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Temperature and Production Efficiency Growth: Empirical Evidence

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Abstract: This paper examines the marginal effects of temperature on the growth rate and variability in growth rate of Total Factor Productivity (TFP) of a country, as measured by its production efficiency relative to a stochastic frontier. Using panel data for 168 countries for the period 1950-2014 to estimate a one-step stochastic frontier function, we find that temperature has a concave relationship with the growth rate of production efficiency and with the variability in this growth rate. We observe that hotter than the average temperature is not only detrimental to production efficiency growth but also makes the growth less stable than otherwise and these effects are larger in very hot countries with average annual temperature greater than 25 ^{o}C. More importantly, we observe that the detrimental marginal effects of higher temperature depend on the level of economic development of a country; they are larger for poor countries relative to rich countries. Our findings have implications for the specification of climate damage functions in integrated assessment models and estimates of country-specific social cost of carbon.

Key Words: Temperature, Production efficiency growth, Stochastic frontier analysis (SFA), Non-linear effects

JEL Classification: E23, O13, Q54, Q56

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1. Introduction

Growing concerns about the impacts of climate change have led to a large literature examining micro-economic and macro-economic effects of rising temperature. This literature has focused on the effects of temperature on agricultural sector (e.g., Mendelsohn et al., 1994; Deschenes and Greenstone, 2007), on labor productivity (e.g., Graff-Zivin and Neidell, 2014) and on other dimensions of economic activities such as mortality and morbidity (e.g., Barreca, 2012; Miljkovic et al., 2018), energy consumption (e.g., Forrest, 2018; Pérez-Lombard et al., 2008; Mansur et al., 2008), manufacturing and trade (e.g., Yunfeng and Laike, 2010; Wenz and Levermann, 2016; Willner et al., 2018), and conflict (e.g., Hsiang et al., 2013).[1] Focusing only on a single sector or single factor of production can provide biased estimates of the effect of temperature increase on economic activities (Zhang et al., 2018).

Other studies have examined the relationship between temperature and macro-economic indicators of economic activity using reduced form statistical methods (e.g., Dell et al., 2012; Heal and Park, 2013; Burke et al., (BHM) 2015; Pretis et al., 2018). Dell et al. (2012) observe linear effects of increases in temperature on economic growth in developing countries only. However, Pretis et al. (2018), Burke et al (2015) and Heal and Park (2013) find that hotter than average years are associated with a decline in per capita income in hot climatic zones but higher per capita income in cold regions, irrespective of the level of development in a country.

A relatively overlooked impact of climate change is on growth in total factor productivity (TFP). TFP is defined as a ratio of aggregate output to aggregate input (Syverson, 2011, p.329). It is preferable to partial productivity measures, such as labor productivity, as it incorporates all outputs and inputs in a single measure (Ortiz-Bobea et al., 2018). TFP can also be interpreted as a measure of the efficiency of a productive process since it shows how productively physical inputs are being utilized. Growth rate of TFP accounts for an economy's ability to increase output without a corresponding increase in the physical input base. It differs across countries and it is an important determinant of economic growth in a country. Since production is uncertain, TFP growth rates can also vary around an average value.

Climate change can affect the growth rate of TFP and variability in this growth rate in various ways: by reducing ecosystem services critical for economic growth, leading to diversion of resources away from research and development (R&D) activities towards climate change mitigation and adaptation and reconstruction of capital as well as by reducing the productivity of factors such as agricultural land and labor (Moyer et al., 2014). In estimating the social cost of carbon, some integrated assessment models (IAMs) such as the Dynamic Integrated Climate-Economy (DICE) model assume that TFP is determined exogenously and climate change reduces aggregate output directly (Tisgaris and Wood, 2016). Several scholars have modified this assumption in IAMs and allowed for the possibility that climate change may reduce TFP growth and thereby alter long term growth instead of affecting output directly. These studies show that the social cost of carbon is very sensitive to the effects of climate change on productivity (Moore and Diaz, 2015; Dietz and Stern, 2015; Moyer et al., 2014). For example, Dietz and Stern (2015) show that consumption per capita will reduce by 11.4 - 15 times in 2205 relative to 2005 if annual global TFP growth

[1]For comprehensive review on the impact of climate change on various economic activities, see Dell et al. (2014) and Carleton and Hsiang (2016)

declines by about 0.20 percentage points. These studies assume that the effect of climate change on TFP is the same across countries which is unlikely to be a correct assumption. A key contribution of this study is to examine the variations in the effect of climate change on TFP across countries, due to differences in the climatic zone in which a country is located and its level of economic development; these can influence the country's capacity for mitigation and adaptation and thus the effects of climate change on productivity. An accurate assessment of the effect of climate variables on TFP and its variation across countries is critical to obtain a valid estimate of the global social cost of carbon.

However, there is relatively limited empirical evidence of the effect of climate change on TFP and how this effect differs across countries. A few studies have estimated the effect for a single country or for a small subset of countries. For example, Ortiz-Bobea et al. (2018) examine the effect of climate variables on agricultural TFP in the US. Zhang et al. (2018) estimate the effect of temperature on TFP of Chinese manufacturing firms. Letta and Tol (2018) examine the relationship between TFP growth and change in temperature shocks using a panel dataset of 60 countries over the period of 1960 to 2006. While Ortiz-Bobea et al. (2018) measure agricultural TFP as a ratio of aggregate agricultural output to aggregate agricultural input, the other two studies measure TFP by Solow residual. These studies have used a two-step approach that involves measuring TFP in the first stage followed by regressing TFP on temperature in the second stage. Moreover, these studies do not consider the effect of temperature on variability in TFP growth. Some studies find that increases in climate variability generally decreases mean crop yields, and increases crop yield variance (e.g., Urban et al., 2012). A two-step approach has been known to lead to biased estimates if the model estimated at the first step for estimating TFP is mis-specified (Wang and Schmidt, 2002). The mis-specification could arise due to correlation between factor inputs and determinants of TFP and lead to biased estimates of the impact of climate change on production efficiency.

In this study we measure TFP of a country by its productive efficiency in converting physical inputs into GDP. Productive efficiency is determined relative to a stochastic frontier and we examine the extent to which climate variables affect a country's ability to grow its productive efficiency or TFP. We use the terms production efficiency growth and TFP growth synonymously and interchangeably throughout the paper. A key contribution of this paper is to analyze the effects of temperature on growth and stability of production efficiency using a one-step stochastic frontier production function approach. We specifically seek to examine whether level of economic development of a country mitigates the effects of climate factors on growth and variability of productive efficiency and the extent of non-linearity in these effects.

Earlier studies have modeled the non-linearity of temperature impacts on economic activities by either adding its quadratic term as an explanatory variable (e.g., Burke et al., 2015) or arbitrarily discretizing the annual distribution of daily temperature in a fixed set of temperature bins (e.g., Zhang et al., 2018).[2] In the present study, we flexibly parameterize both the mean and variance of the one-sided error term (efficiency growth) and the manner in which it is influenced by temperature and precipitation in the stochastic frontier of output growth; within this framework nonlinearity arises as a result rather than an assumption. The

[2]By a non-linear effect, we mean that temperature can have both positive and negative effects on efficiency growth and its variability, within a sample depending on the values of temperature.

mean measures the expected level of growth in production efficiency; whereas variance measures uncertainty in growth of production efficiency (Bera and Sharma, 1999).

We use a panel dataset for 168 countries that differ in their level of economic development and temperature zones in which they are located. The data covers the period 1950-2014.We find that annual temperature variations have non-trivial effects on the expected mean of production efficiency growth, but the direction and magnitude of these effects are related to the location of a country relative to the optimal climate zone. We find that the optimal temperature zone lies somewhere between 12 to 15 degree Celsius (^{o}C). This finding corroborates with Burke et al. (2015).[3] That is, non-linear marginal effects of temperature increase on production efficiency growth at the macro level are consistent with the temperature-performance relationship observed at the micro levels.[4]

We also find that inter-annual variability in temperature affects both, expected mean and variance of production efficiency growth. In countries located in cold regions (average annual temperature less than 15 ^{o}C) an increase in temperature not only increases efficiency growth but makes it more stable than before or the marginal effects are negligible, but in hot countries (average annual temperature greater than 20 ^{o}C) further increase in temperature not only decreases efficiency growth but also renders it less stable than otherwise. This finding reflects the importance of climate driven changes in the 'fatness' of production efficiency distribution tails.[5] The results provide empirical foundation for the parameters of the damage function in the IAMs for assessing possible responses of climate policies.

The results also reveal that higher levels of income moderate the marginal impact of temperature increase on both the mean and variance of efficiency growth; the impacts are more detrimental in poor countries in comparison to rich countries even though they are located in the same temperature zone. However, countries that are located in very hot climate zone (average annual temperature greater than 25 ^{o}C) observe high marginal impacts irrespective of the level of per capita income.

The rest of the paper is organized as follows: Section 2 outlines the conceptual background. Section 3 presents the data and descriptive statistics. The empirical strategy is described in Section 4 and the results are presented in Section 5. Section 6 sums up and concludes the paper.

2. Conceptual Background

We specify a stochastic production frontier with maximal output as a function of factor inputs and a random (normal) error. Actual output, therefore, equals maximal output minus a one-sided error term, which represents a measure of production inefficiency. Econometric

[3]Burke et al (2015) find that productivity peaks at 13^{o} Celsius and declines at higher temperatures. Therefore, the fall-off in productivity concerning hotter and colder limits implies an optimal temperature zone for economic activities.

[4] In the microeconomic literature a single peaked relationship between productivity and temperature has been observed (e.g, Graff-Zivin and Neidell, 2014; Schlenker and Roberts, 2009).

[5]Our application captures climate-driven changes in the 'fatness' of efficiency growth distribution tails, the importance of which was stressed in Nordhaus (2011), Pindyck (2011), and Weitzman (2011).

methods for estimation of stochastic production frontier are well developed in the literature.[6] We incorporate the impact of temperature on efficiency growth in a standard Solow growth model with a Cobb-Douglas production function

$$Y_{it} = A_{it}K_{it}^{\alpha}L_{it}^{\beta}; \quad 0 < A_{it} \leq 1 \qquad (1)$$

where Y is aggregate output, A is Hicks-neutral TFP, K and L are capital and labor inputs, respectively, α and $\beta$are output elasticities of capital and labor, respectively and subscripts *i* and *t* stand for country and year, respectively.

To estimate the effect of temperature change on production efficiency, we specify a stochastic production frontier as follows. Equation (2) shows that output can deviate from maximum possible level due to random shocks (v_{it}) and/or because of production efficiency differentials, [$u_{it} = ln(A_{it})$].

$$ln\, ln\,(Y_{it}) = \alpha ln(K_{it}) + \beta ln(L_{it}) + v_{it} - u_{it} \qquad (2)$$
$$v_{it} \sim N(0, \sigma_v^2)$$
$$u_{it} \sim N^+(\mu_{it}, \sigma_u^2)$$

where random terms v_{it} and u_{it} are assumed to be independently and identically normally (N) distributed with mean 0 and variance σ_v^2 and truncated normally (N^+) distributed with mean μ_{it} and variance σ_u^2; and v_{it} and u_{it} are distributed independently of each other, and of the regressors.

By converting equation (2) into first differences, we can express growth in output as follows:

$$ln(Y_{it}) - ln(Y_{it-1}) = \alpha[ln(K_{it}) - ln(K_{it-1})] + \beta[ln(L_{it}) - ln(L_{it-1})] + [v_{it} - v_{it-1}] - [u_{it} - u_{it-1}]$$

or

$$\Delta ln(Y_{it}) = \alpha \Delta ln(K_{it}) + \beta \Delta ln(L_{it}) + \Delta v_{it} - \Delta u_{it} \qquad (3)$$
$$\Delta v_{it} \sim N(0, \sigma_{\Delta v}^2)$$
$$\Delta u_{it} \sim N^+\left(\Delta\mu_{it}, \sigma_{\Delta u_{it}}^2\right)$$

where $\Delta ln(Y_{it})$ is growth in output, $\Delta ln(K_{it})$and $\Delta ln(L_{it})$ are growth in capital and labor inputs respectively, and Δu_{it} is production inefficiency change. Estimates of production efficiency change are obtained as $exp(-\Delta u_{it})$.

One way to account for the effects of climatic factors on production efficiency is to first obtain estimates of production efficiency change without accounting for these exogenous factors and then regress the estimates on a set of climatic factors. Wang and Schmidt (2002) demonstrate that estimates obtained using this 'two-step' approach are severely biased, and make a case for including all exogenous variables in the first step itself as determinants of production inefficiency. Therefore, we use a 'one-step' approach for estimating the stochastic production frontier. More specifically, mean and variation of change in the one-sided error term are parameterised as:

[6] A number of seminal papers starting with Aigner et al. (1977) and Meeusen and van den Broeck (1977) have contributed in this area.

$$\Delta\mu_{it} = \delta_0 + z_{it}\delta \tag{4}$$
$$\sigma^2_{\Delta u_{it}} = exp\ exp\left(\gamma_0 + z_{it}\gamma\right) \tag{5}$$

where δ_0 and γ_0 are intercept terms and $\boldsymbol{z_{it}}$ is a vector of exogenous climatic factors such as temperature and precipitation. We note that both mean and variance of inefficiency are parameterized by the same variables but allowed to differ in intercept and slope. Thus, though the climatic variables affect both the mean and variance of production inefficiency, the effects are not necessarily the same and could even have opposite signs.

We estimate equations (3) to (5) using a one-step using maximum likelihood estimator. This 'one-step' approach avoids the problem of the functional form affecting the determinants of production efficiency. Marginal effects of climatic factors on production inefficiency are obtained by taking expectations conditional on production inputs and climatic factors and then differentiating with respect to climatic variables (as in Wang 2002, 2003).[7] By parameterizing both the mean and variance of one-sided error term we accommodate non-linear production efficiency effect of exogenous variables such as temperature. If only the mean of inefficiency term is parameterized then $\gamma[k] = 0$, implying monotonic effects of climatic variables on production efficiency and production uncertainty. Parameterization of both the mean and variance of inefficiency term implies that marginal effects depend on both $\delta[k]$and $\gamma[k]$ which may differ both in sign and magnitude and lead to non-monotonic marginal effects. Marginal effects help in understanding the direction and magnitude of the impact of climate variables on production efficiency growth. If the sign of marginal effects of temperature is positive, it shows that an increase in temperature lowers production efficiency growth and enhances its variability. Since output is expressed in logarithmic terms, the marginal effects are interpreted as percentage change in growth of output or production inefficiency as a result of a one unit change in a climatic variable.

3. Data

We estimate the effects of temperature on production efficiency growth using information on output, inputs and climatic factors - temperature and precipitation at the country level. Data for this study is obtained from three sources. Information on GDP, labour and capital has been taken from Penn World Tables (PWT.9). Data on climatic variables is based on Burke et al. (2015) and the World Bank.[8] Temperature is measured in ^{o}C and total precipitation is given in millimetres (mm) per year.[9] The Burke et al (2015) and World Bank data differ in the method used to generate climate data at the country level and the time period covered. Climate data, which is available at a sub-country resolution is converted to a country-specific average by Burke et al (BHM) by constructing a population-weighted average. This data is available for the period 1960-2010. A population-weighted average provide an economically relevant climate realization (Heal and Park, 2013). On the other hand, the World Bank (WB) constructs an area-weighted average of climatic variables using information on temperature and precipitation of land areas obtained from the Climatic Research Unit (CRU) of the University of East Anglia (UEA).[10] This data is available till 2017; however due to lack of availability of recent data on other variables such as capital stock and labor we are

[7] Formulas of estimating the marginal effects are given in Appendix.

[8]http://sdwebx.worldbank.org/climateportal/index.cfm?page=country_historical_climate

[9] For details on data for climatic factors, please see, Burke et al. (2015).

[10]For details on the climatic variable dataset provided by the UEA, please refer to Harrris et al. (2014)

constrained to analyzing data for the 1950-2014 time period. Area weighted weather variables are appropriate from a meteorological perspective while population-weighted variables are likely to reflect the impact of climate on economic activities (Tol, 2017).[11] Note that the sample correlation between temperature variables provided by these two sources is 0.96 and it is 0.90 between the two measures of precipitation.

We consider countries for which complete panel data on climatic and economic variables is available for at least 17 years. This leaves us with an unbalanced panel data for 153 countries over the period of 1960 to 2010 when the climatic variables are obtained from Burke et al. (2015) and for 168 countries when we use climatic data from the World Bank for the time period 1950 - 2014. In the first set we have a total of 6167 observations with 73 poor countries; and in the second set we have 77 poor countries and the total number of observations are 7952.[12] We define a country to be poor if its per capita income, adjusted for purchasing-power-parity (PPP), was below the sample median in 1980, which was 2011US$ 5173.[13]

Table A1 provides descriptive statistics of variables used in the study. It can be observed that poor countries are mainly located in hot temperate zones with an average temperature of about 22.5 ^{o}C whereas rich countries are on average experiencing a mean temperature of about 15.5 ^{o}C. Annual total precipitation does not differ much between the two groups of countries. There is considerable variability within each group of countries with respect to both economic and climatic factors. Table A1 shows that the difference in average temperature over time is higher in case of rich countries relative to poor countries.

