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Salazar, Mateo

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Mateo Salazar*

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Abstract

This paper quantifies the effect of an increase in temperature and precipitation on the average output per worker in the Colombian manufacturing industry. In order to approach this issue rigorously, a methodology is developed with a theoretical model and an empirical estimation. The estimation of the empirical model is done with economic data from the Annual Survey of the Manufacturing Industry, the Monthly Manufacturing Sample and climate data from IDEAM. The results do not allow to reject a negative effect of temperature and a positive effect of precipitation on average output per worker.

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*Code: 200620306. Contact information: Universidad de los Andes, Department of Economics. Cra 1 Nº 18A- 12 Bogotá, Colombia.(email:m.salazar135@uniandes.edu.co) I am grateful to Hernán Vallejo for his valuable comments and his advisory in this project. I also want to thank Román David Zárate and Román Andrés Zárate. Finally, to Adriana Camacho and Ana María Ibañez for providing the data used in the empirical exercises.

Introduction

It is a classical problem in economics to understand what drives and constraints economic development [Smith, 1776] [Solow, 1956] [Ramsey, 1928]. Many theories have been developed to approach this issue, but there is still a debate between the two most popular lines of research: geographical and institutional [Sachs, 2003] [Acemoglu et al., 2002] [Rodrik et al., 2002]. Closely related to both of them are the findings of Hall and Jones that state that differences in capital accumulation, productivity and productivity of workers are closely related to differences in social infrastructure[1] [Hall and Jones, 1999]. This paper uses quarterly municipal data for Colombia to look for evidence to support the hypothesis that a healthy environment makes part of that social infrastructure, in this case through sustained moderate climate. This paper will evaluate the impact of a healthy environment on the manufacturing industry specifically because the losses produced by changes in temperature are 29 times bigger on sectors not related to agriculture [Hsiang, 2010].

There is still a debate about the exact impact of environment on the economy and its relevance on public policy [Daly, 1996] [Arrow, 2004] [Dell et al., 2008] [Stern, 2006] [Tol, 2009]. In this context, it is important to develop methodologies that provide precise and trustworthy results since "climate change is the mother of all externalities: larger, more complex, and more uncertain than any other environmental problem" [Tol, 2009]. Assessing its economic impacts is a very relevant matter in the literature on economic development.

In terms of Colombian public policy specifically, the climate change issue has been gaining relevance in Colombia. The Council of Economic and Social Policy (CONPES) presented its official climate change document on July 14, 2011 [CONPES, 2011]. The aim of the CONPES is to establish an institutional arrangement to articulate a strategy between sectors in order to facilitate and enhance the formulation and implementation of policies, plans, programs, methodologies, incentives and projects on climate change, including climate as the main variable in the design and planning of development projects [Cadena et al., 2012].

It is intended to enhance mainly four strategies changing the way the country understands climate change and sustainable development in general. These four strategies are:

1. The National Adaptation Plan.

2. The Low Carbon Development Strategy.

[1] Social infrastructure defined as "the institutions and government policies that determine the economic environment within which individuals accumulate skills, and firms accumulate capital and produce output." [Hall and Jones, 1999]

3. The National Strategy for Emissions reduction due to Deforestation and Forest Degradation.

4. The Strategy for Financial Protection against Disasters.

It is necessary for the country's productive force in all municipalities to implement adaptation and mitigation actions without affecting the productive sectors of long-term growth of the Colombian economy. This study presents rigorous evidence of another channel of impact of climate change on economic performance and at the same time an opportunity for the productive sector to adapt to the imminent raise in temperature that comes ahead. This study quantifies an additional impact that constitutes also an incentive for the industry to mitigate carbon emissions in order to maximize the benefits in the long-run.

The relationship between climate and economic activity has traditionally been approached using two kinds of models. The first group of models has studied the impact of average temperature on aggregate economic variables using cross-sections [Sachs and Warner, 1997] [Gallup et al., 1999] [Nordhaus, 2006]. One good example is Dell et al. that find evidence of national income falling 8.5% per degree Celsius in a world cross-section [Dell et al., 2009]. Nevertheless, other scholars argue that this results are driven by associations of temperature and other national characteristics which means that the estimations are biased [Acemoglu et al., 2002] [Rodrik et al., 2002] .

The second group of models looks for micro climatic effects that, when added have an effect on aggregate national income. This models are more rigorous in terms of econometrics and the main critique is the complexity of measuring all possible correlations. The set of candidate mechanisms through which temperature affects economic outcomes is very large and quantifying every single one of them is virtually impossible. A recent study done by Dell et al. describes a wide variety of potential channels through which climate affects economic performance: agricultural productivity, mortality, physical performance, cognitive performance, crime, and social unrest but many of these are not measured by quantitative models [Dell et al., 2008]. The main result of that paper is that production decreases in 1.1% for every degree Celsius of temperature increase (-1.1%/+1°C). For exports, the relationship varies from -2.0%/+1°C to -5.7%/+1°C. They find this for a large set of heterogeneous countries without quantifying the impact of productivity per worker. The fact that the impact on output per worker has not yet been measured directly is the main motivation for this research. Cognitive and physical performance are the two main channels that this paper will take into account by choosing the industry sector.

Hsiang's study states that such great variations in GDP cannot be explained only by agriculture [Hsiang, 2010]. The main result of that paper is that losses produced by changes in temperature are 29 times bigger on non-agro sectors than on the agro sector. Even though that paper mentions ergonomics as a possible link between climate and GDP, the dependent variable is historic production. This means that the output of workers is not measured directly as it is measured in the present paper.

This paper develops a theoretical and empirical methodology to evaluate ergonomics[2] as a channel through which climate impacts the average output per worker[3]. The theoretical framework is based on the $Y = AK$-type[4] of production function that depends on temperature. The conclusion of the theoretical model is that the impact of temperature on the average output of workers needs to be analyzed in levels and growth. Based on this, the estimation strategy uses data of temperature and precipitation in each municipality and quarter in Colombia from 2000 to 2004 from the Institute of Hydrology, Meteorology and Environmental Studies (IDEAM) and the Monthly Manufacturing Sample (MMS) with data on output and employment for the same years. The study determines empirically that the average output of workers (levels and growth) has statistical dependence on intra annual variations in local temperature. The key characteristic of the estimation framework is that it uses industry-municipality fixed effects in order to examine only the dynamic variations, reducing potential sources of endogeneity.

There is evidence that suggests a correlation between temperature and income in Colombia. This evidence is shown in figure 1. It is important to notice one bar is the output of workers and the other is the temperature, and that for most departments there is one big bar together with a small one. For Colombia, there is a positive correlation between the competitiveness ranking and temperature [Sánchez and Acosta, 2001]. This means that the department that is ranked first in Colombia (Bogotá D.C.) tends to have lower temperatures

[2] Ergonomics studies the design and arrangement of things people use in order to make their interaction safer and more efficient.

[3] The ergonomics of thermal stress on humans has been well studied and there is a lot of literature on this topic. Laboratory experiments show that when the temperature is higher than 26.62°C WGBT and lower than 18.29°C productivity drops. the WGBT is a composite temperature used to estimate the effect of temperature, humidity, wind speed and solar radiation on humans. (U.S. Army Technical Bulletin Medical 507/Air Force Pamphlet 48-152) [Pilcher et al., 2002]. This is evidence of the non-linearity mentioned above.

[4] The motivation for choosing this specific type of model is that the study focuses on the impact of climate on workers output. The manufacturing industry is chosen because the climate will not affect the output of capital which is the other factor that is taken into account in traditional production functions.

compared to the one that is ranked last. The pattern is evident on the tendency line in figure 2. Even if these are only correlations that do not represent causality, they constitute evidence. The fact that Colombia does not have seasons constitutes an additional motivation for this research. There are very few incentives to develop infrastructure in a country where climate is not an issue. In the long run the lack of this infrastructure would be a problem when dealing with climate change.

The estimates report large, generally negative effects of higher temperatures on growth. Changes in precipitation have relatively mild effects on national growth but is important to include them because they affect both temperature and income. This paper finds consistent results across a wide range of alternative specifications that are used as robustness checks.

After this introductory section, the production function model will be presented concluding with the level-growth theory. Section 2 describes the data sources, the methodology for constructing the indicators used in the empirical exercises and the descriptive statistics of the merged data set. Section 3 contains the empirical framework used to measure the effect of temperature on the output per worker, the presentation of the results, and also some alternative models used as robustness checks. Finally, conclusions are presented together with some policy suggestions.

1 Temperature in the Production Function: A Theoretical Model

At this point it is important to think about the channels through which temperature affects the current average output per worker and the growth of average output per worker through time in the manufacturing industry. In both cases, the impact of thermal stress on workers' performance seems reasonable.[5] Average output per worker could be a channel in the long-run through the creation of a working culture as an institution which is a process that could be affected by the findings of ergonomics[6].

