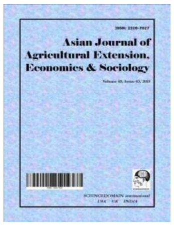


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# Impact of Climate Change on Wheat Production in Nepal

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***Author's contribution***

*This work was carried out in collaboration between both authors. Author RBTP designed the concept, performed the statistical analysis and wrote the first draft of the manuscript. Author ND managed the literature searches, assists to review them, collected the data and commented to manuscript. Both authors read and approved the final manuscript.*

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## ABSTRACT

Following the Ricardian approach, this paper estimates district level fixed effect panel regression on per hectare net wheat revenues with climate variables like precipitation and temperature including other traditional inputs. Both temperature and precipitation coefficients reveal that the climate change caused negative impact on net wheat revenues from wheat production but in a decreasing rate, ceteris paribus. The joint effect of the temperature and precipitation is also significantly negative. Quite trivial that other traditional inputs like population density, manure used, human labour, wages, advanced seed and fertilizer used are positively associated with net revenues. However, per hectare bullock used and tractor price are negatively associated to net revenue. The negative sign reported for the coefficients of quadratic proxy climate change variables but positive for their level form indicate that rising temperature and precipitation initially encourage wheat production in Nepal, but after certain threshold level it start hampering the yield.

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*Keywords: Precipitation; temperature; wheat yield; Ricardian approach; panel regression.*

JEL Classification: Q15; Q51; Q54.

## 1. INTRODUCTION

Detangling impact of climate change on global wheat production, [1] suggest that a degree centigrade rise in temperature reduces the wheat yield by six percent. Another study done by [2] also claims that the temperature and rainfall volatility had hampered wheat production in Italy. Similarly, study done by [3] reveal that the further increase in temperature would reduce wheat production in South African region. In case of Pakistan, the higher temperature adversely affected wheat productivity as argued by [4]. Likewise, [5] conducted more disaggregated regional level study in Pakistan and found the negative association between wheat productivity and temperature rise in low altitude regions only. However, [6] found positive association between wheat yield and climate change induced CO2 concentration, in case of Australia. Supporting this argument further, study done by [7] also reveal that temperature rise promoted wheat yields in India through atmospheric CO2 fertilization channel up to $38^0$C threshold. It sounds like the climate change or weather variability affect wheat production at a global level. However, some of the studies on specific geographical areas have established a positive association between climate change and wheat production.

Studies like [6,8] argue that the adverse effect on wheat yield due to temperature rise could be nullified through precipitation enrichment and CO2 fertilization in the atmosphere. However, the study done by [9] concluded that such atmospheric fertilization can only compensate it scantily. Thus, the further volatility in temperature and rainfall would hamper wheat production as [10] revealed.

Nepal lies near the northern limit of the tropics in the lap of Himalayas and hence it is more vulnerable to climate change. It has wide range of climatic variation like tropical heat with high humidity in summer especially in Terai, the southern plains, and colder dry continental and alpine winter climate through the middle and northern mountainous sections. Such diversity reflects in variations in temperature and precipitation. Thus climate change is a real threat to the lives as it largely affects water resources, agriculture, freshwater habitats, vegetation and forests. At the same time snow melting and geological processes such as landslide, desertification and floods are regular phenomenon.

Agriculture remains by far the most important sector in the Nepalese economy. Due to the complex topography and climatic variation, the agriculture systems varies as per the geographical location. The main crops cultivated are rice, maize, wheat, millet, mustard, pulses, barley, buckwheat and potato**.** Wheat is one of the ‘policy prioritized’ cereal crop, like rice and maize, in Nepal. Wheat is cultivated in 20 percent of the total cultivated land area and contributes 18.8 percent to the total national cereal production. Per capita wheat consumption has increased from 17.4 kg in 1972, at the time of NWRP establishment to 60 kg in 2007 [11].

