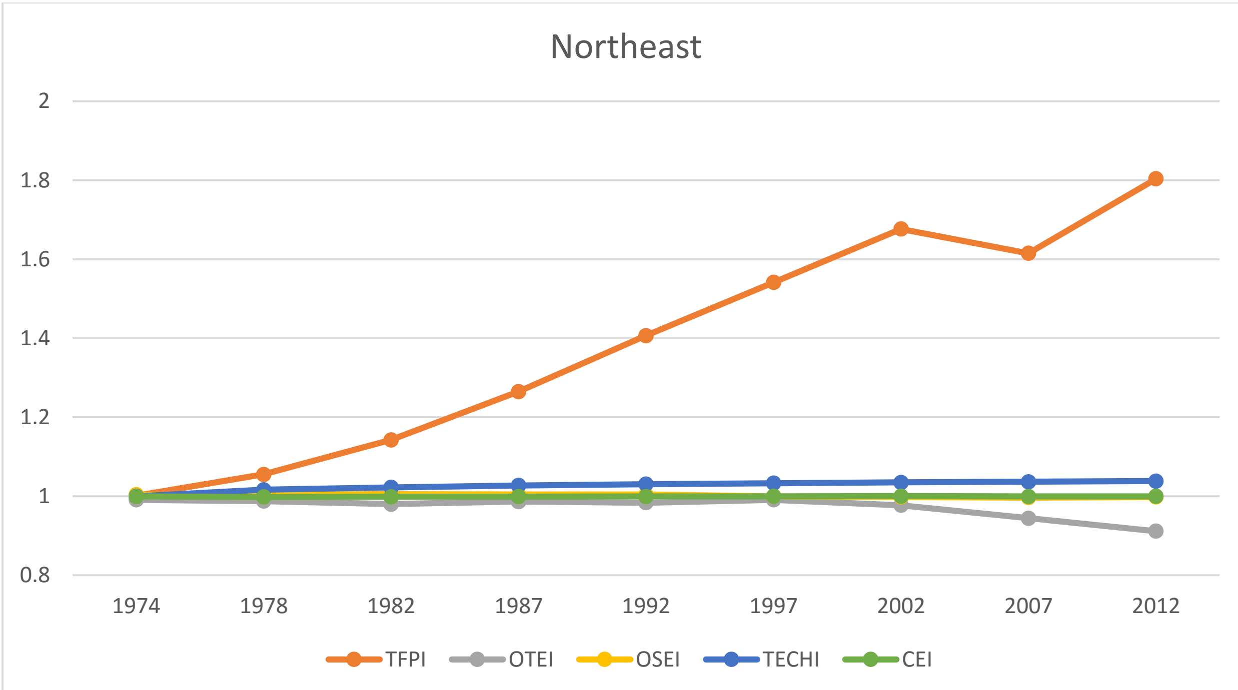

Figure 3: TFPI and Components between 1974 and 2012

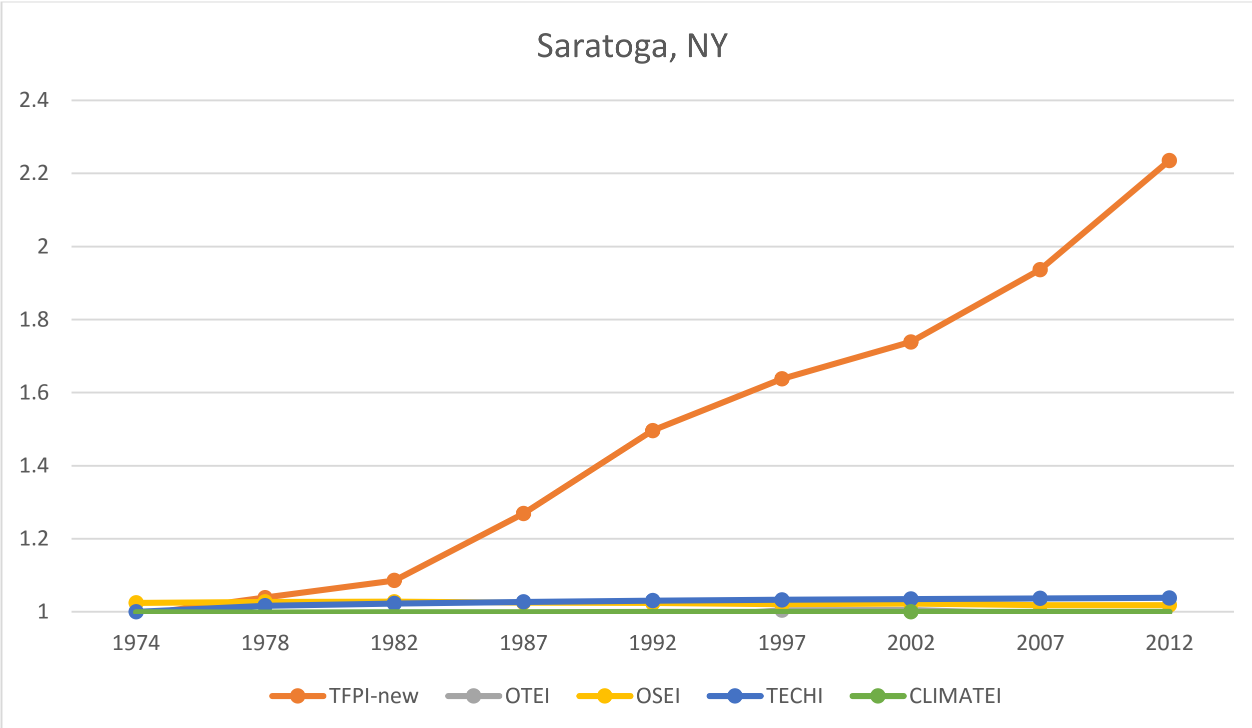