[5] "Three of six non-agricultural industries suffer large and robust reductions in annual output that are dominated by temperatures experienced during the hottest season and are non-linear in temperatures during that season. The magnitude, structure and coherence of these responses support the hypothesis that the underlying mechanism is a reduction in the productivity of human labor when workers are exposed to thermal stress." [Hsiang, 2010]

[6] The Pygmalion effect refers to the phenomenon that the higher the expectation placed upon a person the better that person performs. [Rosenthal and Jacobson, 1992]; Temperature altering the Circadian rhythm (In

Thinking on the impact of temperature on the growth of average output per worker in the long-run puts climate change into the picture. If temperature shifts have an impact on current economic performance and economic growth, climate change will in turn affect this variables by affecting temperature patterns.

The future implications on climate change are very difficult to estimate and the empirical scope of this study is historical and in the short run. Notwithstanding, this section explores a theory through which this long-run phenomenon could affect economic performance, keeping in mind uncertainties about the extent and nature of climate change. The analysis is based on four main effects that need to be controlled for in order to make consistent conclusions in the long-run. First, it is possible that countries adapt to permanent changes in climate. Second, as climate change becomes a global issue, it may affect sea-levels, biodiversity and frequency of extreme climatic events that at the same time could impact economic variables. Third, there is a big chance that mandatory mitigation actions will be implemented and they may distort economic performance. Fourth, convergence forces may offset the impact of climate on the economy, especially within poor countries [Solow, 1956]. This analysis is important because the small effects found in the paper can compound overtime a constitute a substantial effect.

The theoretical framework is a modification of the model presented in Dell et al. 2009, that develops a mathematical relationship between temperature and average output per worker in the long-run [Dell et al., 2009]. The modification consists on using a specific production function in order to justify theoretically the empirical estimation of the missing parameter γ. It is important that in this case the analysis is done for the manufacturing industry only with the purpose of isolating the effect of climate on the output of capital.

The long-run effect of temperature on output per worker can be summarized in two broad categories[7]: adaptation and convergence. These effects are opposite given that convergence tends to increase the output per worker and adaptation tends to pull the opposite way.

biology, circadian rhythms are oscillations of biological variables at regular intervals of time); and implications on the allocation of time. Temperature affects the opportunity cost of working over leisure. Following this logic it will also affect labor supply. [Graff and Neidell, 2010]

[7] Mitigation is another category that is not related to adaptation nor convergence. Universidad de los Andes is now calculating the Abatement Cost Curves (net present value of mitigating climate change) under the framework of the Low Carbon Development Strategy. Once these values are available it would be interesting to redesign this model in order to calculate the impact of such measures in the growth of output per worker in the long-run. The way the adaptation parameter is calculated makes sure to account for impacts on other environmental variables such as biodiversity.

It is important to clarify that the concept of convergence comes from neoclassical theory and the assumption that factors of production grow at the same rate in all countries. This assumption has its roots on the decreasing marginal returns to scale of the production factors. On top of that, the Colombian growth trend is upward sloping and hence it can be said that the convergence level is above current levels. Therefore the convergence effect will increase output per worker in the long-run. This can be understood as a natural inertia that output per worker has in the long-run.

On the other hand, the adaptation effect is directly related to temperature. The relationship consists on the fact that, in the long-run, areas must adapt to changes in geographic conditions. Since the unit of analysis is each industry, the adaptation effect can be viewed in that way. The reference to the production function must be done in order to do a more rigorous analysis. On the capital side of the production function there is an adaptation of technology and physical capital. More specifically, industries face costs caused by the variation of climate in the long-run. On the labor side of the production function, the adaptation occurs through migrations, fertility and mortality rates. People are forced to do things by geographic conditions. In general, what happens is that there are alterations on the industry's relative factor intensity.

The differential equation 1 is the starting point that summarizes the effect of temperature on output per worker. It can interpreted as the evolution of output per worker through time and it depends on the adaptation and the convergence effects.

$$\frac{dlogy_i}{dt} = g + \gamma(T_i(t) - \bar{T}_i) + (\gamma + \rho)\bar{T}_i + \varphi(logy_*(t) - logy_i(t)) \quad \text{for} \quad t \geq 0 \tag{1}$$

where y is the income per capita, y_* is the income per capita to which the regions should converge to, T_i is the temperature and $\bar{T}_i$ is the average temperature of the municipalities where the industry i is present. The subscript i represents the industry and t the period. The coefficient γ captures the short run effect of temperature and ρ captures the degree of adaptation to the average temperature in the long-run. Finally, φ represents the convergence rate.

Integrating the differential equation 1 and taking expectations (see Appendix) the following is obtained:

$$E[logy_i(t)] = E[logy_*(t)] + \frac{\gamma + \rho}{\varphi}(T_i - \bar{T}_i)(1 + \exp^{-\varphi t}) \tag{2}$$

Then, differentiating equation 2 with respect to temperature,

$$\frac{dE[logy_i(t)]}{dT_i} = \frac{\gamma + \rho}{\varphi} \tag{3}$$

Equation 3 shows that the changes of output per worker due to a change in average temperature depends on the convergence parameter (φ), the effect of temperature on the short run (γ) and the degree of adaptation to average temperatures in the long-run (ρ).

Dell et al. (2009) calculate $\frac{dE[logy_i(t)]}{dT_i} = -0.012$ in a within-country context. The convergence parameter, much analyzed in the growth literature, is typically estimated in the cross-country context in the range $0.02 < \varphi < .10$ [Barro and i Martin, 1995]. The convergence rate is calculated between countries so for the purpose of this paper the upper bound will be used as the convergence within countries is higher [Caselli et al., 1996]. The only two parameters left to calculate are ρ and γ. There is no estimation of the within country short-run growth coefficient in the literature, therefore the empirical section of this paper is devoted to calculating it with a result of $\gamma = -0.0031$[8] (see table 5). Due to the lack of information Dell et al. (2009) use country level estimates which is $\gamma = -0.011$. Finally, from equation 3 and doing a sensibility test it is possible to calculate a range for the adaptation parameter $0.0019 < \rho < 0.0029$.

The rest of this section is used to explain how γ is calculated. This parameter is defined as the within country short-run growth coefficient. In order to estimate it the methodology must turn off the long-run effects (adaptation and convergence) and focus in the short run in order to develop a hypothesis that is testable with the data available.

To begin with, it is important to point out that recent empirical literature on economic growth estimates specifications based on variants of the Solow model, in which the long-run growth rate of output per worker is determined by technical progress, which is taken to be exogenous. The most popular model used to evaluate this framework and to study the issue of convergence is derived from the transition dynamics to the steady state growth path, first suggested by Mankiw et al., (1992) [Mankiw et al., 1992].

The model presented below is based on the theoretical framework by Bond et al. [Bond et al., 2009]. For the specific scope of this study a single-sector economy is chosen for the simplicity of the $Y = AK$ type of production function. The motivation for choosing this specific type of model is that the study focuses on the impact of climate on workers output. The manufacturing industry is chosen because the climate will not affect the output of capital

[8] This value is calculated based on the results estimated in section 4. The result is the average country short-run coefficient for the Colombian manufacturing industry.

which is the other factor that is taken into account in traditional production functions. In fact, the assumption here is that the other production factors will no be affected by the variance of the climate in a specific municipality between quarters. It is relevant to clarify this as the empirical methodology compares a municipality to itself through time. For instance, consider the following production function that incorporates temperature:

$$Y_{i,t} = e^{\beta T_{i,t}} A_{i,t} L_{i,t} \tag{4}$$

where Y is aggregate output, L measures workforce, A measures labor productivity and T measures weather. Equation 4 captures a relationship between weather and production.

$$\frac{\Delta A_{i,t}}{A_{i,t}} = g_i + \gamma T_{i,t} \tag{5}$$

Equation 5 represents the growth of labor productivity that is affected by weather.

Now, dividing both sides of equation 4 by $L_{i,t}$, taking logs, differencing with respect to time and replacing equation 5 yields:

$$g_{i,t} = g_i + (\beta + \gamma)T_{i,t} - \beta T_{i,t-1} \tag{6}$$

where $g_{i,t}$ is the growth rate of output per worker (dependent variable) in the short run. There is a direct link between equation 1 and 6. It is obvious that equation 6 ignores the long-run effects such as convergence and adaptation, but it includes the lag of temperature in order to control for short run lagged impacts of temperature on output per worker. The level effects of weather shocks on $g_{i,t}$, which come from equation 4, appear through β. The growth effects of weather shocks, which come from equation 5, appear through γ. Thus,equation 6 implies that not only current levels of average output per worker are affected by temperature, but also the growth of the average output per worker. It also implies that temperatures from previous periods may have an impact. The aim of the empirical exercise is to estimate γ from a variant of regression 6 for the case of Colombia.

2 Data

The task of measuring the impact of climate on the average output per worker in the short run (γ) is done by merging and analyzing several datasets. The datasets that are described in this section complement each other in order to use the most precise and disaggregated information available. Some indexes have to be constructed in oder to obtain the average output per worker which ultimately is the dependent variable. Since the richness of the analysis resides on the comparison of hot seasons with colder seasons, it is vital for the data to be quarterly. The variance of temperature and precipitation within years is larger than their variance between years even in a country without seasons like Colombia.