The delayed monsoon has already been affecting wheat planting and also its yield subsequently. It is worth examining if this has any relation with the changing climate scenario. Most of the discussion about the impact of climate change on wheat production focuses on the temperature regime of the area, which lowers the ripening period. But upland farmers grow wheat crop in unirrigated land, production of which is guided by both temperature as well as the amount of water available. Water requirement of unirrigated wheat is met by the rainfall, which means any change in rainfall time or duration or intensity affects unirrigated wheat yield [12]. Climate change therefore has significant impact in wheat production in countries like Nepal where most of the farming system depends on monsoon and corresponding climate.In this context, it is worth exploring whether the weather volatility has adverse impact in small geographical area with many climatic diversity like Nepal.

The volume of wheat production, cultivated area and productivity increased substantially in Nepal during the last decade. But, surprisingly, about 60 percent variations in wheat productivity was due to weather variability in Nepal [13]. The climate being one of the inevitable inputs in wheat cultivation, weather variability and farm level wheat production, its unpredictability might have some meaningful consequences. There is a dearth of empirical analysis on weather variability and wheat production in Nepal. Thus, this paper aims to untangle this puzzle analysing district level panel information.

## 2. METHOD OF ANALYSIS AND DATA

Considering land value as the reflection of farmland productivity, [14] suggest an empirical approach to examine the impact of climate vis-à-vis other variables on land value. This approach, commonly known as the Ricardian approach, relates farm level economic data on land value or net revenue with climate variables. Studies like [15] in case of overall Ethiopian Agriculture, [16] in case of Kenyan agricultures, [17] in case of South African Sugarcane and [18] in case of Indian agriculture have used this approach. We also follow this approach to analyse the district level wheat yield revenue, climate variable and other inputs. In order to capture the return from wheat production, we specify the land value ($V_L$) as:

$$V_L = \int_0^\infty \left[\frac{P_i . Q_i^*(K_i, E) - C_i(Q^*, \Omega, E_i)}{L_i}\right] e^{-rt} dt \qquad (1)$$

Where $P_i$ is the price and $Q_i$ is the quantity of wheat; $K_i$ is vector of all purchased inputs to produce $Q_i$; $E_i$ is vector of environmental factors including climate and soil variables; $C_i$ is cost of production; Ω is a vector of all other factor besides land; $L_i$ is wheat cultivated land in hectares; 'r' is interest rate; and 't' is time. The (–rt) term represents the discounting factor.

The objective function of the farmer who selects K under perfect competition setting to maximize net revenue ($\pi$) given farm characteristic is:

$$Max(\pi) = [P_i Q_i - C_i(Q_i, \Omega, E) - P_L L_i] \qquad (2)$$

As the environment changes from state A to B, the input availability also changes from $E_A$ to $E_B$. Thus, the annual net economic welfare (ΔW) changes as:

$$\Delta W = \int_0^{Q_B} [(P_i Q_i - C_i(Q_i, \Omega, E_B))/L_i\,] e^{-rt} dQ - \int_0^{Q_A} [(P_i Q_i - C_i(Q_i, \Omega, E_A))/L_i \, e^{-rt} dQ \qquad (3)$$

If market prices do not change as a result of the change in E, then equation (3) reduces to:

$$\Delta W = [PQ_B - \sum_{i=1}^{n} C_i(\, Q_i, \Omega, E_B)] - \; [PQ_A - \sum_{i=1}^{n} C_i(Q_i, \Omega, E_A)] \qquad (4)$$

Since$P_L L = \; P_i Q_i - C_i(Q_i^*, \Omega, E)$holds true under perfect competition, equation (4) becomes:

$$\Delta W = \; \sum_{i=1}^{n} (P_{LB} L_{Bi} - P_{LA} L_{Ai}) \qquad (5)$$

Where, $P_{LA}$ and $L_A$ are quantities under $E_A$ climatic condition and $P_{LB}$ and $L_B$ under $E_B$.