4. Empirical Estimation

We estimate the production relationship defined through equations (3) to (5) with production inefficiency change and its variance as functions of average annual temperature and total annual precipitation. Additionally we account for the heterogeneous effects of climatic factors on developed and developing countries by including interactions of the vectors of temperature and precipitation with the "poor" dummy in equations (4) and (5). The dummy takes a value of one if a country is poor and a value of zero otherwise. Corresponding to equations (3) to (5) the estimated specification is:

$$\Delta ln(Y_{it}) = \alpha \Delta ln(K_{it}) + \beta \Delta ln(L_{it}) + \eta_t + \Delta v_{it} - \Delta u_{it} \quad (6)$$

$$\Delta\mu_{it} = \delta_0 + \delta_1 Temp_{it} + \delta_2 Precip_{it} + \delta_3 Temp_{it} \times \text{"} Poor \text{"} + \delta_4 Precip_{it} \times \text{"} Poor \text{"} + \omega_{it} \quad (7)$$

[11]Relevance of population weighted temperature data over area weighted temperature data for measuring economic impacts is sector specific. For example, if the objective is to measure the impacts on labour productivity then population weighted temperature data may be well suited, but if we are measuring the impacts for agriculture then this might not be the case. We are thankful to one of the reviewers for pointing out this concern.

[12] Choice of countries has been restricted by availability of data. For the countries included in the study, see Appendix Table A.

[13] Burke et al. (2015) have considered a country to be poor if its purchasing power parity (PPP) adjusted per capita income was below the global median in 1980. An alternative way is to include yearly per capita income as many countries have progressed and have better capacity to adapt to climatic changes since then. But allowing the classification to vary over time could make it an endogenous variable since the unobservable variables that affect current per capita income could also affect TFP.

$$\sigma^2_{\Delta u_{it}} = \gamma_0 + \gamma_1 Temp_{it} + \gamma_2 Precip_{it} + \gamma_3 Temp_{it} \times \text{"}Poor\text{"} + \gamma_4 Precip_{it} \times \text{"}Poor\text{"} + \varphi_{it} \quad (8)$$

where countries are indexed by i and years by t; η_t are year fixed effects; $Temp_{it}$ and $Precip_{it}$ are temperature and precipitation variables for country i in year t, respectively; $\delta's$ and $\gamma's$ are parameters of the mean and variance functions of inefficiency change; and ω and φ are the error terms.

We retrieve the parameters of stochastic production frontier and the determinants of inefficiency change and its variance, using panel stochastic frontier approach. Greene (2005) proposes 'true fixed effect' models to differentiate between individual heterogeneity and inefficiency. However, 'true fixed effect' models suffer from an incidental parameters problem (Chen et al., 2014). In the case of MLE, although the parameter estimates remain unbiased, '*but the MLE's of the error variances are biased*' (Chen et al, 2014, p. 66). In stochastic frontier analysis, the error variances are an essential component of the inefficiency term which is extracted from the composite error term. We apply the first difference-MLE model to estimate the production frontier. First difference-MLE removes the incidental parameters while accounting for time invariant effects before estimation and produces consistent estimates of parameters and error variances for fixed time periods by maximizing the likelihood function (Chen et al. 2014). Moreover, we include time dummies to account for year specific effects (e.g., financial crisis of 2008) rather than time trend. This strategy of controlling for time invariant and time variant effects is robust to mis-measurement of controls (Burke et al., 2015).

We conduct a set of tests to confirm the stationarity properties of the data. We perform first- and second- generation panel unit root tests. Among the first generation tests, we consider two tests namely, Im, Pesaran and Shin (IPS) (2003) and Maddala and Wu (1999). In the second generation tests, we use Pesaran's CIPS test (Pesaran, 2007). Results of these stationarity tests are reported in Appendix Tables A1.1 to A1.3. Using 4 lags, we fail to reject the null hypothesis of a unit root for economic variables (real GDP, capital stock and labour expressed in natural logarithm), but are able to reject the null hypothesis of a unit root for the climatic variables. We find that the economic variables are stationary in first differences.

The test results for cross-sectional dependence (CD) are reported in Appendix Table A2. We conduct the Pesaran's CD test (Pesaran, 2004). First, we run fixed effects panel regressions assuming that the growth rate of GDP is a function of growth rate of capital and labour along with climatic variables. We test the results for cross sectional dependence and reject the null hypothesis of cross-sectional independence. Then, we again run the fixed effects panel regressions by including year dummies and test for cross sectional independence by conducting the Pesaran CD test and fail to reject the null hypothesis.

There are possible concerns regarding endogeneity of regressors in stochastic frontier models (Shee and Stefanou, 2015). A possible source of endogeneity could be that factor input variables may be related to unobserved productivity and climatic variables. We address this concern in two ways: (i) stochastic frontier estimation makes explicit distributional assumption of the unobserved productivity (Van-Biesebroeck, 2008).We assume that the distribution of mean and variance of the unobserved productivity is a function of truly exogenous climatic variables;[14] and (ii) if one of the regressors is stationary in first difference

[14]We assume that the one-sided error term has a truncated normal distribution.

and the explained and explanatory variables are co-integrated, then least square estimation provides super-consistent slope parameters even if some of the variables are endogenous (O'Donnell, 2016). We conduct Pedroni (2004) and Westerlund (2007) panel co-integration tests and find that the variables are co-integrated (Appendix Tables A3.1 and A3.2).

To test the hypothesis that effects of the climate variables on mean and variance of production inefficiency change are confined to poor countries, we include interaction variables which are the product of average annual temperature and total annual precipitation in a country and the dummy variable "poor". Estimated coefficients of temperature and precipitation variables describe response function for rich countries and coefficients of the interaction terms define adjustments to these parameters that are only applicable for poor countries. This implies that if the response of climatic factors is limited to poor countries then the coefficients of the interaction terms are statistically significant, but not of temperature and precipitation variables. If coefficients of the adjustment factors are not distinguishable from zero, it implies that climatic factors affect both rich and poor countries equally and if the coefficients of both climatic factors and their adjustment factors are statistically significant, it implies that both rich and poor countries are affected, but the response could be different. To capture nonlinearity of temperature effects on economic activities, we parameterize both the mean and variance of one-sided error term by truly exogenous climatic variables and the nonlinearity arises naturally as a result.

Does temperature change affects the level of income or growth rate of income? To answer this question, earlier studies (e.g., Dell et al., 2012) include lags of climatic factors along with their contemporaneous values in the regression equations. Burke et al. (2015) find that the results become noisier as an increasing number of lags of temperature effects are included and uncertainty in cumulative effect increases. This indicates that by using GDP growth as a dependent variable, it is difficult to distinguish between level and growth effects. We model efficiency growth as a one-sided error term and parameterize it by climatic factors and can therefore estimate medium to long-term effects of temperature on economic activities, which are known to be strongly influenced by efficiency growth.

To check robustness, we estimate the stochastic frontier model using data on climatic variables from two different sources. Table A4 reveals that the estimates of stochastic frontier models are almost identical irrespective of the source of climatic data. We also run the base specification using sub-sample of countries excluding Sub-Saharan countries and only for Sub-Saharan countries using both sources of weather data. Using weather data obtained from the World Bank, we run the specification for the sub-sample of 1960-2010, a period covered by BHM data set, and two sub-samples for the time period 1970-2014 and 1990-2014, respectively. All sub-sample levels estimates are qualitatively not different from the estimates obtained for the whole sample (Table A5). The results reported in Table A5 show that the specification results remain robust regardless of the source of weather variable data, period of study or group of countries.

5. Empirical Results

Table A4 provides parameter estimates of the stochastic production frontier models. We estimate stochastic frontier models including climatic variables. In all versions, we observe that both $\Delta\sigma_u$ and $\Delta\sigma_v$ are statistically significant implying that stochastic frontier model specification is appropriate. Magnitudes of the parameters suggest that one-sided error term explains more of the overall production variance than the usual error term, implying that growth in output is determined by TFP.

Table A4 (Versions 2 and 4) provide estimates of the stochastic production frontier when the mean and variance of inefficiency term are parameterized by both climatic variables and their interactions with the "poor" dummy. We find that both temperature and precipitation variables are statistically significant. Coefficients of the interaction terms (adjustment factors) explaining the meaning of the one-sided error terms are not different from zero but they are statistically significant in explaining the variance of the one-sided error term. Note that marginal effect of climatic factors depends on the coefficients of both mean and variance terms. This implies that the response of climatic variables is not confined to poor countries. Both poor and rich countries are affected by climatic factors, and the response in poor countries is different from rich countries. We find that production efficiency growth is higher in rich countries in comparison to poor countries.[15]

Our interest lies mainly in estimates of the effect of weather variables on growth and variability of efficiency growth. Parameter estimates of the determinants of mean and variance of one-sided error term are not very informative since they are not marginal effects due to model's nonlinearity. Even the direction of marginal effects of a determinant is difficult to observe from slope coefficients since marginal effects depend on the estimates of both the mean and variance functions of the one-sided error term. Table 1 displays estimates of marginal effects of climatic factors on production inefficiency change and its uncertainty for versions 2 and 4 of the models.

Table 1 reports sample means of the marginal effects on production inefficiency change and its uncertainty. Stochastic frontier estimates reveal that the mean and variance effects of weather variables are not confined to poor or rich countries, therefore, we present the marginal effects according to the location of a country in a particular temperature zone. Note that since the model allows nonlinearity, we present the results for 5-bins: 'very hot' (average annual temperature above 25 ^{o}C), 'hot' (average annual temperature 20-25 ^{o}C), 'mild' (average annual temperature 15-20 ^{o}C), 'cold (average annual temperature 10-15 ^{o}C), and 'very cold' (average annual temperature below 10 ^{o}C).[16]

A negative sign of the marginal effect of a determinant of mean production inefficiency change indicates that higher levels of that variable are associated with improved production efficiency change. On the other side, a positive sign signals deterioration in production efficiency change. That is, if the sign of the marginal effect of temperature on production inefficiency change alters from negative to positive within a sample, it implies that the relationship between temperature and its effects on production efficiency change is concave. Similarly, a negative sign for the variance equation parameters implies reduced uncertainty in efficiency growth and a positive sign is an indicator of increasing uncertainty.

The sample mean of marginal production inefficiency change effect and its uncertainty effects of temperature are positive implying that a 1 ^{o}C temperature increase reduces

[15]Detailed country level panel results of production efficiency are available from the authors.

[16]5-bins classification has been done following Heal and Park (2013) and the classification of countries based on these bins is given in Appendix Table A.

production efficiency growth by about 0.1 percentage points[17] and increases its uncertainty by 0.06 percentage points (Table 1). The marginal impact of temperature at the bin levels reflect that temperature increase is beneficial for countries that are located in very cold or cold temperature zones but is harmful for countries located in hot or very hot temperature zones. An average country located in a very cold zone benefits due to the temperature increase, however a country located in a very hot temperature zone is negatively affected by about 0.23 percentage points in terms of efficiency growth loss due to a 1 ^{o}C increase in temperature. In mild temperature zone the marginal effect is negligible in magnitude.

Further, to understand nonlinearity in the effects of temperature on efficiency growth and its variability, we present box plots of the marginal effects according to temperature bins (Figure 1). Panel A of the figure displays that detrimental marginal effects on efficiency growth and its variability are negligible for very cold and cold temperature zones, but are more pronounced in hot and very hot regions. It also reveals differences in magnitude of the effects estimated from two different sources of weather data. Note that population weighted data on weather variables picks up economically relevant climate realizations relative to land area based weather variables. On an average basis, we find that the magnitude of these effects is slightly larger when measured using land based temperature relative to population weighted temperature in very cold and cold regions, but the converse is true for hot and very hot regions. In mild temperature regions, the effects are of equal magnitude, irrespective of the measurement of temperature data.

We are also interested in understanding the effects of temperature change on uncertainty. Estimated results reveal that increasing temperature does not only affect efficiency growth but also its variability (Figure 1, Panel B). Magnitude and direction of the marginal effects of temperature on uncertainty exhibit that additional 1 ^{o}C increase in temperature has negligible effects if a country is located in the cold zone but this effect is detrimental and substantial for a country located in hot or very hot climate zone. Combined results of marginal effects of temperature on production efficiency change and its uncertainty predict that, other things being equal, additional increases in temperature in hot or very hot climate zones not only lowers efficiency growth but also makes it less stable than before.

We find that marginal effects of precipitation on efficiency growth are positive though the magnitude of the effect is small. This is observed to be true irrespective of the location of a country (Table 1). A 100 mm increase in annual total precipitation increases efficiency growth by 0.13 percentage points and reduces the variability.

To understand the level of optimal temperature, we scatter plot the marginal effects in Figure 2. Sign of the marginal effect of temperature alternates from negative to positive as countries move from very cold or cold regime to hot or very hot regime and strengthens in magnitude (Figure 2, Panel A). The marginal effect of temperature on production efficiency growth is equal to zero or negligible somewhere between 12 to 15 ^{o}C of temperature based on weather data obtained from Burke et al (Panel A1) and at about 7-8 ^{o}C for data obtained from the World Bank (Panel A2). This finding corroborates with the findings of Burke et al. (2015). They find that country level productivity peaks at 13 ^{o}C of temperature. The Figure also reveals that at optimal temperature range, not only the efficiency growth touches the peak but

[17]Since $\partial E\Delta\mu\partial T=-\partial E\Delta \ln\ y\ \partial T$, the magnitude of marginal effect of 0.1 percentage points translates into a decrease in output growth by 0.1 percentage points.

it also becomes more stable than before (Figure 2, Panel B1).[18] The discrepancy observed in the optimal temperature level between the two data sets may be attributed to the fact that area weighted temperature is appropriate from a meteorological perspective while the population-weighted temperature reflects the impact of climate on economic activity. For example, in Canada or Russian Federation there is a huge difference in average temperature between the two data-sets. In Canada, 1 ^{o}C population weighted temperature increase enhances production efficiency growth by about 0.01 percentage points and the corresponding marginal effect is 0.006 percentage points due to increases in area weighted temperature (Table A6).

We find that most countries located in very cold temperature zone either benefit from further temperature increases or experience effects that are negligible. However, in hot and very hot countries further increases in temperature is not only detrimental for production efficiency growth but also makes growth rate less stable than before. Figure 3 reveals that countries such as Mongolia (which is the coldest country based on population weighted temperature) benefit from any further temperature increase, but hot countries like Brunei Darussalam have to face the hardest detrimental effects.[19]

Our empirical results of temperature effects on efficiency growth are quite consistent with findings in other studies. For example, Heal and Park (2013) find that 1 ^{o}C increase in contemporaneous temperature in India, Thailand and Nigeria negatively affects per capita output by about 3 to 4 percent whereas a similar increase in temperature increases output in Norway and Sweden significantly. This shows that a concave relationship between temperature and efficiency growth is a good approximation of the underlying relationship.

We observe a positive relationship between temperature level and its marginal effect on mean and variance of production inefficiency. Correlation coefficients between temperature level and its marginal effects on the mean and variance of inefficiency change are 0.90 and 0.92, respectively for poor countries, but the correlation coefficients are 0.17 and 0.08, respectively for rich countries. This implies that the marginal effects of rising temperature on production efficiency change and its uncertainty are more detrimental in poor countries. Further, to understand the role of economic development in moderating impacts of temperature change we regress the marginal impacts on temperature and per capita income using the fixed effect model. Regression results in Table 2 reveal that the detrimental marginal impacts are positively related to temperature level but negatively related to per capita income implying that in the same climate zone, economic development moderates the impacts of temperature change.

To further confirm, we plot the relationship between three variables namely, marginal impacts, level of temperature and per capita income (Figure 4) for the sample of countries in which average temperature is less than 25 ^{o}C. Note that high income countries located in very hot climate zone are generally oil producing and exporting countries (OPEC) which experience marginal impacts similar to poor countries. Figure 4 confirms that marginal impacts of temperature increase on mean and variance of efficiency growth are higher for those countries that are located in hot regions and are low income countries. This result is

[18]Note that we observe a small cluster of points about the optimal zone above the fitted regression line (Panel A1 and Panel B1).These points belong to Bhutan, which is a poor country. It reflects that it is not only the location of a country but also level of development that determines climatic effects on production efficiency growth and its variability.

[19]Average annual marginal effects of temperature on mean and variance of production efficiency growth at the country level are provided in Appendix Table A6 and Figure A1 maps the effects based on temperature (WB).

consistent irrespective of the source of temperature data. These results become shaper as we include poor and very hot countries in the sample (Appendix Figure A2). Our analysis reveals that higher income moderates detrimental temperature effects in countries which observe on average less than 25 ^{o}C temperature. These findings combine the findings of Dell et al. (2012) with the findings of Burke et al. (2015). Reduction in mean efficiency growth is higher for countries in hotter zones and for those with lower per capita income. These countries may have lower growth rates to begin with and so the relative effect is larger for these countries.