The challenge is to construct a dataset with the information available for Colombia that has monthly climate variables for each municipality and production variables for each industry (ISIC).

The National Bureau of Statistics (DANE) constructs the Annual Manufacturing Survey (AMS) that aims to obtain basic information of the Colombian industrial sector in order to characterize its structure and evolution. It is an unbalanced panel[9] that records data for all industrial establishments with 10 or more employed workers, or with a production value of more than $130.5 million pesos of 2005[10]. Some of its variables are: occupied personnel, wages and salaries, total production, mean consumption, costs, energy consumption, etc. The information is available for each municipality and covers the period from 1993 to 2004 at an annual frequency.

The Monthly Manufacturing Sample (MMS) constitutes another valuable source of information. From monthly production information, sales, workforce, employment, wages and salaries, social benefits and hours worked, DANE generates index and variations. Using the Annual Manufacturing Survey (AMS) as reference, the MMS was designed to include 1344 establishments employing 10 or more people, establishing a representative sample of the manufacturing industry. It is divided into 48 groups according to the third revision of the International Standard Industrial Classification adapted to Colombia (ISIC Rev. 3 A.C). The base year for this sample is 2001. From now on, all results will be presented in constant 2001 Colombian pesos.

For the climate variables, the information is obtained from the Institute of Hydrology, Meteorology and Environmental Studies (IDEAM for its Spanish acronym). This dataset is an unbalanced panel that contains monthly information for 772 municipalities in Colombia for the years 1931 to 2005. Some municipalities have more than one climatological station and therefore more that one observation. The variables available are maximum, medium and

[9] The fact that the panel is unbalanced is controlled for with the following strategies: robust errors to control for heterogeneity and within fixed effects only. The panel is lightly unbalanced (the biggest difference in observations between years is never more that 1%.) and therefore the data is not censored.

[10] This assumption had to be made due to budget contraints from the National Bureau of Statistics (DANE)

minimum temperature, precipitation, humidity and solar radiation. The data before 1980 is incomplete but this wont matter as the merge will only take into account the data between 2000 and 2004 because of information constraints.

2.1 Market Share and Labor Share of each Municipality within an Industry

Since the monthly data from the MMS is divided by ISIC but not by municipality, there is the need to use the information from the AMS and merge it with the MMS in order to have monthly data clustered by municipality. The indexes used to do this are the market share and the labor share of each municipality within an industry in a specific year. These indexes are calculated using total production and work force.

$$mktshare_{i,m,t} = \frac{produc_{i,m,t}}{\sum_{m=1}^{N_i} produc_{i,m,t}} \tag{7}$$

$$laborshare_{i,m,t} = \frac{labor_{i,m,t}}{\sum_{m=1}^{N_i} labor_{i,m,t}} \tag{8}$$

where *produc* and *labor* are the number of firms and work force respectively. The subscripts i, m and t from now on correspond to the industry, municipality and year. The top limit of the sum N_i depends on the number of municipalities in which the industry i is present. These market share and labor share will be useful to separate the MMS indexes in municipalities.

2.2 Quarterly Output per Worker

The MMS contains quarterly indexes of production, employment and sales. The index is the value of the variable in a quarter divided by the value of that same variable in the first quarter of 2001 (2001q1: base period). As it was mentioned before, these indexes are not divided into municipalities. This means that from the MMS we have $iproduc_{i,q}$ (where q is quarter) and from the AMS $mktshare_{i,m,t}$. The problem is symmetric for labor. By merging the two datasets and assuming that the market share is constant between quarters[11], the

[11] It is important to highlight the assumption that the market share and the labor share do not change within years. The assumption was made because the data suggests that market and labor shares do not change significantly between years.

$iproduc_{i,m,q}$ is calculated. To convert these indexes into the average output per worker, the following manipulation has to be done. Dividing both indexes, it is obtained:

$$\frac{iproduc_{i,m,q}}{ilabor_{i,m,q}} = \frac{\frac{produc_{i,m,q}}{produc_{i,m,2001}}}{\frac{labor_{i,m,q}}{labor_{i,m,2001}}} \tag{9}$$

After some algebraic manipulation, it is obtained:

$$prodl_{i,m,q} = \frac{produc_{i,m,q}}{labor_{i,m,q}} = \frac{iproduc_{i,m,q}}{ilabor_{i,m,q}} * \frac{produc_{i,m,2001}}{labor_{i,m,2001}} \tag{10}$$

This is the quarterly average output per worker that is used as dependent variable in the empirical estimations. The growth rate, $g_p rodl_{i,m,q}$, is calculated with a standard methodology and will be used as dependent variable as well.

2.3 Summary statistics

The summary statistics are presented in table 1. This section highlights some relevant characteristics about the merged dataset that for the most part are not evident in the summary statistics table.

The average temperature for year 1982 is 21.88°C with a standard deviation of 5.56, a minimum value of 4.15 and a maximum value of 29.72. For 2010, these values are 22.78°C, 5.25, 8.98 and 31, respectively. This suggests that the mean temperature has increased in this period of time and also that, even though Colombia has almost indiscernible seasons, there is significant variance within years. It is also important to note that the data recorded is an average for the whole day, not only the working hours. The hottest municipality in Colombia is Aguachica located in the department of Cesar which is the hottest in Colombia. The coldest municipality is Villamaría, Caldas, and the coldest department is Nariño. In the case of precipitation, the country average for all years is 116.86mm.

The sample for the empirical exercise contains 125 municipalities which are for the most part the biggest urban areas where the manufacturing industry is present. About the economic variables shown in table 1 there are some important facts to highlight. *iproduc* is the MMS indicator multiplied by the market share. The interpretation of its mean is that on average the production of an industry in a municipality for a given year with respect to the base year is 1.55 points of the index. The number is very small because the manufacturing industry is atomized, which means that the market share of every municipality is small. The biggest numbers for this index are the most important urban areas in Colombia, but still no municipality has the total market share of any industry. In the case of *prodl*, which is the average output per worker, the quantities are shown in thousand pesos of 2001, and its interpretation is that the average worker produces 19,745,630 pesos in a year. The standard deviation is very large because of the way the firms register their employees. There are very big and very small values of this variable; for example, for the *Manufacture of general purpose machinery* in Espinal, Tolima it is huge. This industry registered enormous production with only 2 workers. The empirical section will use logarithms to try to control for these outliers. The growth rates of *iproduc* and *prodl* show that the manufacturing industry is growing at a moderate pace over the quarters and this growth is lineally boosted by the productivity of the workforce, that is 3.6% and 2.5% respectively. It is important to highlight that it is growing at roughly the same rate as the aggregate GDP.

Figure 3 shows the relationship between *iproduc* and temperature. The evidence of that figure is in line with figure 4 which shows relevant findings of ergonomics and introduces a possible non-linearity [Pilcher et al., 2002] that will be tested in the empirical section. Figure 4 illustrates the mean percent difference in performance between the neutral temperature groups and five temperature subcategories defined by the author. $Cold2 :< 10.8°C; Cold1 : 10.81 - 18.28°C; Hot1 : 18.29 - 26.62°C; Hot2 : 26.63 - 32.17°C; Hot3 :> 32.18°C$. The interpretation is that performance is not altered when the mean temperature is in the $Hot1$ subcategory. When the temperature is below that level, performance is lowered because of the cool environment, and when it is beyond that point, performance is lowered because of the hot environment. From the total of 125 municipalities in the sample, 67 have higher temperatures than $Hot1$ and 24 have lower, leaving 34 in the temperature comfort zone.

Some interesting conclusions come out when the findings of ergonomics are applied to the Colombian case. The summary statistics (table 1) show that the minimum average temperature of the areas where the productive activities take place is very close to the bottom frontier of $Hot1$ where performance is not altered. In fact, only four departments show temperatures below that subcategory: Nariño, Boyacá, Cundinamarca and Caldas. The whole point of this explanation is to show that Colombia will not be positively affected by an increase in average temperature driven by climate change, both at department and municipality level the evidence is clear. This conclusion is due to the fact that most of the productive activity in Colombia is done where the temperature is in subcategories $Hot1$ and $Hot2$. The mean 21.63°C is also evidence of this point. The findings of ergonomics in this area are relevant because they suggest the existence of non-linearity in the impact. Testing this point is one of the main objectives of this paper as will be seen later on.

3 Estimation of the Effect of Temperature on the Average Output per Worker

In this section the estimation models are described and the results are discussed. Furthermore, some robustness checks are presented.

3.1 Empirical Framework

The empirical model of the study is based on Hsiang (2010) and takes some concepts from Bogliacino et al. (2009) and Dell et al. (2009) that use a similar panel approach to this problem [Hsiang, 2010] [Dell et al., 2009] [Bogliacino and Pianta, 2009]. It is a regression with municipality fixed effects. The output per worker is explained as a function of its lags, the climate variables and some municipality characteristics such as property taxes and violence.