The present value of the welfare change is thus:

$$\int_0^\infty \Delta W e^{-rt} \, dt = \; \sum_{i=1}^{n} (V_{LB} L_{Bi} - V_{LA} L_{Ai}) \qquad (6)$$

Using annual net revenues data, we estimate the extended version of equation (5) as done by [15,19,20].To see the impacts of exogenous climate change on per hectares net wheat revenues (NR), we regressed it with temperature (*temp*) and precipitation (*preci*) controlling population density (*popl*);seed and fertilizer (*seed_fert*); number of per hectare human labor (*hul*); tractors hours per hectare (*trac*); per hectare bullocks(*bul*); labour wage (*wage*); and per hectare manure(*manu*). The panel regression equation is specified as:

$$\begin{aligned} NR_{ij} = \beta_0 + \beta_1 temp_{ij} + \beta_2 temp_{ij}^2 + \beta_3 preci_{ij} + \beta_4 preci_{ij}^2 + \beta_5 temp_{ij} * preci_{ij} + \beta_6 popl_{d_{ij}} \\ + \beta_7 seed\_fert_{ij} + \beta_8 hul_{ij} + \beta_9 trac_{ij} + \beta_{10} bul_{ij} + \beta_{11} manu_{ij} + \beta_{12} wage_{ij} \\ + \varepsilon_{ij} \;\; ; \;\; \varepsilon_{ij} \sim N(0, \sigma^2) \end{aligned} \qquad (7)$$

The ‘climate variables’ are rolling average for each year that captures the yearly regular response by the farmers and other variables are district level annual data spanning 1993 to 2010. Similar to county level fixed effects specified by [21] while analysing US agriculture and state level fixed effect specified by [18] while analysing Indian Agriculture, we specified district level fixed-effect panel regression in this study. The Hausman specification test (*Annex B*) also supports for the same. The brief descriptive statistics are in *Annex A*. Since the districts are heterogeneous in size and other agricultural activities, we weighted each unit of analysis by total wheat cultivated area expecting to reduce heteroscedasticity problem. The autocorrelation, cross-sectional dependence, heteroscedasticity and others necessary tests are performed, and corrected wherever necessary.

The *temperature and precipitation* related data is from the various periodic from the Department of Hydrology and Meteorology, Government of Nepal. These *Climate variables* represent the wheat cultivation season (November to February) in Terai region of Nepal. The mean temperature and precipitation during this time period prepared by the Department of Hydrology and Meteorology, Government of Nepal is the key variables in this study. They compile these information from several local station. The monthly means were estimated from approximately 25 years of time period and the information is publicly available.

In general, wheat grows in cold temperature. However, it requires different temperatures at different stages of growth and development. The required temperature may slightly vary from one variety to another at its germination. They can grow at minimum 3.5-5.5 degree centigrade to maximum up to 35 degree centigrade, optimum temperature being 20-25 degree centigrade. Beyond this range, wheat seed germination decreases slowly. If temperature is more than 30 degree centigrade during the maturity of the plant, it leads to pre-term maturity resulting yield loss. Winter wheat bears more cold waves and frost compared to spring wheat though. The present rate of annual increase of temperature is0.06 degree centigrade in Nepal, though the trends of temperature rise is not uniform.

The wheat is cultivated in the region where annual precipitation occurs from 25 to 175 cm, though 75 per cent of wheat cultivated area in Nepal falls where the annual rainfall precipitation occurs between 37.5 mm to 87.5 mm according to Nepal Agriculture Research Council. Region with 62.54 to 87 mm rainfall are most suitable for wheat cultivation and out of this 10-15 mm rainfall is required when crop is in the field. Rainfall and snowfall at the time of maturity causes severe loss to wheat crop adversely affecting the yield and seed quality. Due to the topographical differences within short north-south span of the country, Nepal has wide variety of climatic condition. About 70 to 90 percent of the rainfall occurs during the summer monsoon months (June to September) in Nepal and the rest of the months are almost dry.

The data related with fertilizer, improved seeds, use of manure and price of agricultural inputs comes from the Department of Agriculture, Government of Nepal. The *Socio-economic variables* included in the estimation are district level population density, use of fertilizer, use of improved seeds, use of manure, total wheat cultivated area, total production and the price of agricultural inputs. The census information produced by Central Bureau of Statistic in every ten years is the base for the *population density*. The population growth rate from 1992/93 to 2000/01 and 2000/01 to 2010/11 gives the district level growth rate, which is sufficient to estimate the district level annual population. We prepared the population density variable by dividing the area of the respective district. Total estimated wheat cultivated area and volume of wheat produced in KG for all sample districts of 20 Terai districts of Nepal during 1992/93 to 2013/14 from various publications of the Ministry of Agriculture & Co-operatives and the Central Bureau of Statistics (CBS).