Figure 4: TFPI and Components between 1974 and 2012

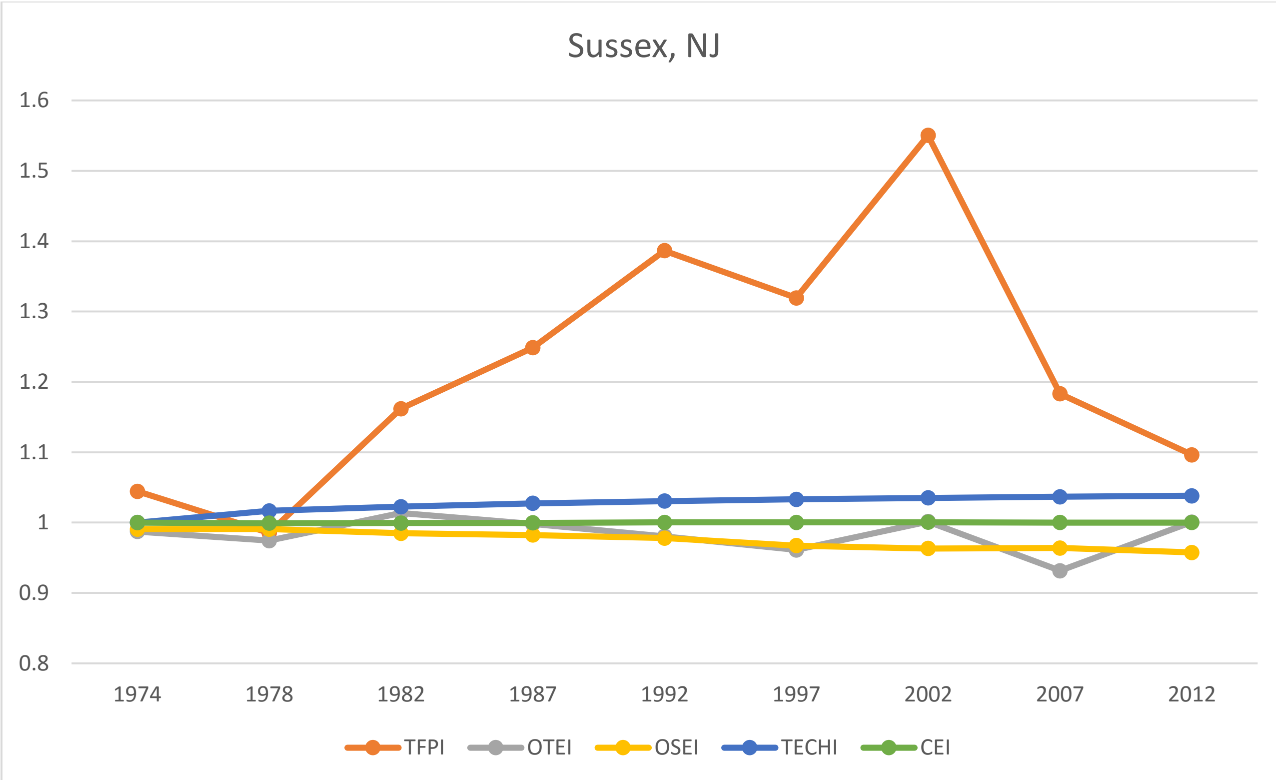

Figure 5: TFPI and Components between 1974 and 2012

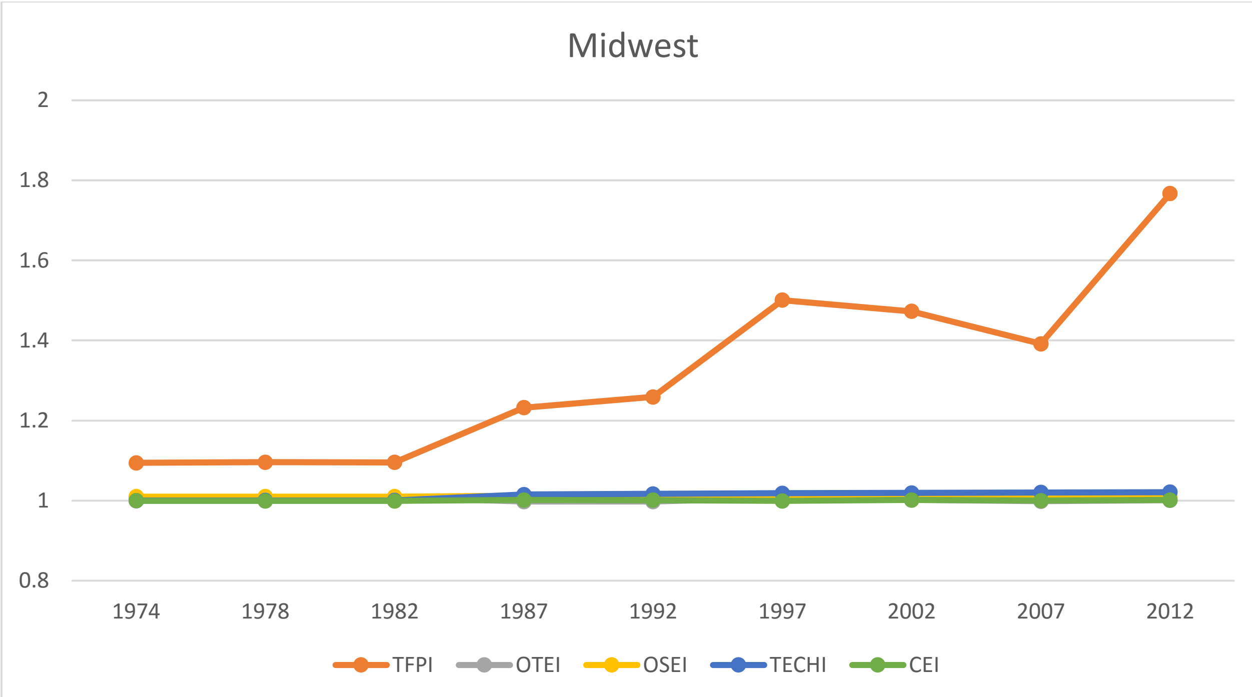