The objective of this study is to determine empirically if the mean output per workers in individual industries has any statistical dependence on intra annual variations in the local temperature. Previous research used a cross-sectional approach where patterns of production are correlated with the average state of the local atmosphere. A critique of this approach is that the average state of the atmosphere (a fixed parameter) may be correlated with other fixed parameters (for example, altitude) which may themselves directly affect patterns of production [Tol, 2009]. This is the omitted-variables problem: without describing all fixed variables affecting an outcome, statistical inference on any single fixed variable may be biased [Greene, 2008].

Since it is almost impossible to control for all of these fixed variables, this study inserts municipality fixed effects and trend in order to examine only the effects related to dynamic variations. The average atmospheric states of any two municipalities are never compared here. Instead, the influence of the atmosphere on production is identified by looking at the response of production to perturbations in the atmospheric state around its mean value. This should only compare a municipality to itself at different points in time when it is experiencing different atmospheric states. To avoid the omitted variable problem mentioned above, the precipitation is also included in the regression and together with temperature constitute the atmospheric state. It is necessary to control for some characteristics of the municipality that are not captured by the fixed effect or the tendency such as violence of taxes that are paid in a specific month. In the case of taxes the property tax is included. For violence, the number of people that are forced to leave their home town was found to be a good proxy of violence in specific municipality. Some argue that cyclones should also be included as they are correlated to temperature and production [Hsiang, 2010]. In the case of Colombia, cyclones are not a major problem and are mostly isolated atmospheric phenomena that are not relevant for the study of this specific country.

Given the variables calculated in the previous section, the following two regressions can be run with fixed effect of municipality, lags, tendency and environmental variables.

$$prodl_{m,q} = \sum_{l=0}^{L}(\alpha_l prodl_{m,q-l}) + \mu_m + \sum_{i=0}^{I} D_i \sum_{j=0}^{J}(\rho_j T_{m,q-j} + \beta_j P_{m,q-j}) + \phi_{m,t} X_{m,t} + \theta_m t + \eta_{m,t}\sigma_{m,q} + \epsilon_{m,q} \quad (11)$$

$$g_i prodl_{m,q} = \mu_m + D_i \sum_{j=0}^{J}(\rho_j T_{m,q-j} + \beta_j P_{m,q-j}) + \theta_m t + \eta_{m,t}\sigma_{m,q} + \epsilon_{m,q} \quad (12)$$

The difference between regression 11 and 12 is the dependent variable. In the first regression it is the level of output per worker and in the second one is the growth rate. For both regressions μ_m is the fixed effect, D_i is an industry dummy variable, t is the tendency, $X_{m,t}$ is the vector that contains the characteristics that are not captured by the fixed effect or the tendency, $\sigma_{m,q}$ is the temperature variance, $P_{m,q-j}$ is the precipitation and $T_{m,q-j}$ is the temperature. The parameter of interest is therefore ρ_j, which accompanies the indicator of temperature. Since the survey is a panel, the regression is run where i is the industry and q is the quarter. The municipality fixed effect is very important, because it captures all the statical differences in levels of production between industries. Finally, the tendency captures all changes in average output per worker that vary smoothly through time. To calculate I the Durbin's h-test is performed to check for serial correlation. The lags are included as long as they are statistically significant. In the case of L, the literature states that only one lag is necessary.

The empirical strategy consists in estimating 11 and 12. The following null hypotheses are tested for each industry (unless otherwise indicated) in order to assess if temperature does not affect growth:

$$H_0(J > 0) : \rho_0 = 0 \quad (13)$$

It is important to highlight that the hypothesis 13 particularly will not be tested for each industry, but rather for the entire panel as a way to motivate the subsequent hypotheses.

This step is relevant because if the hypothesis is not rejected, it would mean that there is an absence of both level and growth effects in the entire manufacturing industry. The industry specific regressions with lags are tested in order to assess the actual effect and calculate the coefficient (γ) needed to complete the long run model. Following the conventions in the distributed-lag literature [Greene, 2008], both null hypotheses are stated:

$$H_0^i(J > 0) : \rho_0 = 0 \tag{14}$$

and the cumulated effect of temperature:

$$H_0^i(J > 0) : \sum_{j=0}^{L} \rho_j = 0 \tag{15}$$

Null hypotheses 14 and 15 are tested for both regressions but the most relevant result is the sum of the lagged coefficients because it constitutes the parameter of interest γ which summarizes the evidence of an effect of temperature on the growth of output per worker in the short run.

3.1.1 Non-linear Temperature Effects

Ergonomic studies state that the effect of temperature on productivity is non-linear because in high-temperature places the effect is higher. In order to prove this, it is useful to replace $T_{m,q}^{i}$ with the $T_{m,q}^{i,max}$, another variable available in the IDEAM dataset.

"If the economic response to temperature is non-linear in agreement with ergonomic studies, temperature changes during the hottest season should have a larger economic impact than temperature changes in other seasons." [Pilcher et al., 2002]

Another strategy is to include $(T_{m,q}^{i,max})^2$ and $(P_{m,q}^{i,max})^2$. If the coefficient of the squared temperature is not zero, it means that the effect is non-linear.

3.2 Results

In this subsection, the results for both level regressions (equation 11)[12] and growth regressions (equation 12)[13]) are reported and discussed (see tables 3, 4 and 5). The first part contains the results from the aggregate regressions. It is called aggregated because the regressions are run

[12] All variables in logarithms and therefore results in elasticities.

[13] All variables in original units. This variables were left in original units because the logarithm can only be taken when all values are positive.

for the entire sample with all industries. As an empirical strategy and given the size of the sample, the panel was divided by industry in order to obtain better estimators. The results by industry are reported afterwards. The results from these regressions by industry are the main findings of this paper, therefore the null hypotheses mentioned above are tested with this data and the parameter γ is calculated. The results of the empirical strategy designed to assess the non-linear effect hypothesis one at the end of this subsection (see tables 6 and **??**). The tables in the Tables and Figures section contain the complete results of the regressions. It is important to highlight that the null hypotheses 13 and 14 are directly tested with the resulting coefficients and the null hypothesis 15 is tested with an F-test.

3.2.1 Aggregate results for the entire manufacturing industry

The first hypothesis that will be tested states that temperature does not affect average output per worker, either through level effects or growth effects (equation 13) in the entire manufacturing industry. As it was mentioned before, this hypothesis is tested for the aggregate regressions. Table 3 registers the results that show that when the estimation is done at aggregate level, there is a negative statistically significant relationship between temperature fluctuations and the level of average output per worker (-0.308%/+1%), and negative but statistically insignificant relationship between temperature fluctuations and the level of average output per worker (-13.1%/+1°C). This means that the analysis has to be taken further in order to obtain a cleaner coefficient with less sources of endogenity.

The strategy designed to estimate this coefficients is to divide the sample by industry and to run the previous regressions keeping the municipality fixed effect and tendency. The null hypotheses are tested based on these results.

3.2.2 Results for each of the sub-sectors of the manufacturing industry

The second hypothesis that will be tested states that temperature does not affect average output per worker, either through level effects or growth effects (equation 14) in each of the sub-sectors of the manufacturing industry. For regressions 11 and 12, the results on tables 4 and 5 are analyzed.

Table 4 presents results from estimating regression 11. Each column of the table represents an industry with the ISIC as they appear in the data sources. In this case, twelve industries present statistically significant results, seven of them (16)(18)(19)(20)(22)(23)(29) at 99%, two of them (31)(36) at 95% and three of them at 90% . These are: *Manufac-*

ture of textiles(17); *Manufacture of apparel, preparation and dyeing of fur*(18); *Tanning and leather preparation, manufacture of footwear, manufacture of travel goods, suitcases, handbags and saddlery*(19); *Wood processing and manufacturing of wood products and cork, except furniture manufacture*(20); *Manufacture of paper, cardboard and paper products*(21); *Publishing, printing and reproduction*(22); *Manufacture of fabricated metal products, except machinery and equipment*(28); *Manufacture of machinery and equipment*(29); *Manufacture of electrical machinery and apparatus*(31); *Manufacture of furniture*(36) that present negative coefficients that can be interpreted as -1.04% change in average output per worker per +1% deviation from the mean temperature, -1.96%/+1%, -1.12%/+1%, -1.39%/+1%, -0.29%/+1%, -2.05%/+1%, -0.34%/+1%, -1.84%/+1%, -0.60%/+1% and -0.99%/+1%, respectively. *Manufacture of tobacco*(16) and *Manufacture of refined petroleum, nuclear fuel and coke*(23) present positive coefficients interpreted as +1.06%/+1% and +1.90%/+1% in quarterly average output of workers by an increase of 1% from the mean average temperature, respectively.