The Department of Agriculture, Market Research and Statistical Management Program, Government of Nepal publishes the “Cash or Production & Marketing Margin of Cereal, Cash, Vegetable & Spices Crops, Nepal” annually. We compiled the *per hectare fertilizer* use at district level from this source. Seeds is another important factor of production for our analysis, therefore we compiled total *improved seeds* used from the same source. The concerned officers in the department revealed that in case of wheat seeds inputs are generally improved seeds. Optimum planting date for Terai is found to be the middle of November. However, wheat sowing in Terai can be delayed up to the second week of December without significant reduction in the yield and wheat seed sown beyond these dates result the yield reduction of 30 to 50 kg/day/ha. In previous years there was general recommendation for the seed rate of 100 kg/ha. Recent experiments have shown that additional seeds of 25 to 50 kg/ha is required under late sown and under farmers' broadcast system. Similarly, we compiled the per hectare for *human labor, bullock labor, tractor use*d and *Manure* and *Price of Agricultural Inputs* at district level from the same sources.

## 3. IMPACT OF CLIMATE CHANGE ON WHEAT PRODUCTION IN NEPAL

The summary of the regression results is in Table 3.1. It reveals that, the temperature and net revenue from wheat are positively associated, but at a decreasing rate. It signifies that as temperature increases, the wheat yield in Nepal increases as well, other things remaining the same. Since wheat is cultivated in winter or cold session in Nepal, the temperature rise might have promoted wheat yield. But, as the temperature increases beyond certain level, it hampers the yield as the coefficient of the quadratic term for temperature suggests. If an average temperature was above 21ºC, the temperature rise would start damaging wheat yield as found by [7] in case of India. The coefficient indicates that one unit increase in temperature helps to produce about NRS 5,643 worth more net revenues per hectare but if the temperature is beyond 19ºC, the revenue starts falling significantly. It is similar to the argument given by [22,23] that the minimum optimal temperature threshold for wheat production in Nepal is 20ºC. According to [24], the annual increase of temperature in Nepal is 0.06ºC. It is recorded at 0.04ºC in wheat cultivating area with 18.30ºCannual average maximum temperature during wheat cultivation period. Thus, it can be argued that the climate change will support wheat production in Nepal up to certain threshold only, analogous to the finding by [7] in case of India.

**Table 3.1. Fixed effect panel regression results**

| **Dependent variable (→)** | **Net revenue from wheat yield** | |
|---|---|---|
| Independent Variables (↓) | (1) | (2) |
| Temperature | 5,643** | - |
| | (2,834) | - |
| Temperature squared | -153.9** | - |
| | (72.23) | - |
| Precipitation | 161.1* | - |
| | (90.45) | - |
| Precipitation squared | -6.222*** | - |
| | (2.017) | - |
| Precipitation * Temperature | - | -4.310** |
| | - | (2.073) |
| Population density | 186.1*** | 179.4*** |
| | (16.00) | (16.14) |
| Manure per hectare | 0.0447 | 0.0279 |
| | (0.0353) | (0.0355) |
| Human labour per hectare | 90.25** | 87.80** |
| | (40.23) | (40.81) |
| Bullock per hectare | -318.6*** | -324.2*** |
| | (63.12) | (63.73) |
| Tractor hour per hectare | -478.1** | -540.1** |
| | (207.4) | (209.8) |
| Wage of human labour per hectare | -0.217*** | -0.176** |
| | (0.0829) | (0.0834) |
| Fertilizer and Seed per hectare | -0.0151 | -0.0732 |
| | (0.0780) | (0.0778) |
| Constant | -100,835*** | -44,340*** |
| | (29,668) | (7,876) |
| Observations | 440 | 440 |
| R-squared | 0.716 | 0.705 |
| Number of district | 20 | 20 |