Implications of Climate Change for Growth in Production Efficiency

We quantify potential effects of climate change on production efficiency growth by combining our parameter estimates with projections of future climatic changes under 'business-as-usual' scenarios (Representative Concentration Pathways (RCP)8.5) for the two periods 2020-2040 and 2080-2100. To quantifying the future potential impacts, we assume that economic activities or TFP changes respond to temperature changes in a manner similar to the response observed during 2000-2010.

We obtain the data on future temperature levels during 2020-2040 (short-run) and 2080-2100 (long-run) from the World Bank's Climate Knowledge Portal for scenario RCP8.5 for 129 countries. This portal provides monthly data on temperature and precipitation from 16 different climate models. A combination of predictions, known as ensembling, is expected to perform better than individual prediction (Athey et al. 2019). We use an arithmetic mean of monthly temperature data for these 16 models to obtain yearly average annual temperature. We observe that as compared to 2000-2010, average temperature in 2020-2040 will be 1.7 ^{o}C higher and in 2080-2100 will be about 4.8 ^{o}C higher.

To project the effect of warming on production efficiency growth, we assume that population weighted temperature change follows the meteorological temperature change pattern. Using parameter estimates derived using BHM temperature dataset, we find that in the short-run and long-run, on an average, production efficiency growth declines by 0.11 and 0.26 percentage points, respectively, while production uncertainty increases by 0.006 and 0.018 percentage points in short-run and long-run temperatures, respectively (Figure 5). The impacts are not uniform across countries if the countries are facing 2020-2040 and 2080-2100 temperature in 2000-2010. Sierra Leone would have been the worst affected as it loses about 3.23 percentage points in TFP growth, but Mongolia gets better off as it would have experienced improvement in TFP growth rate of the magnitude of 0.023 percentage points with higher stability. In the long-run, Sierra Leone will face temperature increase of about 2.7 ^{o}C and there will be about 6 ^{o}C increase in temperature in Mongolia. Note that the projected marginal impacts are a function of baseline temperature (Figure 3).[20] In particular, some European countries and Canada could have benefited from increased average temperatures (Figure 5).

Projected effects show that in short to long run marginal effects of temperature increase would not have been much different in rich countries but would have been more pronounced

[20]Projected marginal effects of temperature on the mean and variance of production efficiency growth at country level for short-run and long-run are provided in Appendix Table A7 and Figure A3 maps the projected short-run values.

in poor countries. For example, for the US the effects would be about 0.013 to 0.018 percentage points of loss in production efficiency growth in short-run and long-run temperatures, but in Zimbabwe the effects would have been 0.051 to 0.11 percentage points despite the fact that temperature increase would have been higher in US than in Zimbabwe. Similarly, we observe that India and Bangladesh would have experienced losses in marginal TFP growth of about 0.11 to 0.28 and 0.21 to 0.94 percentage points, respectively, in short to long-run projected temperatures. Note that further increase in temperature is not affecting the variability of TFP growth in US, but growth rate in TFP in poor countries is less stable than before. Some of the developed countries such as Finland would have been benefited from further temperature increase and countries like the United Kingdom would have been the least affected. Overall we find that poor countries are more vulnerable than rich countries though they face similar or lower temperature increase since marginal effects are a function of base level temperature and economic development. Generally, the marginal effects are more pronounced in the countries of South Asia, Sub-Saharan region, OPEC and Latin America both in short-run and long-run.

6. Discussion and Conclusion

This paper examines the economy-wide relationship between temperature and production efficiency growth using a one-step stochastic frontier approach for a sample for 168 countries over the period 1950-2014. We examine the marginal effects of temperature on production efficiency growth and uncertainty. We find that an increase in temperature by 1 ^{o}C reduces average efficiency growth while increasing its uncertainty. These effects are larger for poor countries relative to rich countries. The marginal effects of an increase in temperature differ widely across countries depending on the temperature zone and GDP level. At the margin we find that a 1 ^{o}C increase in temperature is beneficial for countries located in cold or very cold temperature zones but it is harmful for countries located in hot or very hot temperature zones. These results show the importance of incorporating nonlinearity in the relationship between temperature and efficiency growth and its implications for heterogeneity in the effects of temperature changes across countries in different temperature zones. Our findings also show that the effects of temperature on efficiency growth are not deterministic, particularly for countries located in hot temperature zones; climate change increases uncertainty in production efficiency growth in these countries. In general we find evidence of a concave relationship between temperature and efficiency growth. We also find increased uncertainty in efficiency growth as temperature increases, particularly in developing countries. It is also found that the adverse effects of climate change are largely due to changes in temperature and that the effect of changes in precipitation on production efficiency are negligible, though beneficial.

Furthermore, our forecast of the impact of potential changes in temperature on production efficiency growth and uncertainty shows the effect is not trivial since it is additional to current impact estimates. Our finding that production efficiency growth declines by 0.11 and 0.26 percentage points, respectively, while production uncertainty increases by 0.006 and 0.018 percentage points in short-run and long-run, respectively. Moyer et al (2014) and Dietz and Stern (2015) show that the trajectory of output is highly sensitive to changes in TFP. Even a small magnitude of TFP damages leads to a substantially different consumption growth path. For example, Moyer et al. (2014) observe that consumption in 2300 reduces by 70 percent relative to the no climate change scenario due to the effects of climate change in TFP growth.

Estimates of the effects of temperature on productivity are key to determining the climate damage function in IAMs and estimating the social cost of carbon. Most IAMs are developed at a global level or at regional level and assume a common damage function. However, damage functions can be expected to vary across countries depending on current climatic conditions in those countries and their level of development that can influence the ability to mitigate and adapt to those damages. Moreover, these damages due to climate change can be expected to be stochastic and not deterministic as assumed currently in IAMs. Existing empirical evidence of these damage functions and their heterogeneity across countries are limited and sector specific.

Our analysis shows that climate change has dynamic and nonlinear effects on TFP growth and increases uncertainty of future growth possibilities. These effects are more pronounced in poor countries than rich countries. Since marginal effects are a function of base level temperature and level of economic development in a country, we find that in poor countries a further increase in temperature by 1 ^{o}C affects the TFP growth rate by 0.112 percentage points, but in the rich countries the loss is 0.083 percentage points. Moreover, TFP growth is more stochastic in poor countries than rich countries due to temperature increase. The variance of TFP growth increases by about 0.01 percentage points, on average, among both groups of countries.

Our findings contribute to improved understanding of the mechanisms by which climate change affects economic activity. We provide empirical evidence on the magnitude of the impact and how this impact varies across countries which can be directly incorporated in IAMs to improve their predictive capabilities for estimating the social cost of carbon. We show that these effects are non-linear and occur because temperature affects the productivity of labour and capital and these effects differ both across locations and with the level of development of a country. These findings imply that global IAMs should incorporate damage functions that differ across countries. Estimates of climate damages, i.e. social cost of carbon, will also differ across locations based on their current climatic conditions and country-specific trajectory of changes in temperature. We leave it to future research to use these damage functions to estimate the social cost of carbon at a country-specific level.

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Table1: Marginal effects of climatic variables on the mean and variance of TFP growth (percentage points).

Temperature bin		Temperature (BHM)		Temperature (WB)		Precipitation (BHM)		Precipitation (WB)	
		On E(Δu)	On V(Δu)	On E(Δu)	On V(Δu)	On E(Δu)	On V(Δu)	On E(Δu)	On V(Δu)
Very Cold	Mean	-0.0045***	-0.0004***	0.0106***	0.0005***	-0.0017**	-0.0001**	-0.0014*	-0.0001*
	Std. Dev.	0.0129	0.0009	0.0067	0.0004	0.0003	0.0000	0.0003	0.0000
Cold	Mean	0.0215***	0.0012***	0.0212***	0.0012***	-0.0015**	-0.0001**	-0.0014***	-0.0001*
	Std. Dev.	0.0235	0.0012	0.0040	0.0003	0.0003	0.0000	0.0003	0.0000
Mild	Mean	0.0386***	0.0025***	0.0389***	0.0024***	-0.0017**	-0.0001**	-0.0014***	-0.0001**
	Std. Dev.	0.0161	0.0013	0.0053	0.0006	0.0003	0.0000	0.0003	0.0000
Hot	Mean	0.0967***	0.0055***	0.0612***	0.0032***	-0.0012***	-0.0001***	-0.0011***	-0.0001*
	Std. Dev.	0.0917	0.0092	0.0285	0.0011	0.0004	0.0000	0.0004	0.0000
Very Hot	Mean	0.2269***	0.0156***	0.1040***	0.0062***	-0.0010***	-0.0001***	-0.0009***	-0.0001**
	Std. Dev.	0.7726	0.0976	0.4060	0.0504	0.0022	0.0003	0.0025	0.0003
Total	Mean	0.0961***	0.0062***	0.0562***	0.0032***	-0.0013**	-0.0001**	-0.0011**	-0.0001**
	Std. Dev.	0.4150	0.0514	0.2207	0.0271	0.0012	0.0001	0.0014	0.0002

Note: Countries are classified into 5-bins: 'very hot' (average annual temperature above 25ºC), 'hot' (average annual temperature 20-25ºC), 'mild' (average annual temperature 15-20ºC), 'cold (average annual temperature 10-15ºC), and 'very cold' (average annual temperature below 10ºC). Sample includes all countries for which the complete panel data on both climate and economic variables is available for at least seventeen years. Classification of countries according to temperature bins is given in Appendix Table A. Standard errors (SE) are computed using the delta method.

*** Significant at the 1 percent level.

** Significant at the 5 percent level.

* Significant at the 10 percent level

Table 2: Relationship between the marginal impacts and temperature and per capita income

	Weather variables are taken from Burke et al. (2015)		Weather variables are taken from World Bank	
	Mean	Variance	Mean	Variance
Temperature	0.02264**	0.00234*	0.00503	0.00034
	(2.39)	(1.92)	(1.14)	(0.61)
Per Capita Income	-0.00143**	-0.00019**	-0.00006	-0.00001
	(-2.00)	(-2.04)	(-0.20)	(-0.34)
Constant	-0.30749*	-0.03493	-0.03730	-0.00299
	(-1.76)	(-1.55)	(-0.46)	(-0.29)
F Stat	4.1**	3.31**	0.65	0.2
DF	(2, 6012)	(2, 6012)	(2, 7782)	(2, 7782)
Countries	153	153	168	168
Observations	6167	6167	7952	7952

Note: the Dependent variables are the marginal effects of temperature on mean and variance of inefficiency growth expressed in percentage points. Temperature is measured in ^{o}C and per capita income is measured in thousand 2011US$ expressed in purchasing power parity (PPP). Figures in parentheses are t-statistics.

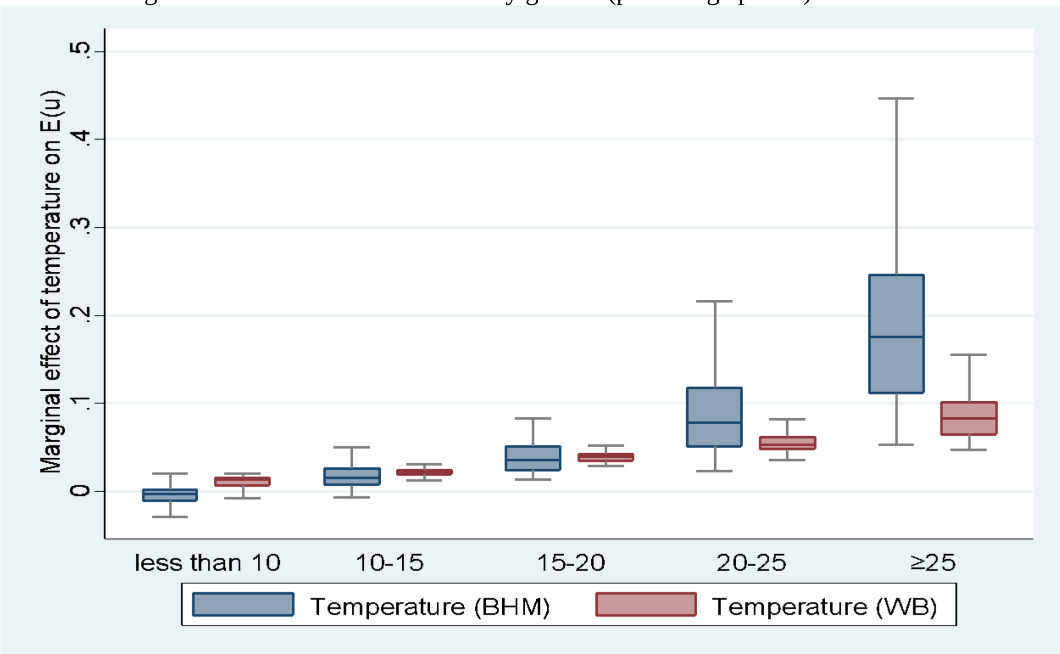
*** Significant at the 1 percent level.

**Significant at the 5 percent level.

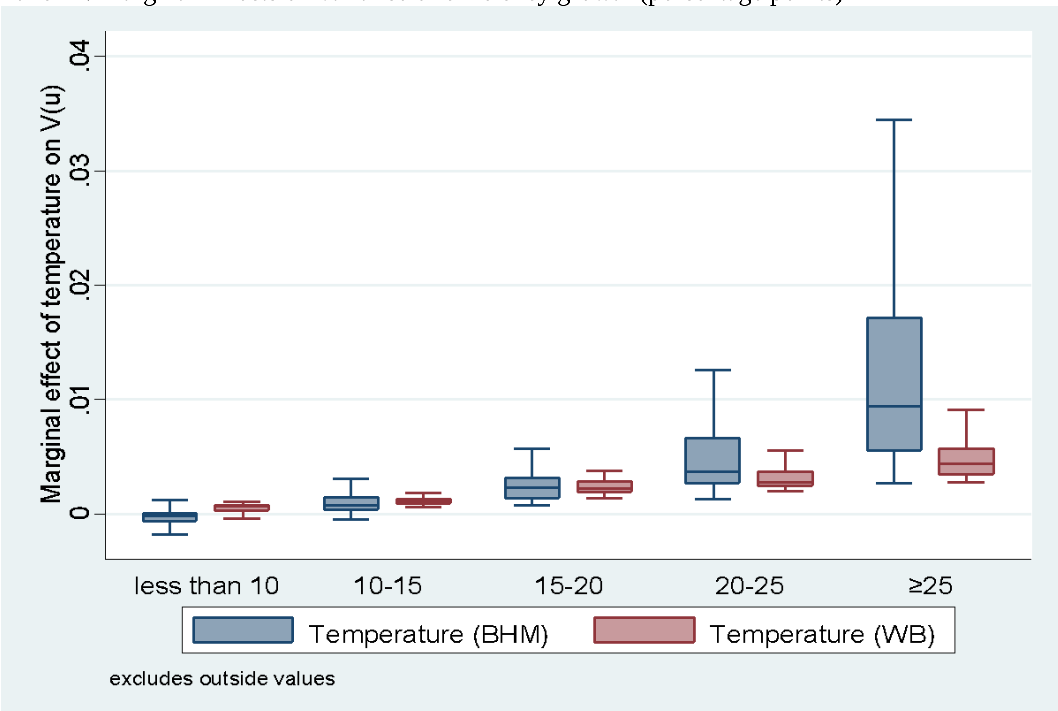
*Significant at the 10 percent level

Figure 1: Non-linear marginal effects of temperature on the average rate of growth of production efficiency and on the variance of efficiency growth (by temperature bins)

Panel A: Marginal Effects on mean of efficiency growth (percentage points)



Panel B: Marginal Effects on variance of efficiency growth (percentage points)



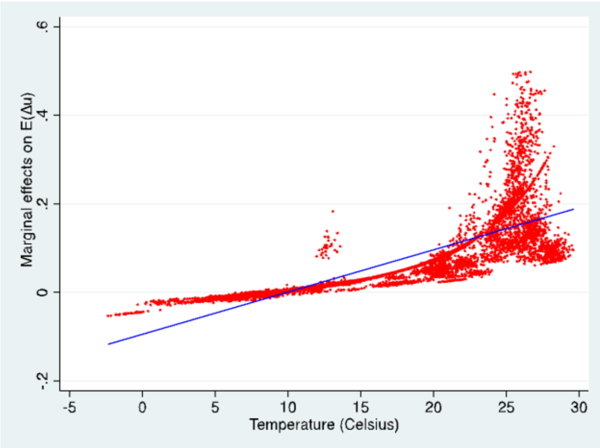
Note: Countries are classified into 5-bins: 'very hot' (average annual temperature above 25°C), 'hot' (average annual temperature 20-25°C), 'mild' (average annual temperature 15-20°C), 'cold (average annual temperature 10-15°C), and 'very cold' (average annual temperature below 10°C). Classification of countries according to temperature bins is given in the Appendix Table A.