Industries (16)(18)(20)(22)(23)(28) presented statistically significant coefficients for current precipitation and temperature. The coefficients for precipitation in industry (18) for example can be interpreted as +0.09% change in average output per worker per +1% deviation from the mean precipitation. In all case presented above, the coefficient presented an opposite sign compared to temperature and a smaller magnitude.

Table 5 presents results from estimating regression 12. In this case eight industries present statistically significant results, three of them (18)(22)(23) at 99%, three of them (19)(29)(31) at 95% and the rest of them at 90%. These are: *Manufacture of apparel, preparation and dyeing of fur*(18); *Tanning and leather preparation, manufacture of footwear, manufacture of travel goods, suitcases, handbags and saddlery*(19); *Manufacture of paper, cardboard and paper products*(21); *Publishing, printing and reproduction*(22); *Manufacture of machinery and equipment*(29); and *Manufacture of electrical machinery and apparatus*(31) present negative coefficients that can be interpreted as -2.04%/+1%, -1.31%/+1%, -0.31%/+1%, -1.56%/+1%, -1.09%/+1%, -0.59%/+1%, in the growth rate of average output of workers by an increase of 1% from the mean average temperature, respectively. *Manufacture of refined petroleum, nuclear fuel and coke*(23) presents a positive coefficient interpreted as +1.87% in growth of average output per worker by an increase of 1% from the mean average temperature. *Manufacture of textiles*(17); *Wood processing and manufacturing of wood products and cork, except furniture manufacture*(20); *Manufacture of fabricated metal products, except machinery and equipment*(28) and *Manufacture of furniture*(36) present negative coefficient of -0.55%/+1%, -0.60%/+1%, -0.14%/+1% and -0.81%/+1% but in this regression they are not statistically significant.

In this regression, industries (18)(22)(29)(33) show statistically significant coefficients for both temperature and precipitation. The same effect is observed as in the previous regression: all have the opposite sign and smaller magnitude. In this case the coefficient for industry (18) for example can be interpreted as +0.101% in growth of average output per worker by an increase of 1% from the mean average precipitation.

It is interesting to see that for both regressions, the industries for which the effect is statistically significant are almost the same and the magnitude of the coefficients is very similar. This supports that for these industries, the thermal stress affects negatively the way workers perform. The industries that presented statistically significant results for temperature also presented for most cases statistically significant results for precipitation. An important result of this paper is the fact that these coefficients in all cases presented an opposite sign and smaller magnitude compared to temperature. This finding supports the hypothesis that climate alters the supply of labor altering the opportunity cost of working over leisure.

Manufacture of tobacco(16) and *Manufacture of refined petroleum, nuclear fuel and coke*(23) are special cases because they present a positive impact on growth and level effect. The results have opposite signs both in temperature and precipitation compared to all other industries. There are many reasons for this phenomena but most probably is that this industry needs to invest when temperature increases and by doing so the industry's workers perform better. In the case of (16), it is possible that since most of the production is done outdoors a high precipitation lowers the workers output. It is necessary to do a qualitative study for these two industries in order to explain the reasons for which ergonomics plays opposite or no role. Nevertheless, this qualitative study is outside of the scope of this paper.

Examining the null hypothesis 15 for regressions 11 and 12, the F-test is analyzed to assess joint significance. In this case, *Manufacture of tobacco*(16); *Manufacture of apparel; preparation and dyeing of fur*(18); *Wood processing and manufacturing of wood products and cork, except furniture manufacture*(20); *Publishing, printing and reproduction*(22); *Manufacture of other non-metallic mineral products*(26); *Manufacture of basic metals*(27); *Manufacture of machinery and equipment*(29); *Manufacture of electrical machinery and apparatus*(31) and *Manufacture of medical, precision and optical and watchmaking*(33) present joint significance which means that the null hypothesis is rejected for these industries and there is an effect on growth over time. The tables on the appendix show that these results are robust.

3.2.3 Non-linearity

Tables 6 and 7 present the results of the methodology developed to asses the non-linearity of the effect of temperature on average output per workers. The industry regressions are run to verify if both hot and cold deviations from the mean temperature have similar effects on average output per worker. The results present negative coefficients for the squared temperature and precipitation.

3.3 Robustness Checks

This section contains two alternative specifications as robustness checks.

3.3.1 Alternative Sample and Data Sources: Regression with Geo-referenced Temperature Data and CEDE Yearly Municipal Panel

This section contains the same empirical framework applied to a data set with different characteristics. Such data set is a panel constructed by the Center of Economic Development Studies (CEDE) for 1993 to 2010 in a yearly frequency. It contains data from the presidency, the National Planning Department and DANE.

Using this municipal level data for Colombia, this section shows the relationship between Geo coded climate variables (obtained from worldclim [Hijmans et al., 2005]) (mean temperature, mean precipitation levels and other climatic variables) and income. Since there is no data for income at a municipal level in Colombia, the independent variable is the proxy *tributary income of industry and commerce*. This makes sense since the taxes that firms have to pay are linearly related to the value added they produce. In turn, this variables are divided by the total workforce of the municipality to get the per-worker level and the logarithm is calculated in order to make the regression in levels.

The results of this subsection support the results previously shown. It can be seen in figure 5 the results that come out of this data are in line with the general methodology. Both linear and non-parametric estimations show a negative correlation between the tributary income of industry and commerce and the mean temperature.

The empirical framework explained above is also applied to this data set and the results are available in table 8. As in the other results, there is a negative statistically significant coefficient of mean temperature.

3.3.2 Alternative Calculation of the Dependent Variable

This section contains an alternative calculation of the dependent variable. In this case the, the AK model is not used, instead the starting point is the Cobb- Douglas functions. To isolate the output of workers from the whole production, this first stage is estimated.

$$Y_{i,t} = \beta_1 K_{i,t} + \beta_2 L_{i,t} + \epsilon_{i,t} \tag{16}$$

$$\widehat{prodl_{i,t}} = \widehat{\beta}_2 L_{i,t} \tag{17}$$

$prodl$ is the output per worker ($(1-\alpha)Y$ in the Cobb-Douglas case) which is the dependent variable. The same regression was run as in the previous subsection in order to obtain the following results.

Table 9 illustrates the main results of the methodology. Since the regressions are run by industry, each line represents one industry. The first column has the CIIU code, the second has the coefficient of the lagged dependent variable, the third the coefficient of the squared tendency and the last two have the coefficients of interest. The last column contains the results of a separate regression run with the logarithm of every variable. Table 9 contains the results that are statistically significant. For all other industries the results were not statistically significant.

Table 9 shows statistical evidence of a negative correlation between temperature and output per worker. It has the same structure as all previous tables except that the ISIC code has 3 digits. For example, the coefficient for industry Manufacture of coffee products(156) can be interpreted as follows: for a 1°C increase in temperature, the aggregate output done by labor decreases -0.186%. All other lines can be interpreted in the same way. The same intuition can be applied to all the other lines.

This results are a robustness check because with a completely different specification and yearly data, the resulting coefficients are similar.

Conclusions

This study uncovered evidence that fails to reject the hypothesis that the average output per worker is in fact a channel through which climate and climate change affect economic performance. The results presented in this paper are robust evidence that the thermal stress affects negatively the way workers perform for the industries in which the level was statistically significant. The study is relevant in the economic growth theory complementing the theory of Hall and Jones by saying that social infrastructure should have a healthy environment as one of its components, in this case through sustained moderate temperatures. Calculating the short run effect of temperature on growth within the country is a key component of the long-run model that was previously unknown. These results suggest that the industries that receive the largest impact are closely related to the agricultural sector. In the long-run, climate change appears to affect the average temperature affecting output per worker by transitivity.

In terms of public policy, the study presents empirical evidence of an alternative channel through which climate change will impact sectors of the Manufacturing Industry presenting Ergonomics as new area of interest for the Low Carbon Development Strategy and the National Adaptation Plan. The quantification of this impact constitutes an incentive for the industry to mitigate carbon emissions in order to maximize the benefits in the long-run. Finally, these results could help environmental agencies and researchers to calculate more accurately the costs of climate change in the long-run. They could also provide valuable inputs in the international and sectoral negotiations.

There is a lot of future research to be done in the country. The methodology could be used with more disaggregated data in order to get more accurate and robust results. Probably, since the unit of analysis is a whole industry, some detailed effects are overlooked. The same methodology will surely be more useful with industrial establishments as the unit of analysis. Further work could also be done to analyze the effect of precipitation that are in fact more robust and statistically significant. It would be interesting to repeat this exercise with municipal quarterly data directly taken from the MMS instead making the assumption in order to merge the AMS with the MMS. About the climatic variables it would be helpful to have temperature for the working hours only.