*Standard errors in parentheses;*** p<0.01, ** p<0.05, * p<0.1*

Similar to the temperature, there is a positive relationship between precipitation and net revenues from wheat but is insignificant. It indicates that precipitation alone is not the primary determinant and other environmental, factors as well as traditional inputs, are important to enhance wheat production. Nevertheless, the negative and significantly negative coefficient of the quadratic term of the precipitation indicates that the precipitation and the net revenue are positively associated but in decreasing rate. After certain threshold level, the association becomes opposite. The precipitation data ranges from zero to sixty five mm with median precipitation 7.8 mm (*Detail in Annex A*). The quadratic coefficient indicates that if the precipitation level is above average (12.95 in proper), an extra unit of precipitation damages the wheat yield. It causes negative impact in the net revenues, ceteris paribus. In this context, a past study by [8] argue that increased precipitation level supports wheat yield but [6] believe opposite.

The precipitation and temperature interaction variable is regressed controlling other variable and the results are reported in the Table 3.1. The negative and statistically significant coefficient suggests that the joint effect of the temperature and precipitation damages the wheat yield significantly. It can be argued that if the temperature and precipitation both increases, the joint climatic impact in wheat yield would be significantly negative in Nepal. Thus, it can be argued that the climate change although initially promotes wheat production in Nepal, but after certain threshold level, it might not.

The statistically significant and positive population density coefficient indicates that higher the population, higher will be the net revenues from wheat production. It might have worked through input market and output market efficiency channel. It might be the case that if more people, more workers available in cheaper price so that the productivity increases. At the same time, more density is proxy to the higher market or aggregate demand for the wheat produced which induced wheat cultivation. The positive though insignificant coefficient for per hectare manure suggests that the wheat cultivation is less manure demanding than other crops. But, positive coefficient suggest for higher the manure used, the higher will be the net revenues from wheat in Terai, Nepal. It is quite natural that the traditional compost is the best for the wheat. The human labour coefficient is positive but insignificant indicating labour as a necessary but not sufficient input for optimum wheat production. More traditional technology like ploughing by Bullock for wheat farming has negative role on net revenue though the coefficient is insignificant. It might be the indication for modern means of ploughing which are effective than the scarce and costly traditional ones that farmers are using.

Tractor, means of modern cultivation, is significant to bring change in net revenues. However, if the price of tractor goes up, their use will decrease and farmers will resort to the same traditional patterns. Interestingly, when wages increase, per hectare net revenues also increase significantly. It indicates for the scarcity of the human labour in Nepal due to outmigration and abundance of traditional farming practices within the household level. As someone starts the commercial wheat farming by hiring labour formally with other inputs, the net revenues generated overweight the average wage paid, ceteris paribus. Advanced seed and fertilized are important input for wheat cultivation like any other agriculture. Generally, farmers buy these two inputs together. The coefficient indicates that one extra rupee invested in seed and fertilizer brings the revenue less by some positive amount though insignificant. It suggests for imperfect input market for the agriculture sector in Nepal.

About 71 percent variation in net revenues is due to the variation in the explanatory as the coefficient of determination ($R^2$) indicates. No cross sectional dependency is detected using Pesaran test. The Wooldridge autocorrelation test signals for presence of autocorrelation and Wald test signals for the presence of Heteroscedasticity. The panel unit root test indicates that the variables we used are unit root free variables. To overcome the autocorrelation and heteroscedasticity problem, we estimated generalized least square regression (*see Appendix C*). Pedroni test statistics for panel co-integration suggest that the variables are almost co-integrated, the summary of the test is mentioned in *Appendix D*.

## 4. CONCLUSIONS

The temperature and wheat net revenues are positively associated, but at a decreasing rate. As temperature increases, the wheat yield in Nepal increases as well, other things remaining the same. However, temperature rise will support wheat production in Nepal up to certain threshold level only. Similarly, the precipitation and net revenues from wheat are also positively associated but not very significantly. Moreover, the association is in a decreasing rate. Nevertheless, the joint effect of the temperature and precipitation damages the wheat yield significantly. If temperature and precipitation both increase, the joint climatic impact in wheat yield would be significantly negative in Nepal. Thus, it can be argued that the climate change initially promotes wheat production in Nepal, but after certain threshold level it might not.