Figure 2: Marginal effects of temperature on efficiency growth and variability (percentage points)

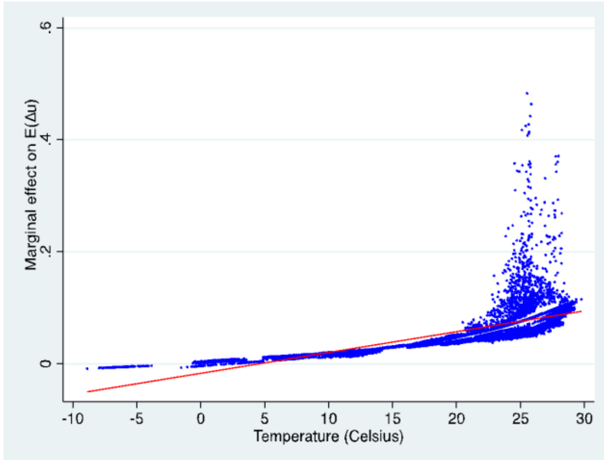
BHM Data | WB Data

Marginal effects on mean of efficiency growth

Panel A1

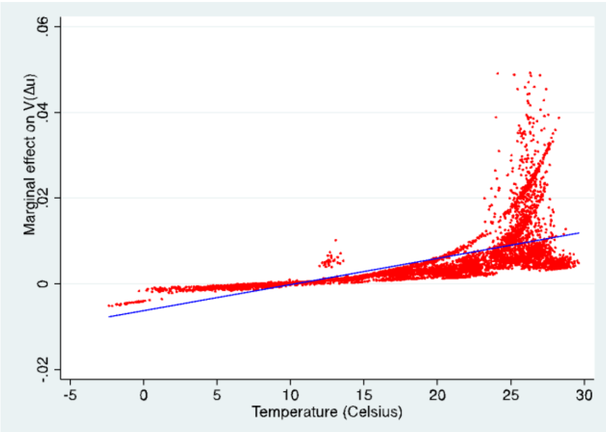


Panel A2

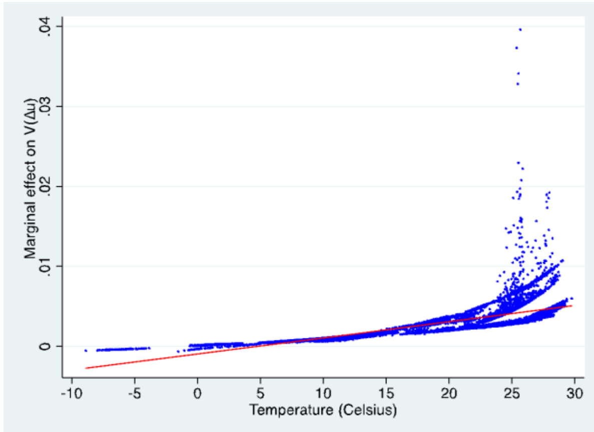


Marginal Effects on variance of efficiency growth

Panel B1



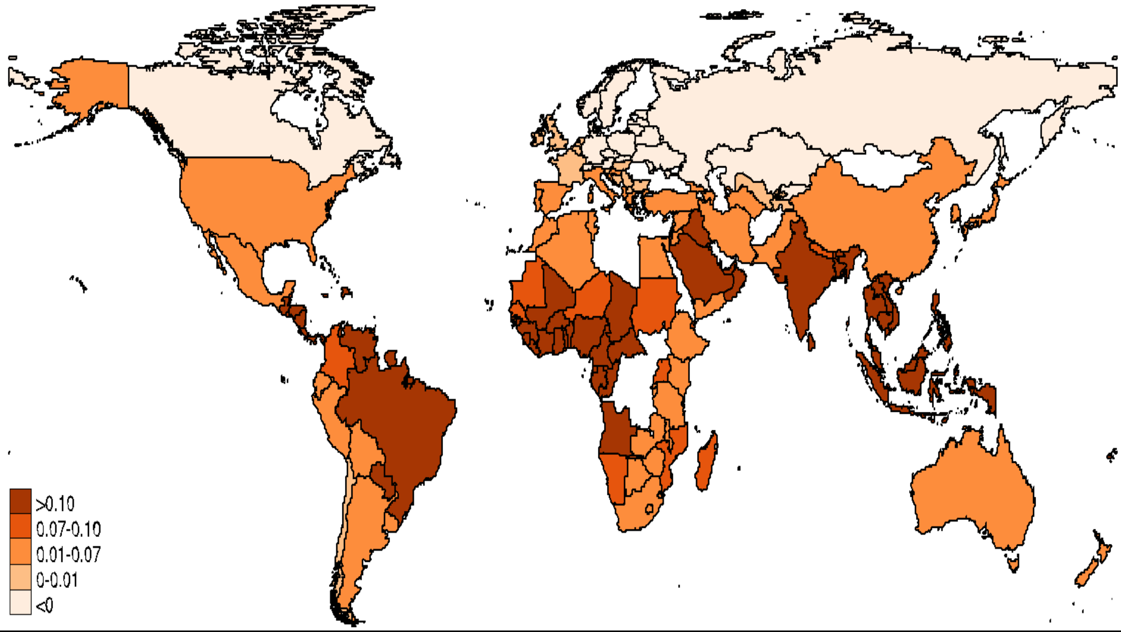
Panel B2



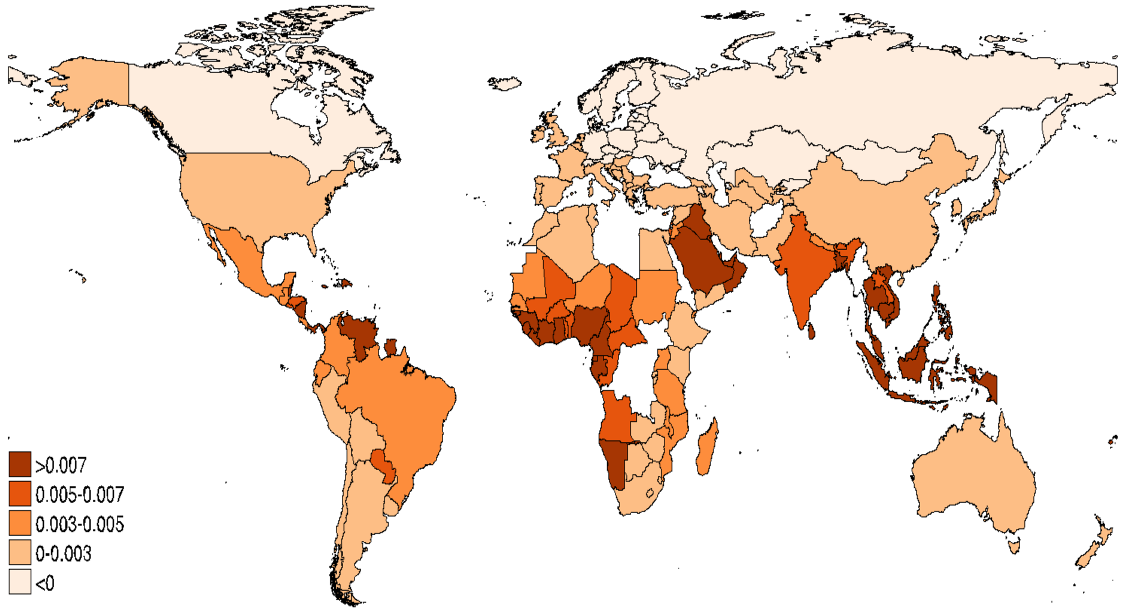
Note: Red color: temperature source Burke et al. (2015); Blue color: temperature source World Bank. Panels A1 and B1 show that marginal effects of temperature on production efficiency growth and its variance are equal to zero or negligible somewhere between 12 to 15 ^{o}C. Similarly Panels A2 and B2 show that optimal temperature is at about 7-8 ^{o}C.

Figure 3: Regional distribution of marginal effects of temperature (BHM) on production inefficiency growth (percentage points)

Panel A: marginal decrease in mean production efficiency growth

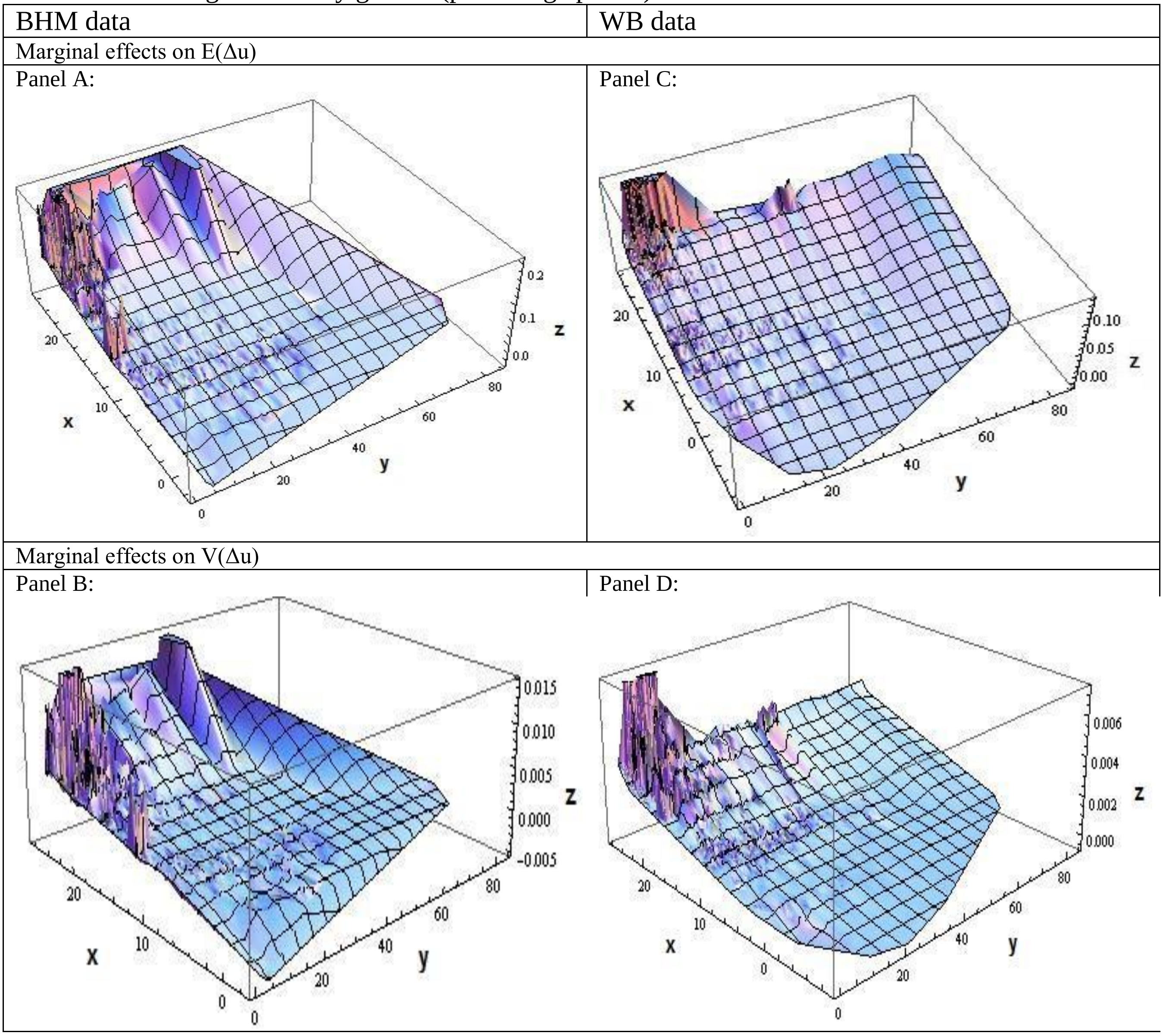


Panel B: marginal increase in variance production efficiency growth



Note: Hotter than average temperature is not only detrimental to production efficiency growth but also makes the growth more variable than otherwise and these effects are larger in very hot countries with average annual temperature greater than 25 ºC. Countries such as Mongolia benefit from any further temperature increase, but hot countries like Brunei Darussalam have to face the hardest detrimental effects.

Figure 4: Marginal effects of temperature and level per-capita income on the mean and variance of average efficiency growth (percentage points)

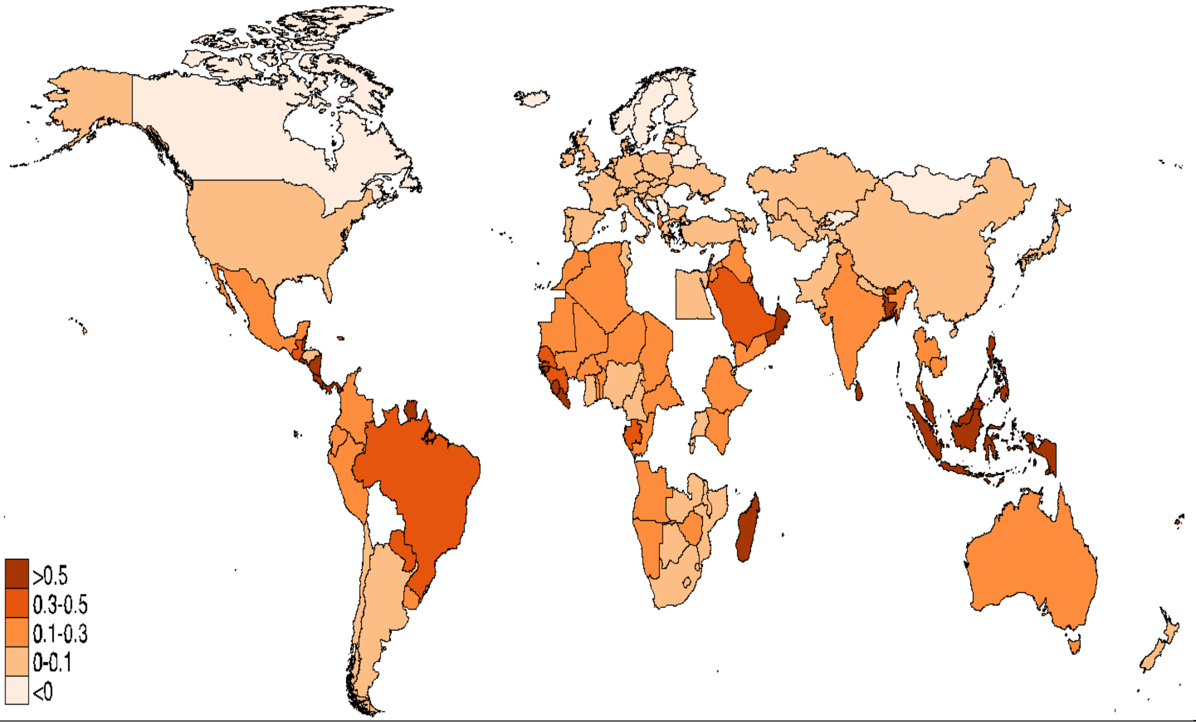


Notes: x-axis measures temperature in ^{o}C; y-axis measures per capita income in thousand 2011US$ in terms of PPP; and z-axis measures the marginal effect of temperature change on mean inefficiency growth. The effects are higher in high temperature and low income countries, i.e., higher income moderates detrimental temperature effects in countries which observe on average less than 25 ^{o}C temperature.[21]