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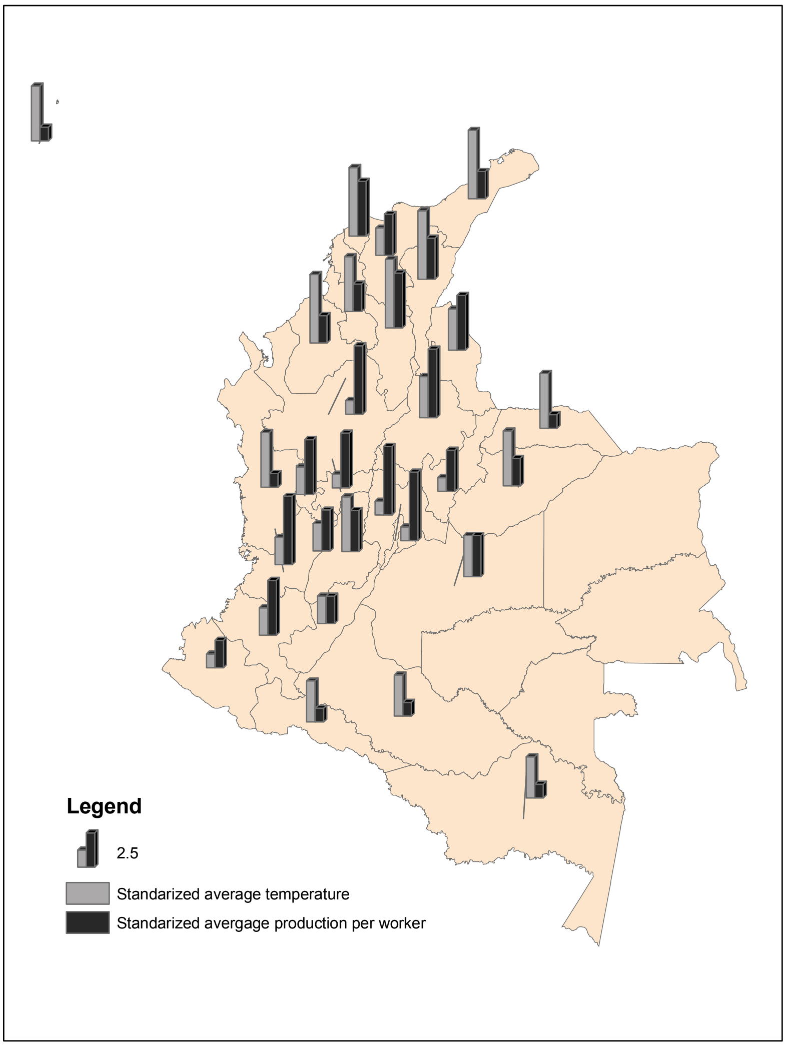
Tables and Figures

Figure 1: Temperature- average production per worker Correlation in Colombia



Source: [DANE, 2004] and [IDEAM, 2011]. The shape to construct the map was provided by Agustin Codazzi.

Table 1: Summary Statistics

Variable	Obs	Mean	Std.Dev.	Min	Max
AverageTemperature (°C)	8118	21.62889	5.520813	4.166667	30.96667
AveragePrecipitation(mm)	10615	116.8755	103.5165	0	4127.852
prodl (thousand pesos 2001)	10704	19745.63	80783.64	3.05256	2600207
gprodl (%)	10002	0.0250183	0.1282123	-0.7529805	1.10747

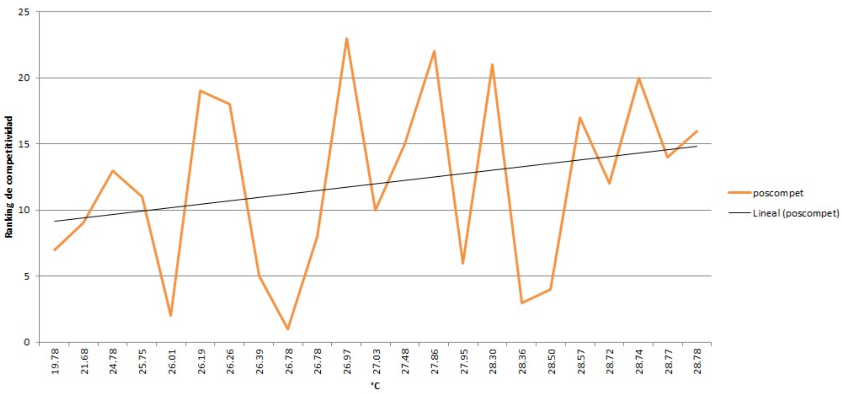
Note: [DANE, 2011] and [IDEAM, 2011]. Unit of observations are industries in a municipality for a given quarter.

Table 2: Summary Statistics by temperature group

	Variable	Obs	Mean	Std. Dev.	Min	Max
$°C < 10.8$	iproduc(points)	84	0.1387284	0.103475	0.0270228	0.405625
	AverageTemperature (°C)	84	4.733333	0.2512219	4.166667	5.133333
	AveragePrecipitation(mm)	84	128.6725	44.29936	54	192.4
	gprodl(%)	77	0.0249912	0.156031	-0.6264041	0.4705379
$10.81 < °C < 18.28$	iproduc(points)	2392	2.332122	3.691641	0.0255457	21.31835
	AverageTemperature (°C)	2392	14.74653	1.875168	10.83333	18.275
	AveragePrecipitation(mm)	2354	92.13116	56.14431	17.24	390.7889
	gprodl(%)	2216	0.0391831	0.4281082	-0.8768122	18.48296
$18.29 < °C < 26.62$	iproduc(points)	3727	1.080892	1.570901	0.0255457	18.8375
	AverageTemperature (°C)	3727	23.14661	1.895901	18.3	26.61111
	AveragePrecipitation(mm)	3713	144.9383	117.2325	0	3006.895
	gprodl(%)	3443	0.0355847	0.1891311	-0.9181016	4.717442
$26.63 < °C < 32.17$	iproduc(points)	1915	0.7119046	0.7482701	0.0255457	4.709375
	AverageTemperature (°C)	1915	28.03133	0.7441994	26.63333	30.96667
	AveragePrecipitation(mm)	1915	110.4198	101.8868	0	990.8333
	gprodl(%)	1838	0.0339258	0.1916559	-0.6404005	3.376283
$32.18 < °C$	iproduc(points)	2586	2.18944	3.6297	0.0255457	21.31835
	AverageTemperature (°C)	0				
	AveragePrecipitation(mm)	2549	102.366	75.55988	0	722.3333
	gprodl(%)	2428	0.035809	0.2360545	-0.6987606	7.908968

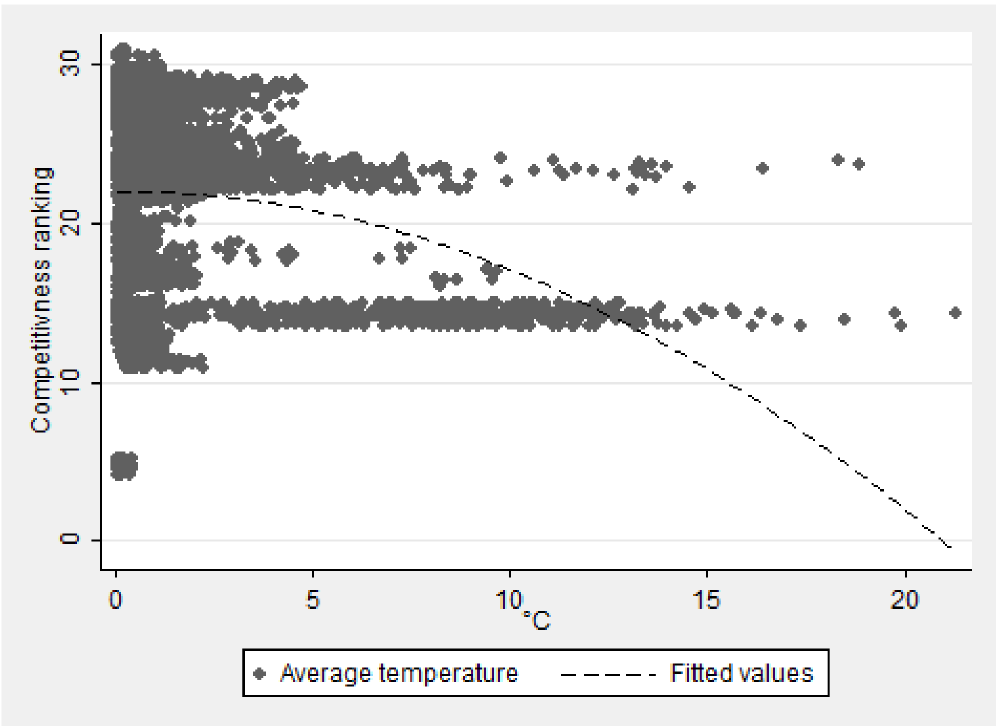
Note: [DANE, 2011] and [IDEAM, 2011].