Other traditional inputs like population density, manure used, human labour, wages, advanced seed and fertilizer used are positively associated with net revenues. However, ploughing by bullock for wheat farming and tractor price are negatively associated to the net revenue from wheat yield in Nepal.

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## COMPETING INTERESTS

Authors have declared that no competing interests exist.

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## Appendix A: Descriptive Statistics

| Variable \| | Obs | Mean | Std. Dev. | Min | Max |
|---|---|---|---|---|---|
| district \| | 440 | 10.5 | 5.772845 | 1 | 20 |
| year \| | 440 | 2003.5 | 6.351511 | 1993 | 2014 |
| n_revenue \| | 440 | 24212.99 | 15110.47 | 400.51 | 64695.56 |
| preci \| | 440 | 11.38584 | 11.90006 | -.43 | 64.9 |
| pre_sq \| | 440 | 270.9271 | 520.411 | 0 | 4212.01 |
| temp \| | 440 | 18.22693 | 1.612997 | 12.1 | 26.4 |
| temp_sq \| | 440 | 334.8169 | 61.5078 | 146.41 | 696.96 |
| pre_temp \| | 440 | 203.288 | 210.9269 | -6.4285 | 1148.73 |
| popln_den \| | 440 | 384.7586 | 156.0365 | 124.77 | 694.02 |
| manure_hec \| | 440 | 30587.71 | 14679.36 | 3500 | 104221.3 |
| human_l_hec \| | 440 | 108.2523 | 10.7255 | 77 | 130 |
| bullock_hec \| | 440 | 14.04545 | 11.89831 | 0 | 43 |
| tractor_hec \| | 440 | 4.480682 | 2.754183 | 0 | 13 |
| f_s \| | 440 | 14968.6 | 6057.095 | 8060 | 62228 |
| p_humanlabor \| | 440 | 10601.71 | 8107.095 | 2430 | 38500 |