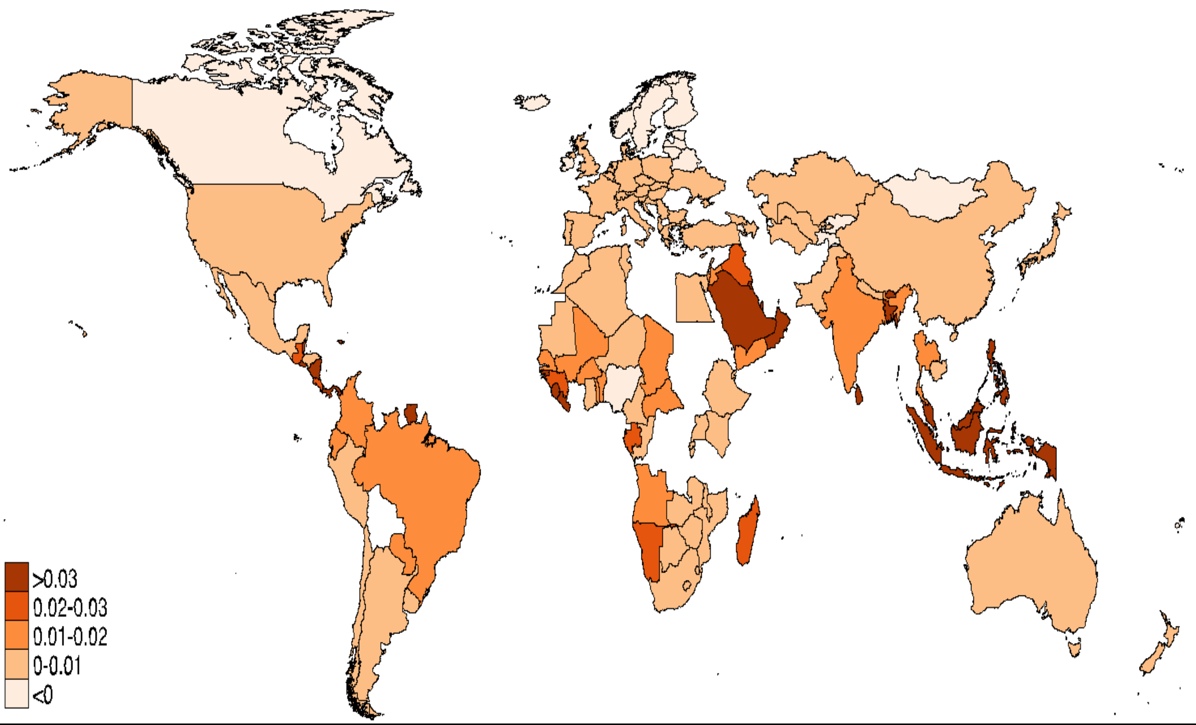
[21] In the formulation of these figures following countries information is not included: Countries with average temperature (WB) > 25: Aruba, Anguilla, United Arab Emirates, Benin, Burkina Faso, Bangladesh, Bahrain, Bahamas, Belize, Brazil, Barbados, Brunei Darussalam, Central African Republic, Cote D' Ivoire, Comoros, Cayman Islands, Djibouti, Gabon, Ghana, Guinea, Gambia, Guinea-Bissau, Indonesia, Jamaica, Cambodia, Kuwait, Liberia, Saint Lucia, Sri Lanka, Maldives, Mali, Mauritania, Malaysia, Niger, Nigeria, Nicaragua, Oman, Panama, Philippines, Qatar, Saudi Arabia, Sudan (Former), Senegal, Singapore, Sierra Leone, Suriname, Seychelles, Chad, Togo, Thailand, Trinidad and Tobago, St. Vincent and the Grenadines, Bolivarian Republic of Venezuela. Countries with average temperature (BHM) > 25: United Arab Emirates, Benin, Burkina Faso, Bangladesh, Bahamas, Belize, Brazil, Brunei Darussalam, Central African Republic, Cote D' Ivoire, Congo, Comoros, Dominican Republic, Djibouti, Gabon, Ghana, Guinea, Gambia, Guinea-Bissau, Indonesia, India, Cambodia, Kuwait, Liberia, Sri Lanka, Mali, Mauritania, Malaysia, Niger, Nigeria, Nicaragua, Oman, Panama, Philippines, Qatar, Saudi Arabia, Sudan (Former), Senegal, Sierra Leone, Suriname, Sao Tome

Figure 5: Projected marginal effects based on 2080-2100 temperatures (percentage points)

Panel A: Marginal decrease in mean production efficiency growth



Panel B: Marginal increase in variance production efficiency growth



Note: Poor countries are more vulnerable than rich countries though they face similar or lower temperature increase since marginal effects are a function of base level temperature and economic development. The marginal effects are more pronounced in the countries of South Asia, Sub-Saharan region, OPEC and Latin America.

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and Principe, Chad, Togo, Thailand, Trinidad and Tobago, St. Vincent and the Grenadines, Bolivarian Republic of Venezuela. Since these countries experience identical temperature effects irrespective of their level of economic development.

Appendix

Estimating Marginal Effects of Temperature on the Mean and Variance of Production Efficiency Growth:

To estimate the marginal effects of temperature on production efficiency growth and its variance we follow (Wang, 2002; 2003). The unconditional mean and variance of production inefficiency change are:

$$E(\Delta u_{it}) = \sigma_{\Delta u_{it}} \left[\Lambda + \frac{\phi(\Lambda)}{\Phi(\Lambda)}\right] \qquad \text{(a1)}$$

and

$$V(\Delta u_{it}) = \sigma^2_{\Delta u_{it}} [1 - \Lambda \left[\frac{\phi(\Lambda)}{\Phi(\Lambda)}\right] - \left[\frac{\phi(\Lambda)}{\Phi(\Lambda)}\right]^2] \qquad \text{(a2)}$$

where $\Delta\mu_{it}$ and $\sigma^2_{\Delta u_{it}}$ are the mean and variance of production inefficiency; $\Lambda = \Delta\mu_{it}/\sigma_{\Delta u_{it}}$; and ϕ and Φ are the probability and cumulative density functions of a standard normal distribution, respectively. The marginal effects of temperature and precipitation can be derived by differentiating (a1) and (a2) with respect to these variables. With tedious maniputation the formula of marginal effects on mean production inefficeincy change is obtained as follows:

$$\frac{\partial[E(\Delta u_{it})]}{\partial z[k]} = \delta[k] \left[1 - \Lambda \left[\frac{\phi(\Lambda)}{\Phi(\Lambda)}\right] - \left[\frac{\phi(\Lambda)}{\Phi(\Lambda)}\right]^2\right] + \gamma[k] \frac{\sigma_{\Delta u_{it}}}{2} \left[(1 + \Lambda^2) \left[\frac{\phi(\Lambda)}{\Phi(\Lambda)}\right] + \Lambda \left[\frac{\phi(\Lambda)}{\Phi(\Lambda)}\right]^2\right] \text{(a3)}$$

where $\delta[k]$ and $\gamma[k]$ are corresponding slope coefficients in equations (4) and (5), and *z[k]* denotes the *kth* element of the determinants, i.e., temperature or precipitation. Similarly, the formula of marginal effect of temperature or precipitation on variance of production inefficiency is obtained as:

$$\frac{\partial[V(\Delta u_{it})]}{\partial z_{it}} = \frac{\delta[k]}{\sigma_{\Delta u_{it}}} \left[\frac{\phi(\Lambda)}{\Phi(\Lambda)}\right] ([E(\Delta u_{it})]^2 - V(\Delta u_{it})) + \gamma[k] \sigma^2_{\Delta u_{it}} \left\{1 - \frac{1}{2} \left[\frac{\phi(\Lambda)}{\Phi(\Lambda)}\right] \left(\Lambda + \Lambda^3 + (2 + 3\Lambda^2) \left[\frac{\phi(\Lambda)}{\Phi(\Lambda)}\right] + 2\Lambda \left[\frac{\phi(\Lambda)}{\Phi(\Lambda)}\right]^2\right)\right\} \qquad \text{(a4)}$$

where $\frac{\partial[V(\Delta u_{it})]}{\partial z_{it}}$ can be interpreted as an estimator of the partial effect of climatic factors production uncertainty.

Table A: Countries in the sample according to the classification of temperature bins

Weather variables are taken from the World Bank (Total Countries 168)
Less than 10 ºC: Armenia, Austria, Belarus, Belgium, Canada, Chile, China, Czech Republic, Denmark, Estonia, Finland, Georgia, Germany, Iceland, Ireland, Kazakhstan, Kyrgyzstan, Latvia, Lithuania, Luxembourg, Mongolia, Montenegro, Netherlands, New Zealand, Norway, Poland, Russian Federation, Slovakia, Slovenia, Sweden, Switzerland, Tajikistan, Ukraine, United, Kingdom, United States
10 ºC to 15 ºC: Albania, Argentina, Azerbaijan, Bhutan, Bosnia and Herzegovina, Bulgaria, Croatia, France, Greece, Hungary, Italy, Japan, Lesotho, Nepal, Portugal, Republic of Korea, Republic of Moldova, Serbia, Spain, TFYR of Macedonia, Turkey, Uzbekistan
15 ºC to 20 ºC: Cyprus, Iran (Islamic Republic), Israel, Jordan, Lebanon, Malta, Morocco, Peru, Rwanda, South Africa, Syrian Arab Republic, Tunisia, Turkmenistan, Uruguay
20 ºC to 25 ºC: Algeria, Angola, Australia, Bermuda, Bolivia (Plurinational State of), Botswana, Burundi, Cabo Verde, Cameroon, China, Macao SAR, Colombia, Congo, Costa Rica, Dominican Republic, Ecuador, Egypt, El Salvador, Equatorial Guinea, Ethiopia, Fiji, Guatemala, Haiti, Honduras, India, Iraq, Kenya, Lao People's DR, Madagascar, Malawi, Mauritius, Mexico, Mozambique, Myanmar, Namibia, Pakistan, Paraguay, Sao Tome and Principe, Swaziland, U.R. of Tanzania, Uganda, Viet Nam, Yemen, Zambia, Zimbabwe
More than 25 ºC: Anguilla, Aruba, Bahamas, Bahrain, Bangladesh, Barbados, Belize, Benin, Brazil, Brunei Darussalam, Burkina Faso, Cambodia, Cayman Islands, Central African Republic, Chad, Comoros, Côte d'Ivoire, Djibouti, Gabon, Gambia, Ghana, Guinea, Guinea-Bissau, Indonesia, Jamaica, Kuwait, Liberia, Malaysia, Maldives, Mali, Mauritania, Nicaragua, Niger, Nigeria, Oman, Panama, Philippines, Qatar, Saint Lucia, Saudi Arabia, Senegal, Seychelles, Sierra Leone, Singapore, Sri Lanka, St. Vincent and the Grenadines, Sudan (Former), Suriname, Thailand, Togo, Trinidad and Tobago, United Arab Emirate, Venezuela (Bolivia)
Weather variables are taken from BHM (Total Countries 153)
Less than 10 ºC: Armenia, Austria, Belarus, Belgium, Bosnia and Herzegovina, Canada, Chile, Czech Republic, Denmark, Estonia, Finland, Germany, Iceland, Ireland, Kazakhstan, Kyrgyzstan, Latvia, Lithuania, Luxembourg, Mongolia, Netherlands, Norway, Poland, Republic of Moldova, Russian, Federation, Slovakia, Slovenia, Sweden, Switzerland, TFYR of Macedonia, Ukraine, United Kingdom
10 ºC to 15 ºC: Albania, Azerbaijan, Bhutan, Bulgaria, China, Croatia, France, Georgia, Greece, Hungary, Italy, Japan, Lebanon, Lesotho, New Zealand, Republic of Korea, Serbia, Spain, Tajikistan, Turkey, United States, Uzbekistan
15 ºC to 20 ºC: Algeria, Argentina, Australia, Bolivia (Plurinational State of), Cyprus, Ecuador, Ethiopia, Iran (Islamic Republic), Jordan, Kenya, Mexico, Morocco, Peru, Portugal, South Africa, Syrian Arab Republic, Tunisia, Turkmenistan, Uruguay
20 ºC to 25 ºC: Angola, Botswana, Brazil, Burundi, Cabo Verde, Cameroon, Colombia, Costa Rica, Egypt, El Salvador, Equatorial Guinea, Fiji, Guatemala, Honduras, Iraq, Israel, Jamaica, Lao People's DR, Madagascar, Malawi, Mauritius, Mozambique, Namibia, Nepal, Pakistan, Paraguay, Rwanda, Swaziland, U.R. of Tanzania, Uganda, Viet Nam, Yemen, Zambia, Zimbabwe
More than 25 ºC: Anguilla, Aruba, Bahamas, Bahrain, Bangladesh, Barbados, Belize, Benin, Bermuda, Brunei Darussalam, Burkina Faso, Cambodia, Cayman Islands, Central African Republic, Chad China Macao SAR, Comoros, Congo, Côte d'Ivoire, Djibouti, Dominican Republic, Gabon, Gambia, Ghana, Guinea, Guinea-Bissau, Haiti, India, Indonesia, Kuwait, Liberia, Malaysia, Maldives, Mali, Malta, Mauritania, Montenegro, Myanmar, Nicaragua, Niger, Nigeria, Oman,

Panama, Philippines, Qatar, Saint, Lucia, Sao Tome and Principe, Saudi Arabia, Senegal, Seychelles, Sierra Leone, Singapore, Sri Lanka, St. Vincent and, Sudan (Former), Suriname, Thailand, Togo, Trinidad and Tobago, United Arab Emirate, Venezuela (Bolivia)

Table A1: Descriptive statistics

Variable	Obs	Unit	Mean	Std. Dev.	Min	Max
All Countries						
Real GDP at constant 2011 national prices	7,952	Million 2011US$	323293	1090965	42.11	1.72e+07
Capital stock GDP at constant 2011 national prices	7,952	Million 2011US$	1044899	3578327	317.68	6.76e+07
Number of persons engaged (Employment)	7,952	Millions	14.50	57. 5	.001	798.37
Temperature (BHM)	6,167	Celsius (^{0}C)	18.66	7.30	-2.37	29.61
Precipitation (BHM)	6,167	Millimeters (mm)	1088.09	698.27	5.38	4877.74
Temperature (WB)	7,952	Celsius (^{0}C)	18.77	8.14	-8.89	29.75
Precipitation (WB)	7,952	Millimeters (mm)	1121.264	768.62	11.27	4370.79
Rich Countries						
Real GDP at constant 2011 national prices	4503	Million 2011US$	441940.6	1230183	42.11	1.65e+07
Capital stock GDP at constant 2011 national prices	4503	Million 2011US$	1461970	3999648	317.68	5.12e+07
Number of persons engaged (Employment)	4503	Millions	8.90	17.75	0.001	148.46
Temperature (BHM)	3352	Celsius (^{0}C)	15.38	7.077	-0.32	28.27
Precipitation (BHM)	3352	Millimeters (mm)	990.44	689.02	5.38	4877.74
Temperature (WB)	4503	Celsius (^{0}C)	15.77	8.39	-8.89	29.03
Precipitation (WB)	4503	Millimeters (mm)	1070.44	789.32	11.27	4370.79
Poor Countries						
Real GDP at constant 2011 national prices	3449	Million 2011US$	168387.1	852194.8	267.33	1.72e+07
Capital stock GDP at constant 2011 national prices	3449	Million 2011US$	500373.4	2848797	405.58	6.76e+07

Number of persons engaged (Employment)	3449	Millions	21.81	84.37	0.03	798.37
Temperature (BHM)	2815	Celsius (^{0}C)	22.57	5.39	-2.37	29.61
Precipitation (BHM)	2815	Millimeters (mm)	1204.37	691.48	9.12	4008.5
Temperature (WB)	3449	Celsius (^{0}C)	22.68	5.83	-1.55	29.75
Precipitation (WB)	3449	Millimeters (mm)	1187.62	735.57	18.62	3605.38

Note: A country is defined to be poor if its per capita income, adjusted for purchasing-power-parity (PPP), was below the sample median in 1980, which was 2011US$ 5173. Number countries are 77 and number of countries are 91 for un-weighted temperature and economic variables. However, Number of countries are153 (poor: 73 and rich: 80) for population weighted climatic variables. WB and BHM in parentheses implies that the information on temperature and precipitation are taken from the World Bank and Burke et al. (2015), respectively.

Table A1.1: Im-Pesaran-Shin panel unit-root test

In Levels		In First Difference	
Variable	Z-t-tilde-bar	Variable	Z-t-tilde-bar
Ln(real GDP)	10.30	Ln(real GDP)	-40.56***
ln(capital stock)	19.73	ln(capital stock)	-7.70***
ln(employment)	18.96	ln(employment)	-35.08***
Temperature (BHM)	-24.19***		
Precipitation (BHM)	-38.26***		
Temperature (WB)	-28.87***		
Precipitation (WB)	-49.06***		

Note: Ho: All panels contain unit roots; Ha: Some panels are stationary
*** Significant at the 1 percent level.

Table A1.2: Panel unit root tests for economic variables

		(A) Maddala and Wu (1999) (MW)		(B) Pesaran (2007) (CIPS)	
		without trend	with trend	without trend	with trend
Variable	Lags	chi_sq	chi_sq	Zt-bar	Zt-bar
In Levels					
Ln(real GDP)	0	652.02***	378.79	-0.97	4.47
	1	333.77	660.09***	-0.20	1.03
	2	372.37	371.89	0.37	3.01
	3	381.04	418.05	1.28	5.59
	4	329.53	290.41	2.82	7.39
Ln(capital stock)	0	1902.24***	337.73	5.65	19.44
	1	314.45	400.43***	2.01	4.26
	2	313.57	257.73	4.96	10.23
	3	297.67	315.55	5.45	9.58
	4	296.29	341.88	5.69	11.85
Ln(employment)	0	527.19***	361.18	13.17	4.54
	1	219.62	503.26***	11.36	-2.49***
	2	189.26	362.50	12.43	0.81
	3	168.26	365.86	13.07	0.76
	4	157.48	286.34	13.90	2.82
In First Difference					
ln(real GDP)	0	4243.57***	4029.27***	-44.48***	-44.21***
	1	2734.53***	2501.23***	-30.68***	-29.63***
	2	1666.09***	1495.88***	-19.93***	-18.45***
	3	1260.53***	1128.54***	-13.57***	-11.81***
	4	912.41***	888.15***	-6.91***	-5.38***
ln(capital stock)	0	597.27***	613.73***	-8.33***	-9.55***
	1	672.79***	666.49***	-9.20***	-11.39***
	2	511.63***	509.97***	-3.41***	-5.23***
	3	487.22***	436.97***	-2.21**	-3.81***

	4	445.53***	476.61***	0.30	-1.67**
ln(employment)	0	3835.52***	3426.46***	-36.90***	-35.15***
	1	2237.52***	1915.29***	-26.19***	-23.31***
	2	1378.30***	1094.61***	-15.14***	-11.36***
	3	1098.66***	853.16***	-10.76***	-6.95***
	4	863.85***	667.42***	-6.08***	-2.31**

Note: Null for MW and CIPS tests: series is I(1). MW test assumes cross-section independence. CIPS test assumes cross-section dependence is in form of a single unobserved common factor.
*** Significant at the 1 percent level.
** Significant at the 5 percent level.