Figure 6: TFPI and Components between 1974 and 2012

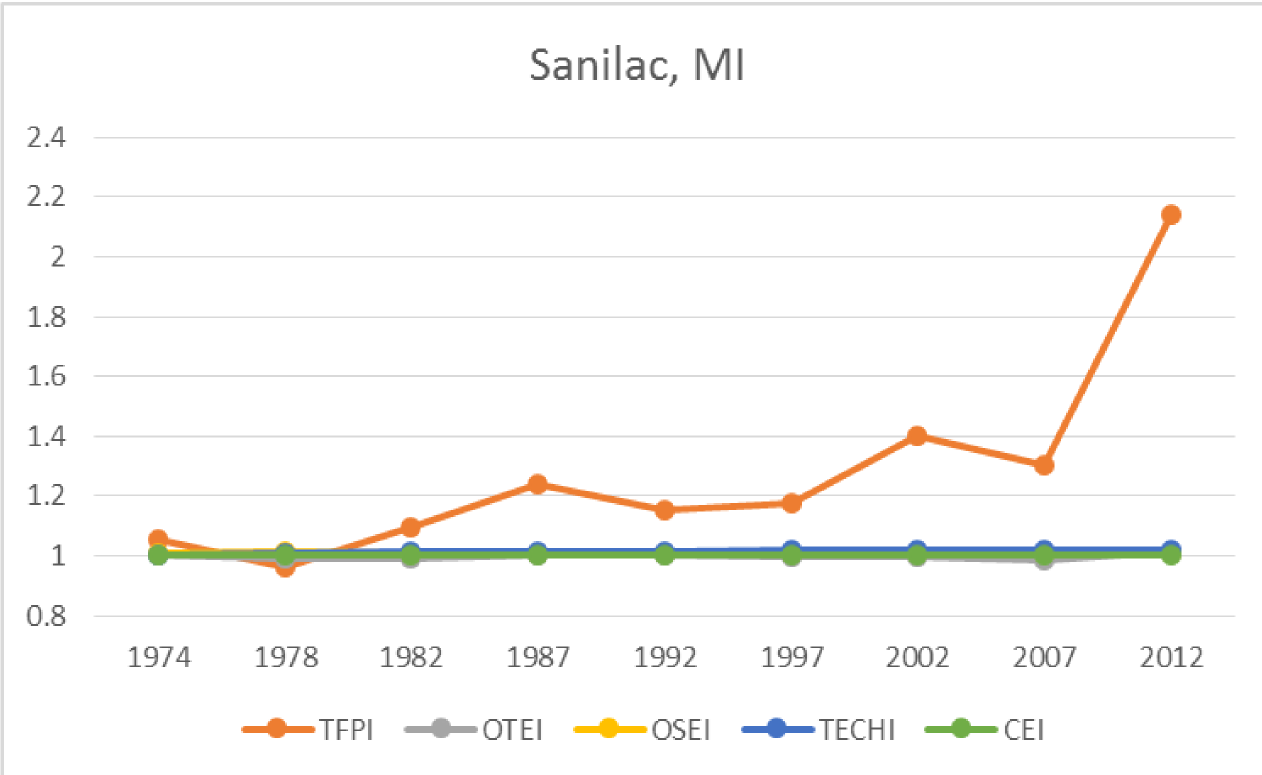

Figure 7: TFPI and Components between 1974 and 2012