## Appendix B: Hausman Test for Fixed Effect

```
. xtregn_revenueprecipre_sq temp
temp_sqpre_temppopln_denmanure_hechuman_l_hecbullock_hectractor_hecp_humanlaborf_s, fe

Fixed-effects (within) regression                Number of obs      =      360
Group variable: district                         Number of groups   =       20

R-sq:  within  = 0.8494                          Obs per group: min =       18
         between = 0.0480                         avg =      18.0
         overall = 0.1640                         max =       18

                                                  F(12,328)        =    154.14
corr(u_i, Xb)  = -0.8551                          Prob> F          =    0.0000

------------------------------------------------------------------------------
n_revenue |      Coef.         Std. Err.      t          P>|t|     [95% Conf. Interval]
-------------+----------------------------------------------------------------
      preci |       -84.9092      351.2157    -0.24   0.809    -775.8288    606.0104
     pre_sq |      -4.129809    1.493781    -2.76   0.006    -7.068409    -1.19121
       temp |       8652.686     2623.735     3.30   0.001     3491.215    13814.16
    temp_sq |     -215.3559    64.0424    -3.36   0.001    -341.3415   -89.37017
   pre_temp |      9.026758    18.38951     0.49   0.624    -27.14951    45.20303
  popln_den |     142.9818    14.64646     9.76   0.000     114.1689    171.7947
manure_hec |     1.362966    .537247      2.54   0.012      .306081     2.41985
human_l_hec |   17.95916     34.55132     0.52   0.604    -50.01098     85.9293
bullock_hec |    -56.44384     56.03452    -1.01   0.315    -166.6762    53.78854
tractor_hec |      -1120.388   155.2621     -7.22   0.000    -1425.823   -814.9526
p_humanlabor |   329.3814    58.9499       5.59   0.000     213.4138     445.349
f_s |   2.384321   .4445116     5.36            0.000             1.509867    3.258774
      _cons |       -145503.1     27646.24      -5.26   0.000    -199889.5   -91116.82
-------------+----------------------------------------------------------------
sigma_u |  22841.213
sigma_e |  5469.3652
        rho |  .94577219   (fraction of variance due to u_i)
------------------------------------------------------------------------------
F test that all u_i=0:     F(19, 328) =     11.62           Prob> F = 0.0000

. estimates store fixed

. xtregn_revenueprecipre_sq temp
temp_sqpre_temppopln_denmanure_hechuman_l_hecbullock_hectractor_hecp_humanlaborf_s, re

Random-effects GLS regression               Number of obs      =      360
Group variable: district                 Number of groups   =       20

R-sq:  within  = 0.8059                  Obs per group: min =       18
      between = 0.0005                              avg =      18.0
      overall = 0.7471                            max =       18

                                 Wald chi2(12)      =   1331.59
corr(u_i, X)   = 0 (assumed)                 Prob > chi2        =    0.0000

------------------------------------------------------------------------------
   n_revenue |      Coef.   Std. Err.      z    P>|z|     [95% Conf. Interval]
-------------+----------------------------------------------------------------
```

```
      preci |   334.9989   397.4231     0.84   0.399     -443.936    1113.934
     pre_sq |  -4.272225   1.703212    -2.51   0.012    -7.610459   -.9339906
       temp |   5969.376   2874.481     2.08   0.038     335.4959    11603.26
    temp_sq |  -150.5612    70.3799    -2.14   0.032    -288.5032   -12.61912
   pre_temp |  -14.75355    20.7848    -0.71   0.478    -55.49102    25.98391
  popln_den |   4.087303   5.401135     0.76   0.449    -6.498727    14.67333
manure_hec |   .9143847   .6084557     1.50   0.133    -.2781665    2.106936
human_l_hec |   77.91307   37.99867     2.05   0.040     3.437041    152.3891
bullock_hec |  -366.8832   54.52007    -6.73   0.000    -473.7406   -260.0258
tractor_hec |  -1615.167   167.9277    -9.62   0.000    -1944.299   -1286.034
p_humanlabor |   333.3264   67.15762     4.96   0.000     201.6998    464.9529
f_s |   4.311713   .4570843     9.43   0.000     3.415844    5.207582
      _cons |  -73703.23   29533.36    -2.50   0.013    -131587.6    -15818.9
-------------+----------------------------------------------------------------
sigma_u |  2541.0059
sigma_e |  5469.3652
        rho |  .17752523   (fraction of variance due to u_i)
------------------------------------------------------------------------------

. hausman fixed ., sigmamore

Note: the rank of the differenced variance matrix (9) does not equal the number of coefficients
being tested (12); be sure this is what you expect, or there may be problems
computing the test.  Examine the output of your estimators for anything unexpected and possibly
consider scaling your variables so that the coefficients are on a similar
scale.

                ---- Coefficients ----
             |      (b)          (B)            (b-B)     sqrt(diag(V_b-V_B))
             |     fixed          .          Difference          S.E.
-------------+----------------------------------------------------------------
preci |    -84.9092     334.9989       -419.9081        63.80529
pre_sq |   -4.129809    -4.272225        .1424156        .1727872
       temp |    8652.686     5969.376        2683.311        882.6468
temp_sq |   -215.3559    -150.5612       -64.79467         20.8244
pre_temp |    9.026758    -14.75355        23.78031        3.487651
popln_den |    142.9818     4.087303        138.8945        15.89294
manure_hec |    1.362966     .9143847        .4485808        .0942647
human_l_hec |    17.95916     77.91307       -59.95391        11.13905
bullock_hec |   -56.44384    -366.8832        310.4393        33.93511
tractor_hec |   -1120.388    -1615.167         494.779        58.84288
p_humanlabor |    329.3814     333.3264       -3.944976        7.360771
f_s |    2.384321     4.311713       -1.927392        .2249387
------------------------------------------------------------------------------
                           b = consistent under Ho and Ha; obtained from xtreg
            B = inconsistent under Ha, efficient under Ho; obtained from xtreg

    Test:  Ho:  difference in coefficients not systematic

                  chi2(9) = (b-B)'[(V_b-V_B)^(-1)](b-B)
                          =       89.06
Prob>chi2 =      0.0000
                (V_b-V_B is not positive definite)
```