Table 1.3 Panel unit root tests for weather variables

		(A) Maddala and Wu (1999) (MW)		(B) Pesaran (2007) (CIPS)	
		without trend	with trend	without trend	with trend
Variable	Lags	chi_sq	chi_sq	Zt-bar	Zt-bar
In Levels					
Temperature (BHM)	0	1732.84***	2592.19***	-22.85***	-33.06***
	1	963.85***	1716.64***	-12.45***	-23.68***
	2	550.10***	909.44***	-2.44***	-12.01***
	3	414.62***	695.60***	2.88	-4.84***
	4	272.44	484.91***	4.35	-3.71***
Precipitation (BHM)	0	3807.29***	3384.58***	-42.42***	-40.48***
	1	1874.85***	1607.08***	-24.41***	-21.75***
	2	1235.28***	982.53***	-15.31***	-11.82***
	3	1018.61***	793.97***	-12.01***	-8.23***
	4	743.28***	564.01***	-6.38***	-2.37***
Temperature (WB)	0	2104.22***	3452.17***	-31.27***	-45.06***
	1	1024.45***	1951.55***	-14.57***	-27.73***
	2	528.87***	1064.59***	-4.93***	-15.38***
	3	381.85**	844.66***	-0.89	-11.36***
	4	318.06	651.34***	2.61	-5.26***
Precipitation (WB)	0	5786.70***	5309.68***	-50.13***	-49.13***
	1	2983.76***	2707.63***	-33.90***	-32.29***
	2	1893.09***	1654.45***	-22.81***	-20.33***
	3	1385.22***	1183.67***	-15.50***	-12.74***
	4	1045.54***	910.46***	-10.21***	-6.41***

Note: Null for MW and CIPS tests: series is I(1). MW test assumes cross-section independence. CIPS test assumes cross-section dependence is in form of a single unobserved common factor.

*** Significant at the 1 percent level.

Table A2: Cross-sectional depedence test

Pesaran's test of cross sectional independence: 54.64***	Without year dummies, weather variables (BHM)
Pesaran's test of cross sectional independence: -0.12	With year dummies, weather variables (BHM)
Pesaran's test of cross sectional independence: 58.24***	Without year dummies, weather variables (WB)
Pesaran's test of cross sectional independence: -0.12	With year dummies, weather variables (WB)

Note: Ho: Cross-sectional independence; Ha: Cross-sectional dependence
*** Significant at the 1 percent level.

Table A3.1: Pedroni Co-integration tests

	Area		Population	
Test Stats.	Panel	Group	Panel	Group
v	5.663***	.	4.643***	.
rho	-36.63***	-27.95***	-24.72***	-18.38***
t	-48.49***	-53.93***	-37.7***	-42.73***
adf	-38.73***	-36.97***	-29.88***	-29.56***

All test statistics are distributed N(0,1), under a null of no cointegration, and diverge to negative infinity (save for panel v).
*** Significant at the 1 percent level.

Table A3.2: Westerlund ECM panel co-integration tests

	Area		Population	
Statistic	Value	Z-value	Value	Z-value
Gt	-3.81***	-35.36	-3.61***	-31.26
Ga	-27.44***	-67.36	-23.08***	-52.42
Pt	-63.62***	-48.84	-57.54***	-43.89
Pa	-32.96***	-142.95	-27.84***	-114.56

Results for H0: no co-integration
*** Significant at the 1 percent level.

Table A4: Parameter estimates of stochastic frontier

	Weather variables are taken from Burke et al. (2015)		Weather variables are taken from the World Bank	
	(1)	(2)	(3)	(4)
Frontier				
Δ*ln*(rkna)	0.570***	0.573***	0.562***	0.570***
	(27.6)	(27.84)	(31.31)	(31.65)
Δ*ln*(emp)	0.286***	0.292***	0.295***	0.302***

	(13.01)	(13.28)	(14.55)	(14.87)
Year fixed effects	Yes	Yes	Yes	Yes
$\Delta\mu$				
Temperature	0.946***	0.914**	0.635**	0.612***
	(3.5)	(2.55)	(2.41)	(2.82)
Precipitation	0.005***	0.003	0.006***	0.004***
	(4.29)	(1.55)	(4.16)	(4.21)
Poor×Temperature		-0.178		0.165
		(-1.17)		(0.78)
Poor×Precipitation		0.002		-0.005
		(1.17)		(-1.35)
Constant	-47.10***	-35.86	-42.71***	-32.11***
	(-4.22)	(-1.6)	(-4.21)	(-4.4)
$\Delta\sigma_u$				
Temperature	-0.032***	-0.036***	-0.019**	-0.020**
	(-4.88)	(-3.59)	(-2.32)	(-2.18)
Precipitation	-0.0005***	-0.001***	-0.0005***	-0.001***
	(-13.86)	(-12.31)	(-15.13)	(-17.29)
Poor×Temperature		-0.017*		-0.037**
		(-1.71)		(-2.43)
Poor×Precipitation		0.0004***		0.001***
		(3.5)		(3.3)
Constant	0.729***	0.534	0.483*	0.242
	(2.84)	(0.83)	(1.86)	(0.95)
$\Delta\sigma_v$				
Constant	-6.296***	-6.286***	-6.251***	-6.244***
	(-267.62)	(-266.78)	(-303.16)	(-302.73)
E($\Delta\sigma_u$)	0.840***	0.685***	0.824***	0.688***
	(89.65)	(78.86)	(106.09)	(99.27)
$\Delta\sigma_v$	0.043***	0.043***	0.044***	0.044***
	(85.01)	(84.87)	(97.0)	(96.96)
Log likelihood	9296.98	9330.03	11849.54	11882.84

Number of obs	6112	6112	7784	7784
Number of Countries	153	153	168	168

Note: Dependent variable is Δln(rgdpna) and independent variables in frontier are Δln(rkna) and Δln(emp). In the equations of Mu and Usigma the indepdeent variables are temperature and precipitation in levels. Figures in parentheses are t-statistics. A country is defined to be poor if its per capita income, adjusted for purchasing-power-parity (PPP), was below the sample median in 1980, which was 2011US$ 5173. Sample includes all the countries for which the complete panel data on both climate and economic variables is available for at least eighteen years.

*** Significant at the 1 percent level.

** Significant at the 5 percent level.

* Significant at the 10 percent level

Table A5: Parameter estimates of stochastic frontier (for different samples)

	Excluding SSA (BHM)	Excluding SSA (WB)	Only SSA (BHM)	Only SSA (WB)	Sample 1970 to 2014 (WB)	Sample 1990-2014 (WB)	Sample 1960-2010 (WB)
	(1)	(2)	(3)	(4)	(5)	(6)	(7)
Frontier							
Δln(rkna)	0.539***	0.575***	0.562***	0.521***	0.548***	0.523***	0.587***
	(20.65)	(25.62)	(16.21)	(16.55)	(29.14)	(22.86)	(29.07)
Δln(emp)	0.314***	0.319***	0.164***	0.158***	0.285***	0.238***	0.280***
	(12.68)	(14.01)	(3.75)	(3.72)	(13.95)	(9.93)	(13.0)
Year fixed effects	Yes	Yes	Yes	Yes	Yes	Yes	Yes
$\Delta\mu$							
Temperature	0.692***	0.629**	0.164	1.325	0.706**	0.993*	0.767***
	(3.25)	(2.58)	(0.22)	(1.41)	(2.43)	(1.85)	(2.83)
Precipitation	0.004***	0.004***	0.008*	-0.016**	0.006***	0.007**	0.006***
	(3.97)	(4.24)	(1.88)	(-2.1)	(4.04)	(2.43)	(4.98)
Constant	-36.792***	-33.870***	-31.213	-40.785	-46.18***	-56.514**	-45.51***
	(-4.09)	(-3.9)	(-1.31)	(1.44)	(-4.05)	(-2.43)	(-4.87)
$\Delta\sigma_u$							
Temperature	-0.025***	-0.024***	-0.0001	-0.071**	-0.022***	-0.040***	-0.026***
	(-3.5)	(-2.73)	(1.10)	(-2.17)	(-2.64)	(-4.05)	(-3.15)
Precipitation	-0.001	-0.001	-0.0002	0.001	-0.0005	-0.0004	-0.0005

	(-15.74)	(-19.23)	(-1.28)	(7.76)	(-12.93)	(-6.3)	(-14.21)
Constant	0.535**	0.320	-0.690	0.006	0.604**	0.98**	0.645***
	(2.04)	(1.13)	(-0.61)	(0.01)	(2.23)	(2.24)	(2.76)
$\Delta\sigma_v$							
Constant	-6.46***	-6.34***	-5.98***	-6.05***	-6.34***	-6.29***	-6.17***
	(-233.39)	(-267.87)	(-135.06)	(-146.4)	(-274.72)	(-225.09)	(-277.25)
E($\Delta\sigma_u$)	0.772***	0.698***	0.650***	0.799***	0.867***	0.931***	0.843***
	(66.95)	(70.15)	(262.88)	(32.70)	(97.42)	(63.05)	(90.63)
$\Delta\sigma_v$	0.040***	0.042***	0.050***	0.049***	0.042***	0.043***	0.046***
	(72.26)	(84.51)	(45.17)	(48.44)	(86.72)	(71.51)	(89.85)
Log likelihood	7047.28	9191.66	2403.43	2807.46	9891.83	6127.72	9806.23
Number of obs	4450	5870	1662	1914	6415	4002	6609
Number of Countries	110	124	43	44	168	168	168

Note: SSA: Sub Saharan Africa. Dependent variable is Δln(rgdpna) and independent variables in frontier are Δln(rkna) and Δln(emp). In the equations of Mu and Usigma the indepdeent variables are temperature and precipitation in levels. Figures in parentheses are t-statistics. Sample includes all the countries for which the complete panel data on both climate and economic variables is available for at least eighteen years.

*** Significant at the 1 percent level.

** Significant at the 5 percent level.

* Significant at the 10 percent level.

Table A6: Average annual marginal effects of temperature on mean and variance of production efficiency growth at the country level (percentage points)

Country	Country Code	Average Annual Temperature (ºC) (BHM)	$\partial E(\Delta\mu)/\partial T$ (BHM)	$\partial \Delta\sigma_u^2/\partial T$ (BHM)	Average Annual Temperature (ºC) (WB)	$\partial E(\Delta\mu)/\partial T$ (WB)	$\partial \Delta\sigma_u^2/\partial T$ (WB)
Iceland	ISL	1.44	-0.0207	-0.0012	1.90	0.0063	0.0003
Finland	FIN	3.42	-0.0209	-0.0014	1.67	0.0035	0.0002
Russian Federation	RUS	4.32	-0.0191	-0.0013	-5.22	-0.0052	-0.0003
Norway	NOR	4.65	-0.0107	-0.0006	1.13	0.0054	0.0002
Sweden	SWE	5.65	-0.0137	-0.0009	1.83	0.0044	0.0002
Estonia	EST	5.65	-0.0132	-0.0008	6.18	0.0108	0.0006
Canada	CAN	5.65	-0.0096	-0.0005	-6.56	-0.0063	-0.0004
Kazakhstan	KAZ	6.34	-0.0166	-0.0012	6.69	0.0096	0.0007
Latvia	LVA	6.54	-0.0102	-0.0006	6.71	0.0117	0.0006
Belarus	BLR	6.76	-0.0098	-0.0006	7.39	0.0126	0.0007
Lithuania	LTU	6.93	-0.0089	-0.0006	7.24	0.0125	0.0007
Switzerland	CHE	7.29	-0.0011	-0.0001	6.34	0.0134	0.0005
Austria	AUT	7.70	-0.0029	-0.0002	6.52	0.0129	0.0006
Denmark	DNK	7.85	-0.0066	-0.0004	8.09	0.0142	0.0008
Czech Republic	CZE	7.96	-0.0056	-0.0004	8.70	0.0152	0.0008
Poland	POL	8.05	-0.0059	-0.0004	8.24	0.0141	0.0008
Slovakia	SVK	8.42	-0.0031	-0.0002	8.38	0.0148	0.0008
Slovenia	SVN	8.56	0.0023	0.0001	9.66	0.0185	0.0008
Ukraine	UKR	8.57	-0.0043	-0.0003	9.03	0.0154	0.0009
Germany	DEU	8.76	-0.0011	-0.0001	8.86	0.0156	0.0009
Ireland	IRL	8.82	0.0013	0.0001	9.33	0.0175	0.0008
Luxembourg	LUX	9.02	-0.0003	0.0000	9.32	0.0171	0.0008
United Kingdom	GBR	9.40	0.0015	0.0001	8.65	0.0164	0.0007
Chile	CHL	9.86	0.0015	0.0001	8.34	0.0143	0.0008
Netherlands	NLD	9.90	0.0032	0.0002	9.69	0.0174	0.0009
Belgium	BEL	9.95	0.0037	0.0002	9.89	0.0180	0.0009
TFYR of Macedoni	MKD	9.96	0.0021	0.0001	10.50	0.0186	0.0011
Bulgaria	BGR	10.08	0.0022	0.0001	10.87	0.0193	0.0011
Serbia	SRB	10.13	0.0030	0.0002	11.05	0.0201	0.0011
Hungary	HUN	10.27	0.0027	0.0002	10.43	0.0184	0.0011
France	FRA	10.90	0.0074	0.0004	11.10	0.0205	0.0011
Georgia	GEO	11.30	0.0103	0.0005	7.05	0.0131	0.0006
Republic of Korea	KOR	11.51	0.0129	0.0006	11.00	0.0212	0.0009
Croatia	HRV	11.89	0.0129	0.0007	11.39	0.0216	0.0010

Turkey	TUR	12.31	0.0126	0.0008	11.31	0.0201	0.0012
New Zealand	NZL	12.70	0.0176	0.0008	9.93	0.0195	0.0007
Italy	ITA	12.84	0.0175	0.0009	12.03	0.0227	0.0012
Azerbaijan	AZE	12.97	0.0145	0.0010	11.71	0.0207	0.0013
United States	USA	13.43	0.0203	0.0011	7.10	0.0122	0.0007
Lebanon	LBN	13.83	0.0227	0.0012	16.11	0.0330	0.0021
Japan	JPN	13.86	0.0238	0.0009	10.82	0.0212	0.0008
Spain	ESP	14.48	0.0250	0.0016	13.35	0.0252	0.0015
Greece	GRC	14.92	0.0277	0.0017	14.01	0.0271	0.0016
Iran (Islamic Republic of)	IRN	15.07	0.0273	0.0020	17.28	0.0362	0.0027
Portugal	PRT	15.10	0.0298	0.0016	14.99	0.0302	0.0016
Peru	PER	15.36	0.0308	0.0019	19.49	0.0490	0.0021
Turkmenistan	TKM	15.81	0.0317	0.0026	15.97	0.0315	0.0024
Australia	AUS	16.54	0.0395	0.0022	21.62	0.0558	0.0039
Algeria	DZA	16.85	0.0417	0.0029	22.98	0.0621	0.0053
Argentina	ARG	17.23	0.0449	0.0025	14.37	0.0278	0.0017
South Africa	ZAF	17.44	0.0468	0.0029	17.76	0.0386	0.0026
Jordan	JOR	17.55	0.0475	0.0038	18.83	0.0418	0.0033
Uruguay	URY	17.96	0.0510	0.0027	17.74	0.0403	0.0019
Mexico	MEX	18.71	0.0583	0.0033	20.78	0.0523	0.0032
Cyprus	CYP	18.72	0.0595	0.0044	18.98	0.0434	0.0029
Ecuador	ECU	19.34	0.0641	0.0031	21.40	0.0665	0.0025
Israel	ISR	20.15	0.0770	0.0060	19.70	0.0459	0.0035
Colombia	COL	20.52	0.0775	0.0032	24.45	0.1245	0.0047
Namibia	NAM	21.48	0.0971	0.0079	20.59	0.0499	0.0038
Angola	AGO	21.92	0.1016	0.0061	21.74	0.0584	0.0033
Guatemala	GTM	21.92	0.1023	0.0041	23.51	0.1057	0.0038
Iraq	IRQ	22.01	0.1075	0.0093	21.93	0.0566	0.0045
Brazil	BRA	22.02	0.1025	0.0049	25.09	0.0956	0.0045
Paraguay	PRY	22.03	0.1028	0.0051	23.45	0.0706	0.0039
Costa Rica	CRI	22.13	0.1480	0.0035	24.69	0.1849	0.0071
Jamaica	JAM	24.86	0.1935	0.0093	25.07	0.1211	0.0053
Dominican Republic	DOM	25.04	0.1892	0.0106	24.02	0.0791	0.0040
Gabon	GAB	25.15	0.2050	0.0103	25.13	0.0982	0.0046
Venezuela (Bolivia)	VEN	25.25	0.1913	0.0126	25.50	0.1088	0.0049
Bahamas	BHS	25.41	0.1986	0.0130	25.18	0.0876	0.0048
Panama	PAN	25.42	0.3051	0.0128	25.31	0.1448	0.0058
Trinidad and Tobago	TTO	25.50	0.2206	0.0118	26.24	0.1076	0.0056
Kuwait	KWT	25.57	0.2003	0.0203	25.64	0.0805	0.0070
Saudi Arabia	SAU	25.74	0.2066	0.0211	25.04	0.0756	0.0067
Malaysia	MYS	25.96	0.3217	0.0148	25.41	0.2141	0.0088
Oman	OMN	26.08	0.2181	0.0225	25.79	0.0813	0.0072