Figure 2: Temperature- Competitiveness ranking



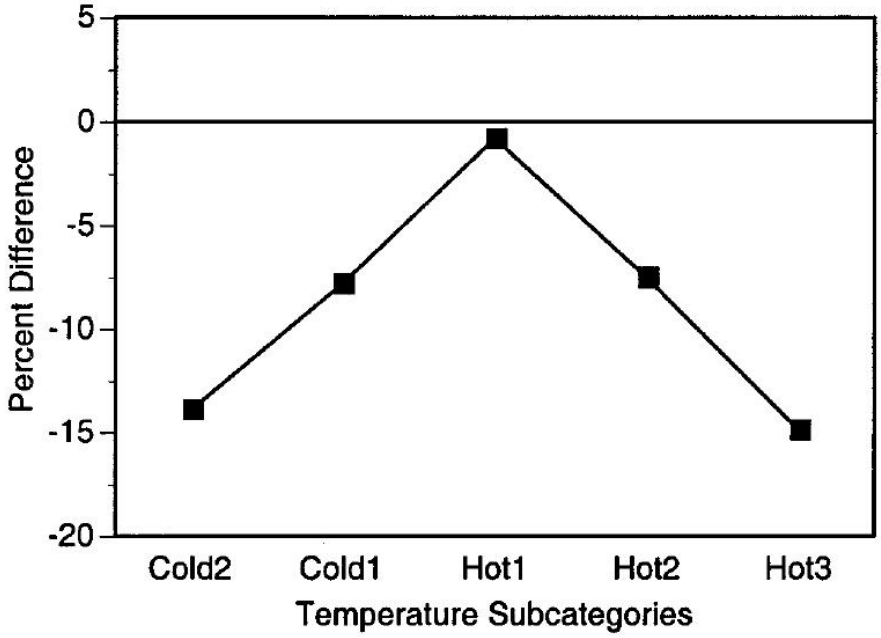
Source: [Sánchez and Acosta, 2001] and [IDEAM, 2011]. Note: The peaks represent the departments for which the productivity is lower than average. The departments with the lowest competitiveness ranking are Chóco, Córdoba and Sucre.

Figure 3: Negative relationship between production and average temperature



Source: [DANE, 2004] and [IDEAM, 2011].

Figure 4: The mean percent difference in performance between the neutral temperature group and five temperature subcategories [Pilcher et al., 2002]



Source: [Pilcher et al., 2002]. $Cold2 :< 10.8°C; Cold1 : 10.81 - 18.28°C; Hot1 : 18.29 - 26.62°C; Hot2 : 26.63 - 32.17°C); Hot3 :> 32.18°C$

Table 3: Aggregate results for the entire manufacturing industry

	(Level($\Delta/+1\%$))	(Growth($\Delta\%/+1°C$))
AverageTemperature$_q$	-0.308***	-0.131
	(0.103)	(0.116)
AveragePrecipitation$_q$	0.016***	0.011*
	(0.004)	(0.006)
AvergaeTemperature$_{q-1}$	0.249**	0.234**
	(0.097)	(0.097)
AveragePrecipitation$_{q-1}$	-0.004	-0.007***
	(0.003)	(0.002)
TemperatureVariance	-0.001	0.002
	(0.005)	(0.007)
F-test	0.69	0.39
R^2	0.46	0.00
Observations	5,338	7,153
Municipality fixed effect	Yes	Yes
Lagged dependent variable	4	No

Note: [DANE, 2011] and [IDEAM, 2011]. Beta coefficients presented for an increase in temperature and precipitation. Unit of observations are industries in a municipality for a given quarter. Robust standard errors presented in brackets. Durbin's h-test was performed to check for serial correlation. The fourth lag is no longer statistically significant hence no further lag is included. *** p<0.01, ** p<0.05, * p<0.1.

Table 4: Main Panel Results- levels ($\Delta / +1\%$)

	(15)	(16)	(17)	(18)	(19)	(20)	(21)	(22)	(23)	(24)	(25)	(26)	(27)	(28)	(29)	(31)	(33)	(35)	(36)
AverageTemperature$_q$	0.254	1.060***	-1.040*	-1.961***	-1.120***	-1.390***	-0.293*	-2.045***	1.895***	0.197	0.487	0.280	0.191	-0.337*	-1.842***	-0.602**	0.132	-0.056	-0.985**
	(0.173)	(0.396)	(0.625)	(0.419)	(0.420)	(0.404)	(0.166)	(0.339)	(0.584)	(0.150)	(0.297)	(0.215)	(0.234)	(0.189)	(0.410)	(0.291)	(0.658)	(0.331)	(0.397)
AverageTemperature$_{q-1}$	0.206	1.443***	0.302	1.341***	0.975**	0.210	0.207	0.185	0.298	-0.121	-0.045	-0.082	0.029	0.078	0.667	0.357	-0.136	0.055	0.906
	(0.192)	(0.532)	(0.240)	(0.515)	(0.392)	(0.303)	(0.193)	(0.415)	(1.133)	(0.131)	(0.635)	(0.199)	(0.211)	(0.200)	(0.530)	(0.348)	(0.192)	(0.508)	(0.563)
AveragePrecipitation$_q$	0.005	-0.037***	0.017	0.099***	-0.005	0.046***	0.009	0.057***	-0.035**	0.023***	-0.019	0.034***	0.019**	0.020**	0.029	-0.006	0.024***	0.066***	0.012
	(0.005)	(0.006)	(0.013)	(0.022)	(0.022)	(0.010)	(0.007)	(0.015)	(0.014)	(0.006)	(0.014)	(0.011)	(0.008)	(0.009)	(0.021)	(0.028)	(0.004)	(0.016)	(0.018)
AveragePrecipitation$_{q-1}$	0.000	-0.029***	0.010	-0.018	-0.043***	0.031**	-0.000	-0.048***	-0.034***	-0.003	0.001	0.011*	0.003	0.012	-0.050***	-0.007	-0.004	0.033**	-0.014
	(0.003)	(0.007)	(0.011)	(0.015)	(0.009)	(0.013)	(0.003)	(0.015)	(0.008)	(0.007)	(0.014)	(0.006)	(0.005)	(0.008)	(0.009)	(0.020)	(0.003)	(0.014)	(0.009)
F-test	0.16	0.01	0.25	0.15	0.66	0.00	0.54	0.00	0.12	0.59	0.55	0.51	0.16	0.42	0.04	0.06	1.00	1.00	0.85
R^2	0.49	0.49	0.49	0.49	0.49	0.49	0.49	0.49	0.49	0.49	0.49	0.49	0.49	0.49	0.49	0.49	0.49	0.49	0.49
Observations	5,338	5,338	5,338	5,338	5,338	5,338	5,338	5,338	5,338	5,338	5,338	5,338	5,338	5,338	5,338	5,338	5,338	5,338	5,338
Fixed effect	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Lagged dependent variable	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4

Note: [DANE, 2011] and [IDEAM, 2011]. Beta coefficients presented for an increase in temperature and precipitation. Variables are in logarithms, therefore results are elasticities. Unit of observations are industries in a municipality for a given quarter. Robust standard errors presented in brackets. Durbin's h-test was performed to check for serial correlation. The fourth lag is no longer statistically significant hence no further lag is included. *** $p<0.01$, ** $p<0.05$, * $p<0.1$.

Table 5: Main Panel Results- growth ($\Delta / + 1\%$)

	(15)	(16)	(17)	(18)	(19)	(20)	(21)	(22)	(23)	(24)	(25)	(26)	(27)	(28)	(29)	(31)	(33)	(35)	(36)
$\text{AverageTemperature}_q$	0.351	0.401	-0.551	-2.044***	-1.317**	-0.595	-0.305*	-1.558***	1.871***	0.213	0.517	0.338	0.199	-0.135	-1.090**	-0.586**	0.169*	0.199	-0.805
	(0.232)	(0.596)	(0.389)	(0.530)	(0.581)	(0.395)	(0.182)	(0.355)	(0.660)	(0.234)	(0.363)	(0.218)	(0.161)	(0.177)	(0.507)	(0.259)	(0.096)	(0.339)	(0.568)
$\text{AverageTemperature}_{q-1}$	-0.010	0.720	0.510*	1.438**	1.015*	0.683*	0.162	0.774*	1.597	-0.367**	-0.710	-0.175	0.272**	0.004	0.931***	0.509**	0.149	-0.137	1.092
	(0.148)	(0.627)	(0.278)	(0.600)	(0.589)	(0.393)	(0.236)	(0.446)	(1.806)	(0.184)	(0.935)	(0.167)	(0.135)	(0.166)	(0.309)	(0.236)	(0.135)	(0.356)	(0.871)
$\text{AveragePrecipitation}_q$	-0.002	-0.045***	0.016	0.101***	0.023	0.040***	0.014	0.070***	0.001	0.030***	-0.031	0.034**	0.001	0.012	0.042*	0.032	0.018***	0.036*	-0.083
	(0.007)	(0.010)	(0.018)	(0.021)	(0.018)	(0.010)	(0.009)	(0.017)	(0.011)	(0.005)	(0.022)	(0.015)	(0.006)	(0.012)	(0.022)	(0.028)	(0.005)	(0.019)	(0.089)
$\text{AveragePrecipitation}_{q-1}$	0.001	-0.026***	-0.000	-0.042**	-0.016	0.019	0.002	-0.051***	-0.025	-0.003	0.017	0.010	-0.004	0.008	-0.052***	0.002	-0.007***	0.014	-0.033**
	(0.003)	(0.007)	(0.007)	(0.017)	(0.014)	(0.013)	(0.005)	(0.010)	(0.022)	(0.005)	(0.011)	(0.006)	(0.005)	(0.007)	(0.013)	(0.019)	(0.001)	(0.011)	(0.016)
F-test	0.28	0.34	0.80	0.09	0.21	0.67	0.18	0.15	0.11	0.40	0.82	0.36	0.00	0.56	0.73	0.32	0.00	0.82	0.63
R^2	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02
Observations	6,829	6,829	6,829	6,829	6,829	6,829	6,829	6,829	6,829	6,829	6,829	6,829	6,829	6,829	6,829	6,829	6,829	6,829	6,829
Fixed effect	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Lagged dependent variable	No	No	No	No	No	No	No	No	No	No	No	No	No	No	No	No	No	No	No

Note: [DANE, 2011] and [IDEAM, 2011]. Beta coefficients presented for an increase in temperature and precipitation. Variables are in original units. Unit of observations are industries in a municipality for a given quarter. Robust standard errors presented in brackets. *** p<0.01, ** p<0.05, * p<0.1.