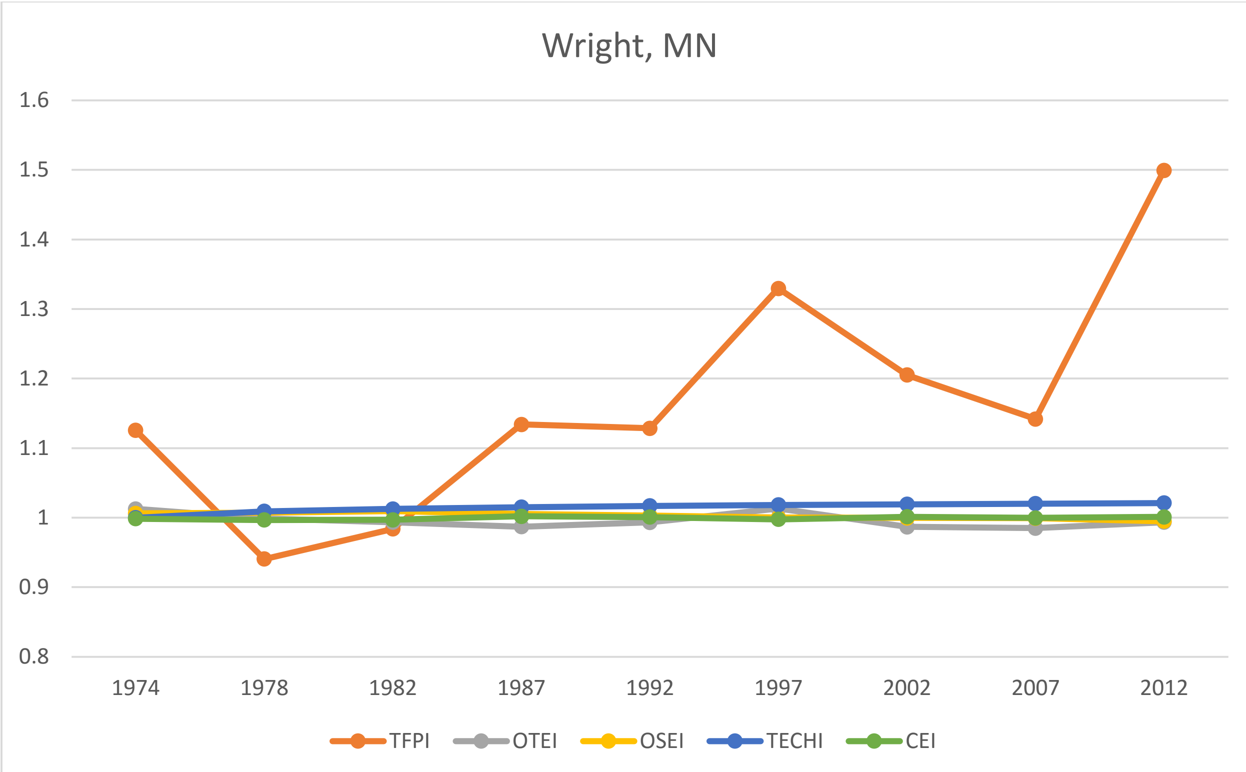

Figure 8: TFPI and Components between 1974 and 2012

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