Qatar	QAT	26.80	0.2507	0.0272	27.48	0.0959	0.0088
Suriname	SUR	26.91	0.3567	0.0201	25.87	0.1369	0.0059
United Arab Emirates	ARE	26.92	0.2560	0.0273	27.25	0.0937	0.0086
Brunei Darussalam	BRN	27.13	1.7561	0.1730	25.63	0.9525	0.0904
Montenegro	MNE	.	.	.	9.52	0.0179	0.0008
Malta	MLT	.	.	.	18.85	0.0428	0.0029
Bermuda	BMU	.	.	.	21.81	0.0621	0.0029
China, Macao SAR	MAC	.	.	.	23.08	0.0812	0.0032
Anguilla	AIA	.	.	.	25.66	0.1030	0.0051
Barbados	BRB	.	.	.	26.38	0.1424	0.0066
Seychelles	SYC	.	.	.	27.30	0.1269	0.0067
Singapore	SGP	.	.	.	27.34	0.2057	0.0099
Bahrain	BHR	.	.	.	27.37	0.0950	0.0087
Cayman Islands	CYM	.	.	.	27.55	0.1163	0.0069
Aruba	ABW	.	.	.	28.34	0.1164	0.0083
Rich Countries		**14.98**	**0.0828**	**0.0062**	**15.86**	**0.0616**	**0.0038**
Mongolia	MNG	-0.80	-0.0469	-0.0044	0.28	-0.0035	-0.0003
Kyrgyzstan	KGZ	6.93	-0.0168	-0.0012	3.06	0.0012	0.0001
Armenia	ARM	8.37	-0.0110	-0.0008	7.86	0.0099	0.0006
Bosnia and Herzegovina	BIH	9.65	0.0073	0.0004	10.42	0.0132	0.0009
Republic of Moldova	MDA	9.72	-0.0049	-0.0003	10.33	0.0148	0.0009
Lesotho	LSO	11.68	0.0057	0.0003	13.26	0.0202	0.0012
Tajikistan	TJK	11.97	0.0014	0.0001	3.96	0.0025	0.0002
Bhutan	BTN	12.75	0.1055	0.0055	11.86	0.0135	0.0009
Albania	ALB	13.25	0.0218	0.0012	11.69	0.0162	0.0010
China	CHN	14.07	0.0203	0.0011	6.54	0.0072	0.0005
Uzbekistan	UZB	14.27	0.0064	0.0004	13.09	0.0215	0.0012
Morocco	MAR	16.76	0.0182	0.0010	17.55	0.0325	0.0017
Syrian Arab Repu	SYR	17.41	0.0199	0.0011	18.01	0.0341	0.0018
Bolivia (Plurinational State of)	BOL	17.41	0.0350	0.0019	20.88	0.0402	0.0021
Tunisia	TUN	18.74	0.0253	0.0014	19.82	0.0402	0.0020
Ethiopia	ETH	19.19	0.0477	0.0025	22.68	0.0490	0.0025
Kenya	KEN	19.95	0.0570	0.0029	24.65	0.0603	0.0030
Swaziland	SWZ	20.10	0.0417	0.0022	20.32	0.0394	0.0021
Rwanda	RWA	20.28	0.0545	0.0028	19.77	0.0359	0.0020
Zimbabwe	ZWE	20.46	0.0401	0.0021	21.69	0.0457	0.0023
Burundi	BDI	20.56	0.0553	0.0028	20.68	0.0389	0.0021
Madagascar	MDG	20.56	0.0773	0.0039	22.80	0.0461	0.0025
Nepal	NPL	20.77	0.0771	0.0039	12.64	0.0172	0.0011
Cabo Verde	CPV	21.07	0.0458	0.0024	23.01	0.0536	0.0027

Zambia	ZMB	21.18	0.0558	0.0029	21.84	0.0444	0.0023
Botswana	BWA	21.18	0.0364	0.0019	22.18	0.0494	0.0025
Egypt	EGY	21.33	0.0271	0.0015	22.52	0.0533	0.0026
Malawi	MWI	22.13	0.0651	0.0033	22.06	0.0449	0.0023
Uganda	UGA	22.18	0.0731	0.0037	22.93	0.0478	0.0025
U.R. of Tanzania	TZA	22.26	0.0642	0.0033	22.60	0.0475	0.0025
El Salvador	SLV	22.78	0.1127	0.0059	24.22	0.0505	0.0027
Pakistan	PAK	22.99	0.0455	0.0024	20.15	0.0412	0.0021
Yemen	YEM	23.14	0.0419	0.0022	23.86	0.0597	0.0029
Fiji	FJI	23.80	0.4339	0.0358	24.25	0.0456	0.0026
Lao People's DR	LAO	23.89	0.1313	0.0069	23.72	0.0478	0.0026
Mozambique	MOZ	24.15	0.0773	0.0039	23.86	0.0536	0.0028
Mauritius	MUS	24.18	0.1363	0.0077	23.48	0.0468	0.0026
Cameroon	CMR	24.22	0.1375	0.0073	24.72	0.0539	0.0029
Honduras	HND	24.41	0.1125	0.0058	23.80	0.0475	0.0026
Equatorial Guinea	GNQ	24.53	0.1784	0.0099	24.78	0.0504	0.0028
Viet Nam	VNM	24.76	0.1429	0.0077	24.33	0.0504	0.0027
Congo	COG	25.02	0.1205	0.0063	24.74	0.0539	0.0029
Central African	CAF	25.05	0.1132	0.0059	25.14	0.0581	0.0030
Indonesia	IDN	25.32	0.2716	0.0169	25.93	0.0517	0.0030
Comoros	COM	25.33	0.2726	0.0174	25.61	0.0583	0.0031
Guinea	GIN	25.33	0.1900	0.0107	26.05	0.0609	0.0032
India	IND	25.58	0.1043	0.0054	24.27	0.0554	0.0029
Bangladesh	BGD	25.63	0.2181	0.0128	25.18	0.0515	0.0029
Sao Tome and Principe	STP	25.83	0.1562	0.0086	23.86	0.0466	0.0026
Philippines	PHL	25.90	0.3448	0.0234	25.61	0.0529	0.0030
Liberia	LBR	25.94	0.4188	0.0296	25.56	0.0532	0.0030
Belize	BLZ	25.97	0.2051	0.0117	25.56	0.0549	0.0030
Gambia	GMB	26.22	0.0965	0.0049	27.88	0.0819	0.0042
Côte d'Ivoire	CIV	26.23	0.1406	0.0075	26.43	0.0657	0.0034
Nicaragua	NIC	26.29	0.1507	0.0081	25.16	0.0510	0.0029
Sri Lanka	LKA	26.46	0.4292	0.0303	26.86	0.0656	0.0035
Togo	TGO	26.48	0.1161	0.0060	27.36	0.0749	0.0039
Sierra Leone	SLE	26.51	0.4489	0.0326	26.27	0.0565	0.0031
St. Vincent and the Grenadines	VCT	26.54	0.2375	0.0143	27.57	0.0713	0.0038
Ghana	GHA	26.66	0.1322	0.0070	27.33	0.0743	0.0039
Nigeria	NGA	26.72	0.1405	0.0074	26.89	0.0712	0.0037
Senegal	SEN	26.81	0.0815	0.0041	28.25	0.0892	0.0046
Thailand	THA	26.99	0.1587	0.0086	26.35	0.0635	0.0034
Guinea-Bissau	GNB	27.00	0.1653	0.0090	27.23	0.0702	0.0037
Benin	BEN	27.23	0.1214	0.0063	27.87	0.0806	0.0042

Cambodia	KHM	27.69	0.1860	0.0104	27.21	0.0662	0.0036
Burkina Faso	BFA	27.85	0.1068	0.0055	28.39	0.0895	0.0046
Sudan (Former)	SDN	27.97	0.0829	0.0042	27.13	0.0826	0.0041
Djibouti	DJI	28.06	0.0726	0.0037	28.06	0.0945	0.0048
Chad	TCD	28.09	0.1029	0.0053	27.17	0.0839	0.0042
Mali	MLI	28.12	0.1031	0.0053	28.55	0.0996	0.0051
Niger	NER	28.37	0.0880	0.0045	27.48	0.0894	0.0045
Mauritania	MRT	28.59	0.0769	0.0039	28.26	0.1001	0.0050
Myanmar	MMR	.	.	.	22.99	0.0450	0.0025
Haiti	HTI	.	.	.	24.73	0.0551	0.0029
Saint Lucia	LCA	.	.	.	26.36	0.0570	0.0032
Maldives	MDV	.	.	.	28.12	0.0704	0.0038
Poor Countries		**22.05**	**0.1124**	**0.0066**	**22.15**	**0.0511**	**0.0027**

Note: These marginal effects are based on the stochastic production function estimates presented in Table 2 (Version 3, for both WB and BHM weather variables).

Table A7: Projected production efficiency growth impacts of temperature change based on RCP 8.5

Country	Country code	Temperature change in 2020-40 over 2000-10	Marginal effects on mean of TFP growth (2020-40)	Marginal effects on variance of TFP growth (2020-40)	Temperature change in 2080-2100 over 2000-10	Marginal effects on mean of TFP growth (2080-2100)	Marginal effects on variance of TFP growth (2080-2100)
Albania	ALB	5.01	0.054	0.003	8.26	0.127	0.007
Algeria	DZA	0.87	0.134	0.007	4.68	0.213	0.009
Angola	AGO	2.43	0.151	0.009	5.68	0.254	0.011
Argentina	ARG	1.84	0.037	0.002	4.24	0.057	0.003
Armenia	ARM	2.06	-0.007	0.000	5.72	0.005	0.000
Australia	AUS	1.70	0.115	-0.001	4.64	0.163	0.010
Austria	AUT	3.66	0.008	0.000	6.80	0.031	0.002
Azerbaijan	AZE	1.44	0.015	0.001	4.80	0.037	0.003
Bangladesh	BGD	1.35	0.212	0.012	4.29	0.936	0.055
Belarus	BLR	1.69	-0.004	0.000	5.02	-0.004	-0.001
Belgium	BEL	1.72	0.010	0.001	4.43	0.022	0.001
Belize	BLZ	0.82	0.205	0.012	3.40	0.698	0.040
Benin	BEN	0.20	0.144	0.008	3.11	0.242	0.014
Bhutan	BTN	2.78	0.046	0.002	5.99	0.632	0.033
Botswana	BWA	0.94	0.042	0.002	4.86	0.068	0.003
Brazil	BRA	1.24	0.224	0.011	4.37	0.364	0.017

Bulgaria	BGR	3.43	0.029	0.002	6.90	0.066	0.004
Burkina Faso	BFA	0.79	0.128	0.007	4.01	0.267	0.015
Burundi	BDI	1.59	0.064	0.003	4.62	0.088	0.004
Cambodia	KHM	-0.54	0.139	0.007	2.02	0.191	0.010
Cameroon	CMR	0.18	0.145	0.008	2.97	0.091	0.005
Canada	CAN	3.51	-0.018	-0.001	8.55	-0.017	-0.001
Central African	CAF	0.79	0.127	0.007	3.79	0.209	0.012
Chad	TCD	0.71	0.099	0.005	4.08	0.197	0.011
Chile	CHL	2.72	0.007	0.000	5.22	0.023	0.001
China	CHN	0.57	0.020	0.001	4.32	0.013	0.001
Colombia	COL	1.00	0.161	-0.008	3.98	0.223	0.013
Comoros	COM	1.37	0.602	0.038	3.61	1.329	0.071
Congo	COG	0.34	0.121	0.006	3.31	0.148	0.007
Costa Rica	CRI	2.64	0.470	0.018	5.05	0.712	0.030
Croatia	HRV	2.65	0.023	0.001	5.85	0.043	0.003
Cyprus	CYP	1.26	0.078	0.006	4.12	0.122	0.010
Czech Republic	CZE	1.34	0.002	0.000	4.37	0.013	0.001
Denmark	DNK	1.99	0.005	0.000	4.42	0.026	0.002
Djibouti	DJI	-1.44	0.062	0.003	1.48	0.080	0.004
Ecuador	ECU	2.01	0.115	0.001	4.73	0.158	0.015
Egypt	EGY	1.75	0.039	0.002	5.26	0.053	0.003
El Salvador	SLV	3.70	-0.036	-0.003	6.29	0.708	0.037
Estonia	EST	1.03	-0.011	-0.001	4.36	-0.016	-0.002
Ethiopia	ETH	1.12	0.077	0.004	3.95	0.102	0.005
Fiji	FJI	2.14	1.412	0.070	4.10	1.914	-0.029
Finland	FIN	0.85	-0.024	-0.002	4.68	-0.010	-0.001
France	FRA	1.98	0.016	0.001	4.85	0.027	0.002
Gabon	GAB	0.67	0.239	0.013	3.28	0.497	0.028
Georgia	GEO	2.80	0.005	0.000	6.22	0.020	0.001
Germany	DEU	1.40	0.004	0.000	4.24	0.013	0.001
Ghana	GHA	0.42	0.137	0.007	3.11	0.092	0.005
Greece	GRC	3.63	0.049	0.003	6.87	0.085	0.004
Guatemala	GTM	2.45	0.216	0.012	5.31	0.341	0.023

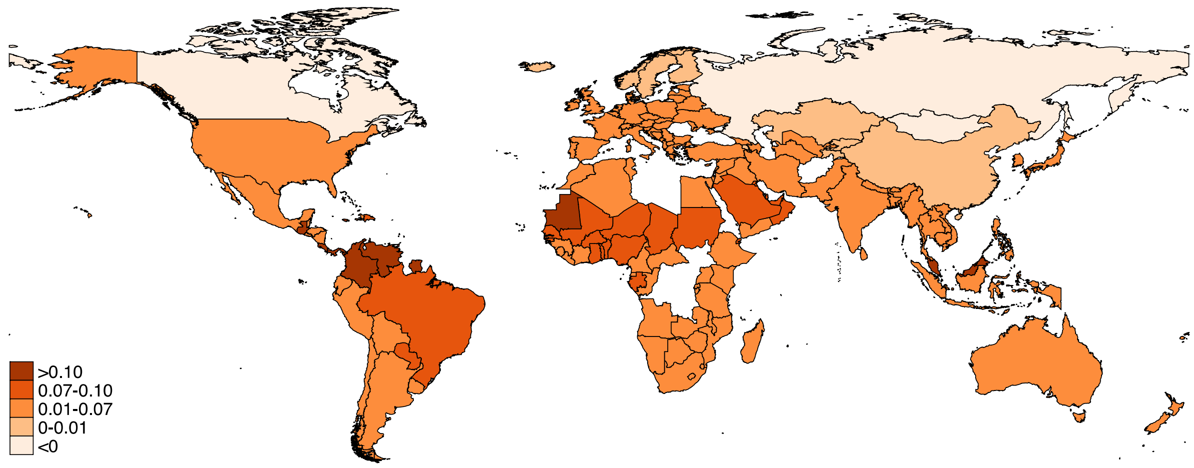
Guinea	GIN	0.53	0.220	0.014	3.40	0.309	0.027
Guinea-Bissau	GNB	1.31	0.372	0.023	4.05	1.459	0.096
Honduras	HND	2.38	0.113	0.006	5.05	0.084	0.004
Hungary	HUN	2.09	0.013	0.001	5.38	0.031	0.002
Iceland	ISL	0.51	-0.018	-0.001	2.94	-0.008	0.000
India	IND	1.79	0.108	0.006	4.95	0.283	0.015
Indonesia	IDN	0.98	-0.042	-0.007	3.33	0.904	0.056
Iraq	IRQ	1.00	0.125	0.011	4.84	0.235	0.024
Ireland	IRL	2.07	0.007	0.000	3.95	0.008	0.000
Israel	ISR	1.64	0.094	0.008	4.80	0.158	0.014
Italy	ITA	3.76	0.034	0.002	6.75	0.056	0.004
Jamaica	JAM	2.10	0.313	0.019	4.26	0.436	0.035
Japan	JPN	3.27	0.025	0.001	6.37	0.042	0.001
Jordan	JOR	2.26	0.090	0.008	5.85	0.150	0.013
Kazakhstan	KAZ	3.81	-0.002	0.000	7.56	0.014	0.001
Kenya	KEN	0.09	0.099	0.005	2.77	0.154	0.008
Kuwait	KWT	0.90	0.237	0.025	4.75	0.472	0.061
Kyrgyzstan	KGZ	1.45	-0.022	-0.002	5.45	-0.014	-0.001
Latvia	LVA	1.44	-0.005	0.000	4.63	0.002	0.000
Lebanon	LBN	4.62	0.076	0.005	7.64	0.110	0.007
Lesotho	LSO	2.10	0.015	0.001	5.53	0.029	0.002
Liberia	LBR	0.99	0.579	0.048	3.48	0.745	0.138
Lithuania	LTU	1.65	-0.004	0.000	4.80	-0.006	-0.001
Luxembourg	LUX	1.75	0.008	0.000	4.52	0.023	0.001
Madagascar	MDG	1.44	0.256	0.013	4.00	0.593	0.030
Malawi	MWI	1.13	0.068	0.003	4.38	0.097	0.005
Malaysia	MYS	0.77	0.352	0.016	3.22	0.596	0.042
Mali	MLI	0.58	0.116	0.006	4.25	0.265	0.014
Mauritania	MRT	0.55	0.079	0.004	4.27	0.166	0.009
Mauritius	MUS	1.31	0.143	0.008	3.40	0.463	0.026
Mexico	MEX	0.33	0.087	0.005	3.34	0.133	0.005
Mongolia	MNG	2.14	-0.036	-0.003	6.14	-0.023	-0.002
Morocco	MAR	2.62	0.044	0.002	6.30	0.104	0.005
Mozambique	MOZ	0.76	0.077	0.004	3.74	0.021	0.001