Table 6: Non-linear effects- Maximum Temperature ($\Delta / +1\%$)

	(15)	(16)	(17)	(18)	(19)	(20)	(21)	(22)	(23)	(24)	(25)	(26)	(27)	(28)	(29)	(31)	(33)	(35)	(36)
$\text{MaximumTemperature}_q$	0.100	-0.840*	-0.301**	-1.206***	-0.221	-1.021***	0.317	-0.738***	1.116*	-0.199***	-0.164	0.104	-0.173	-0.241***	-0.891*	-0.397***	0.209	-0.254	-0.383
	(0.074)	(0.304)	(0.129)	(0.140)	(0.423)	(0.232)	(0.178)	(0.199)	(0.434)	(0.066)	(0.305)	(0.107)	(0.196)	(0.071)	(0.462)	(0.059)	(0.280)	(0.173)	(0.226)
$\text{MaximumTemperature}_{q-1}$	0.098	0.014	0.079	0.621***	0.252	0.614***	-0.133	0.435***	0.813	0.079	-0.632	-0.138	0.248**	-0.023	1.224***	0.194***	0.209	0.143	0.180
	(0.059)	(0.272)	(0.123)	(0.169)	(0.299)	(0.166)	(0.078)	(0.120)	(1.068)	(0.142)	(0.432)	(0.085)	(0.091)	(0.138)	(0.279)	(0.056)	(0.243)	(0.159)	(0.188)
R^2	0.65	0.67	0.55	0.71	0.61	0.69	0.57	0.45	0.51	0.71	0.72	0.61	0.77	0.62	0.51	0.47	0.88	0.77	0.58
Observations	2,276	47	240	255	242	310	169	294	54	345	344	444	153	296	235	116	39	223	364
Fixed effect	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Lagged dependent variable	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4

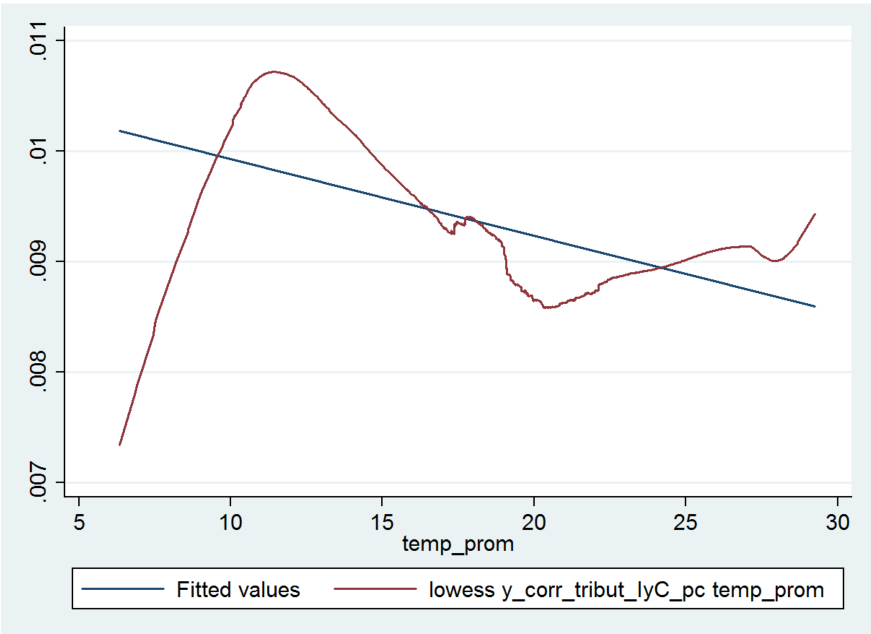
Note: [DANE, 2011] and [IDEAM, 2011]. Beta coefficients presented for an increase in the maximum temperature and precipitation. The mean temperature is replaced by the maximum temperature. Unit of observations are industries in a municipality for a given quarter. Robust standard errors presented in brackets. *** p<0.01, ** p<0.05, * p<0.1.

Table 7: Non-linear effects- Temperature squared ($\Delta\%/+1°C$)

	($°C < 10.8$)	($10.81 < °C < 18.28$)	($18.29 < °C < 26.62$)	($26.63 < °C$)
AverageTemperature^2	-0.086	-0.001	-0.000	-0.012**
	(0.856)	(0.001)	(0.001)	(0.005)
AveragePrecipitation^2	0.000	-0.000**	-0.000***	-0.000***
	(0.000)	(0.000)	(0.000)	(0.000)
R^2	0.98	0.99	0.99	0.99
Observations	77	2,179	3,430	1,838

Note: [DANE, 2011] and [IDEAM, 2011]. Beta coefficients presented for the non-linear effect of temperature and precipitation on output per worker. The linear temperature and precipitation are also included. Unit of observations are industries in a municipality for a given quarter. Robust standard errors presented in brackets. Durbin's h-test was performed to check for serial correlation. The fourth lag is no longer statistically significant hence no further lag is included. *** p<0.01, ** p<0.05, * p<0.1.

Figure 5: Linear and non-parametric estimations- $temp_p rom$



Source: [CEDE, 2010] and [Hijmans et al., 2005]

Table 8: Robustness check 1 ($\Delta\%/+1°C$)

	(FE)
Average temperature	-0.039**
	(0.020)
Average Precipitation	0.000
	(0.000)
R^2	0.68
Observations	4,618
Municipality fixed effect	Yes
Lagged dependent variable	Yes

Source: [CEDE, 2010] and [Hijmans et al., 2005]

Table 9: Robustness check 2 (thousand pesos/+1°C)

	(152)	(156)	(157)	(192)	(252)	(291)
$\text{AverageTemperature}_q$	-0.141	-0.186*	0.251	-0.012*	-0.101	-0.042
	(0.087)	(0.103)	(1.796)	(0.006)	(0.072)	(0.168)
$\text{AveragePrecipitation}_q$	-0.001	-0.002***	-0.006	0.000*	0.000	0.002
	(0.001)	(0.001)	(0.015)	(0.000)	(0.000)	(0.001)
R^2	0.16	0.42	0.09	0.36	0.26	0.28
Observations	48.00	52.00	12.00	33.00	45.00	32.00

Notes: [DANE, 2004] and [CIAT, 2005]. The standard errors are calculated with 250 bootstrap replications. Processing of fruits, vegetables, oils and fats (152), Manufacture of coffee products (156), Mills, sugar refineries and sugar mills (157), Shoemaking (192), Manufacture of plastic products (252), Manufacture of general purpose machinery (291)

Table 10: ISIC

ISIC	Industry
15	Manufacture of food products and beverages
16	Manufacture of tobacco
17	Manufacture of textiles
18	Manufacture of apparel; preparation and dyeing of fur
19	Tanning and leather preparation, manufacture of footwear, manufacture of travel goods, suitcases, handbags and saddlery
20	Wood processing and manufacturing of wood products and cork, except furniture manufacture
21	Manufacture of paper, cardboard and paper products
22	Publishing, printing and reproduction
23	Manufacture of refined petroleum, nuclear fuel and coke
24	Manufacture of chemicals and chemical products
25	Manufacture of rubber and plastic
26	Manufacture of other non-metallic mineral products
27	Manufacture of basic metals
28	Manufacture of fabricated metal products, except machinery and equipment
29	Manufacture of machinery and equipment
30	Manufacture of office, accounting and computing
31	Manufacture of electrical machinery and apparatus
32	Manufacturing equipment and radios, television and communication
33	Manufacture of medical, precision and optical and watchmaking
34	Manufacture of motor vehicles, trailers and semitrailers
35	Manufacture of other transport equipment
36	Manufacture of furniture

Source: [DANE, 2004]. This classification corresponds to the literal translation of CIIU 3 A.C.