Namibia	NAM	2.48	0.127	0.011	5.78	0.218	0.026
Nepal	NPL	6.99	0.062	0.003	10.41	0.044	0.002
Netherlands	NLD	1.86	0.010	0.001	4.40	0.022	0.001
New Zealand	NZL	3.07	0.019	0.001	5.35	0.029	0.002
Nicaragua	NIC	1.87	0.132	0.007	4.40	0.663	0.036
Niger	NER	0.22	0.084	0.004	3.75	0.148	0.008
Nigeria	NGA	0.41	0.149	0.008	3.32	0.017	0.000
Norway	NOR	1.65	-0.016	-0.001	4.79	-0.006	0.000
Oman	OMN	2.54	0.330	0.035	5.66	0.563	0.056
Pakistan	PAK	1.48	0.041	0.002	5.21	0.048	0.002
Panama	PAN	1.72	0.523	0.027	4.14	0.990	0.061
Paraguay	PRY	2.45	0.204	0.010	5.56	0.327	0.013
Peru	PER	1.81	0.086	0.005	4.97	0.127	0.008
Philippines	PHL	1.78	-0.168	-0.024	4.08	1.407	0.096
Poland	POL	2.17	0.004	0.000	5.21	0.021	0.001
Portugal	PRT	1.81	0.042	0.002	4.83	0.072	0.001
Qatar	QAT	0.93	0.338	0.040	4.53	0.642	0.085
Rwanda	RWA	1.56	0.063	0.003	4.54	0.084	0.004
Saudi Arabia	SAU	0.98	0.215	0.022	4.72	0.418	0.051
Senegal	SEN	1.32	0.165	0.009	4.29	0.373	0.020
Serbia	SRB	1.98	0.008	0.001	5.41	-0.004	0.001
Sierra Leone	SLE	0.05	0.401	0.026	2.68	3.232	0.381
Slovakia	SVK	2.98	0.010	0.001	6.19	0.032	0.002
Slovenia	SVN	3.28	0.025	0.001	6.47	0.054	0.003
South Africa	ZAF	0.81	0.058	0.004	4.08	0.099	0.007
Spain	ESP	2.73	0.036	0.002	5.89	0.069	0.004
Sri Lanka	LKA	0.85	0.470	0.033	3.18	1.594	0.127
Suriname	SUR	1.64	0.407	0.025	4.35	0.744	0.066
Swaziland	SWZ	-1.50	0.041	0.002	1.46	0.034	0.002
Sweden	SWE	2.30	-0.018	-0.001	5.53	-0.008	-0.001
Switzerland	CHE	3.34	0.006	0.000	6.45	0.014	0.001
Tajikistan	TJK	-0.21	0.051	0.003	4.03	0.008	0.000
Thailand	THA	-0.04	0.156	0.008	2.60	0.273	0.016
Togo	TGO	0.56	0.140	0.007	3.36	0.232	0.014

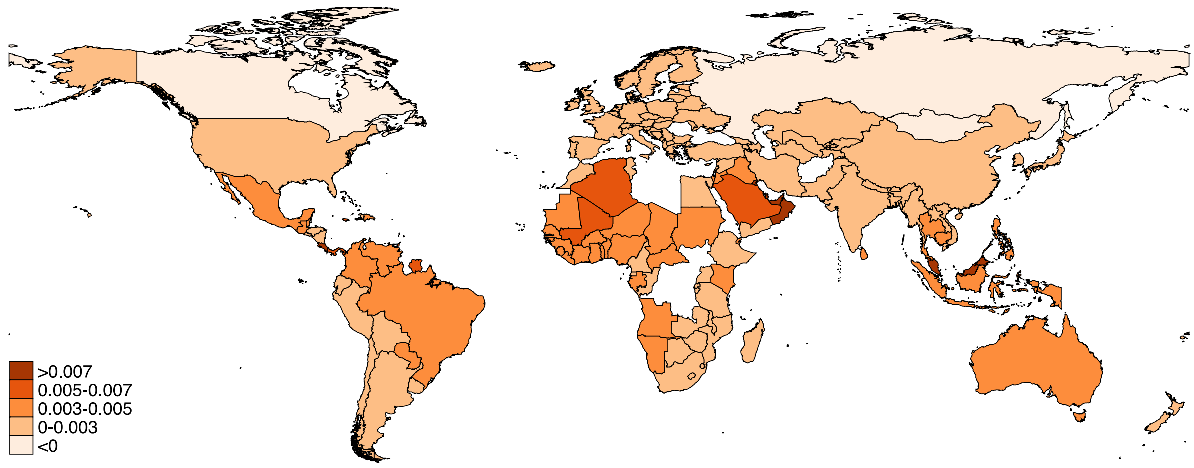
Tunisia	TUN	1.25	0.040	0.002	4.61	0.086	0.004
Turkey	TUR	3.35	0.026	0.002	6.84	0.053	0.003
Turkmenistan	TKM	1.85	0.049	0.004	5.32	0.089	0.008
Uganda	UGA	0.40	0.076	0.004	3.22	0.064	0.003
Ukraine	UKR	2.91	0.011	0.001	6.22	0.030	0.002
United Kingdom	GBR	2.00	0.006	0.000	4.12	0.011	0.001
United States	USA	2.25	0.003	0.000	5.97	0.018	0.001
Uruguay	URY	2.11	0.070	0.004	4.42	0.100	0.006
Uzbekistan	UZB	2.86	0.014	0.001	6.41	0.052	0.003
Yemen	YEM	2.55	0.038	0.002	5.56	0.233	0.012
Zambia	ZMB	1.55	0.063	0.003	5.03	0.074	0.004
Zimbabwe	ZWE	1.36	0.051	0.003	4.88	0.107	0.005
Average		1.70	0.110	0.006	4.76	0.258	0.018
Standard Deviation		1.19	0.174	0.011	1.35	0.437	0.041
Maximum		6.99	1.412	0.070	10.41	3.232	0.381
Minimum		-1.50	-0.168	-0.024	1.46	-0.023	-0.029

Figure A1: Regional distribution of marginal effects of temperature (WB) on production inefficiency growth

Panel A: marginal decrease in mean production efficiency growth



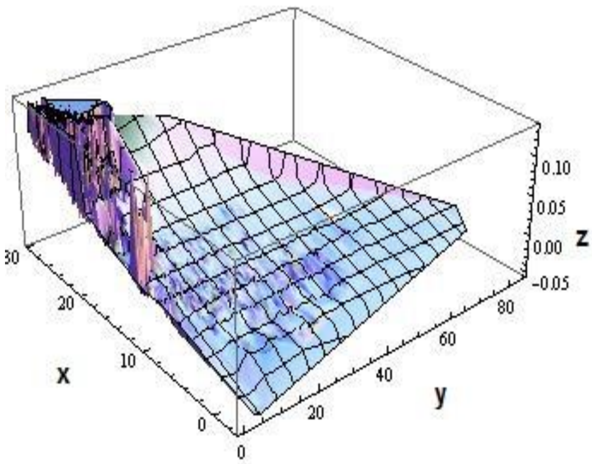
Panel B: marginal increase in variance production efficiency growth

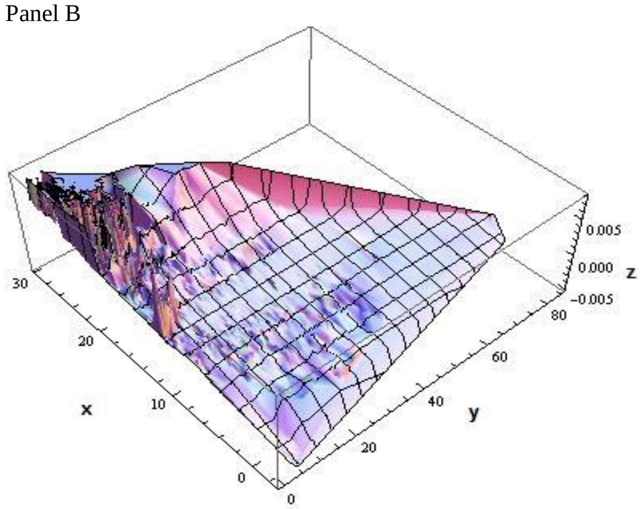


Note: Hotter than average temperature is not only detrimental to production efficiency growth but also makes the growth less stable than otherwise and these effects are larger in very hot countries with average annual temperature greater than 25 ºC. Countries such as Mongolia benefit from any further temperature increase, but hot countries like Brunei Darussalam have to face the hardest detrimental effects.

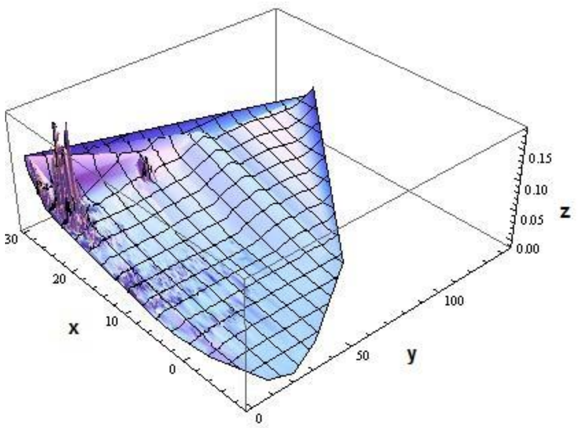
Figure 2A: Relationship between the marginal effects of temperature, its level and per capita income

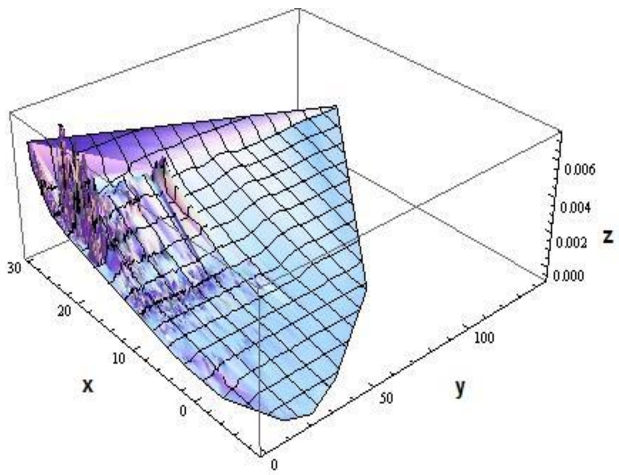
Marginal effects on E(Δu)	Marginal effects on V(Δu)
BHM data	
Panel A	Panel B





WB data	
Panel C (WB): Marginal effects on E(Δu)	Panel D (WB): Marginal effects on V(Δu)



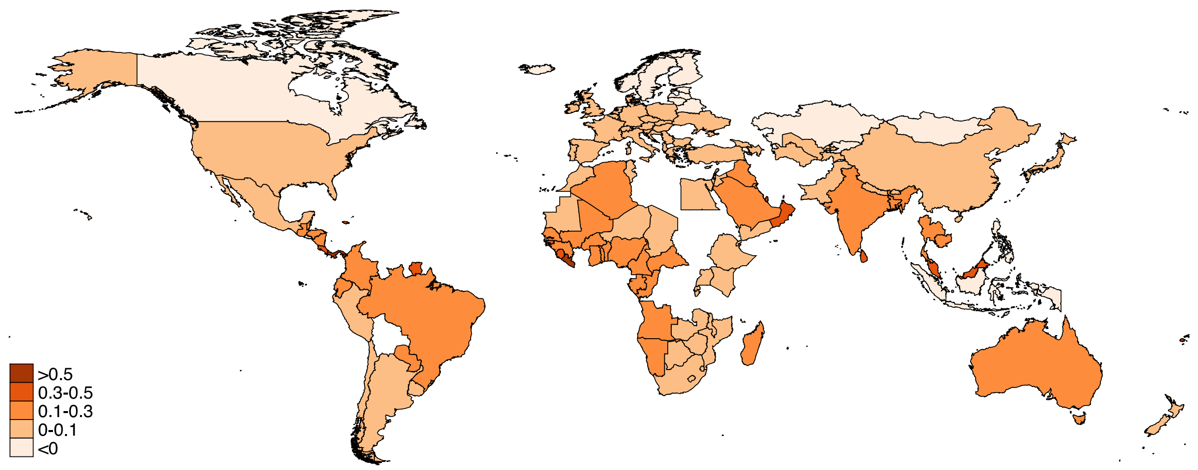


Note: Notes: x-axis measures temperature in °C; y-axis measures per capita income in thousand 2011US$ in terms of PPP; and z-axis measures the marginal effect of temperature change on mean inefficiency growth. The effects are higher in high temperature and low income countries, i.e., higher income moderates detrimental temperature effects in countries which observe on average less than 25 °C temperature.[22]

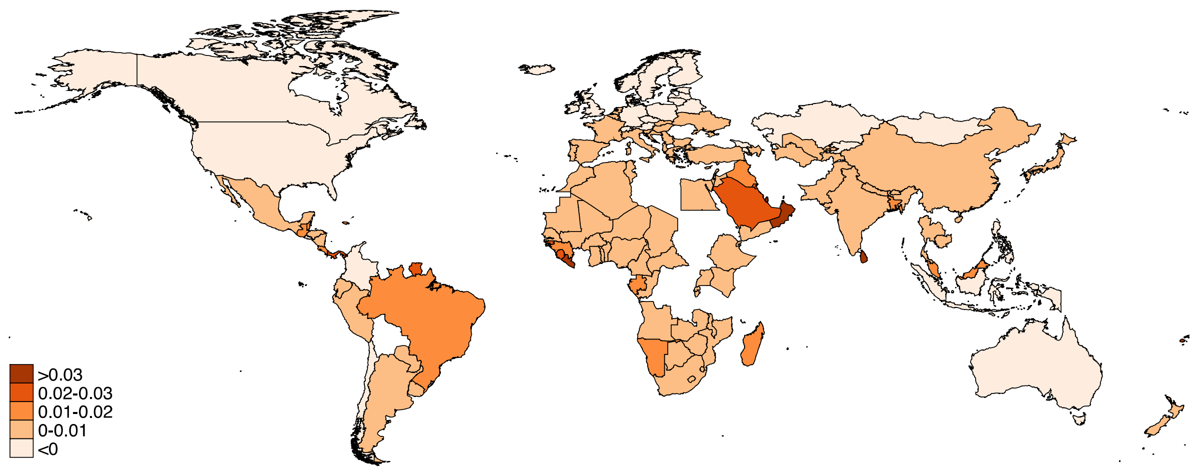
[22] In the formulation of these figures following countries information is not included: Countries with high per capita income and temperature (BHM) > 25: United Arab Emirates, Bahamas, Brunei Darussalam, Dominican Republic, Gabon, Equatorial Guinea, Kuwait, Malaysia, Oman, Panama, Qatar, Saudi Arabia, Suriname, Thailand, Trinidad and Tobago, Bolivarian Republic of Venezuela. Countries with high per capita income and temperature (WB) > 25: Aruba, Anguilla, United Arab Emirates, Bahrain, Bahamas, Brazil, Barbados, Brunei Darussalam, Costa Rica, Cayman Islands, Gabon, Equatorial Guinea, Kuwait, Maldives, Malaysia, Oman, Panama, Qatar, Saudi Arabia, Singapore, Suriname, Seychelles, Thailand,

Figure A3: Projected Marginal Effects based on projected temperature of 2020-2040

Panel A: marginal decrease in mean production efficiency growth



Panel B: marginal increase in variance production efficiency growth



Note: Poor countries are more vulnerable than rich countries though they face similar or lower temperature increase since marginal effects are a function of base level temperature and economic development. The marginal effects are more pronounced in the countries of South Asia, Sub-Saharan region, OPEC and Latin America.

Trinidad and Tobago, Bolivarian Republic of Venezuela. In very hot climate zone, the marginal effects of temperature are identical across countries irrespective of their level of development, therefore excluding these rich countries in the Figure makes the three-way relationship sharper.