## Appendix C: Pre and Post Estimation Tests

Heteroskedasticity Test

```
. xttest3

Modified Wald test for groupwiseheteroskedasticity
in fixed effect regression model

H0: sigma(i)^2 = sigma^2 for all i

chi2 (20)  =     233.03
Prob>chi2 =      0.0000
```

Panel Unit root test

```
. xtunitrootllcn_revenue if district, demean lags(aic 5) kernel(bartlettnwest)

Levin-Lin-Chu unit-root test for n_revenue
------------------------------------------
Ho: Panels contain unit roots              Number of panels  =     20
Ha: Panels are stationary                  Number of periods =     18

AR parameter: Common                       Asymptotics: N/T -> 0
Panel means:  Included
Time trend:   Not included                 Cross-sectional means removed

ADF regressions: 0.60 lags average (chosen by AIC)
LR variance:     Bartlett kernel, 4.40 lags average
              (chosen by Newey-West)
------------------------------------------------------------------------------
                 Statistic      p-value
------------------------------------------------------------------------------
 Unadjusted t       -5.8025
 Adjusted t*         0.4329       0.6675
------------------------------------------------------------------------------
```

**Panel Autocorrelation**

Wooldridge test for autocorrelation in panel data and found the presence of first-order autocorrelation test: F( 1, 19) = 21.303; Prob> F = 0.0002

**Cross Section Dependence**

```
xtcsd, pesaran show

Pesaran's test of cross sectional independence =    11.474, Pr = 0.0000
```

**Correction of Autocorrelation and Heteroskedasticity**

```
. xtglsn_revenueprecipre_sq temp
temp_sqpre_temppopln_denmanure_hechuman_l_hecbullock_hectractor_hecp_humanlaborf_s

Cross-sectional time-series FGLS regression

Coefficients:  generalized least squares
Panels:        homoskedastic
Correlation:   no autocorrelation

Estimated covariances      =        1              Number of obs      =       360
```

```
Estimated autocorrelations =        0         Number of groups   =       20
Estimated coefficients     =       13         Time periods       =       18
                                              Wald chi2(12)      =   1155.00
Log likelihood           = -3685.208          Prob> chi2         =    0.0000

------------------------------------------------------------------------------
n_revenue |      Coef.   Std. Err.      z    P>|z|     [95% Conf. Interval]
-------------+----------------------------------------------------------------
preci |  475.2884   418.2541    1.14   0.256    -344.4745    1295.051
pre_sq |  -4.606559   1.801752    -2.56   0.011    -8.137928   -1.075189
      temp |  5762.312   2766.743    2.08   0.037    339.5948    11185.03
temp_sq |  -151.8942   68.14121    -2.23   0.026    -285.4485   -18.33993
pre_temp |  -20.82191   21.89278    -0.95   0.342    -63.73098    22.08715
popln_den |  -3.195161   3.236932    -0.99   0.324    -9.539432    3.149109
manure_hec |  .3688337   .6318778    0.58   0.559    -.8696241    1.607292
human_l_hec |  43.37647   38.44246    1.13   0.259    -31.96937    118.7223
bullock_hec |  -454.4937   55.56617    -8.18   0.000    -563.4014    -345.586
tractor_hec |  -1676.273   175.1353    -9.57   0.000    -2019.532   -1333.014
p_humanlabor |  281.9043   71.10775    3.96   0.000    142.5356    421.2729
f_s |   4.324616   .4823708    8.97   0.000    3.379186    5.270045
     _cons |  -57580.59   28292.03    -2.04   0.042    -113031.9   -2129.237
------------------------------------------------------------------------------
```

## Appendix D: Pedroni Test Results for Panel Co-integration

```
Pedroni panel co-integration test:
Pedroni's PDOLS (Group mean average):
No. of Panel units: 20       Lags and leads: 2
Number of obs: 340          Avg obs. per unit: 17
Data has been time-demeaned.
-------------------------------------
       Variables    |     Beta    t-stat
   ---------------+---------------------
        preci_td     |   -375.8     -7.112
       pre_sq_td    |    2.062      6.156
   -------------------------------------
temp_td|     44854      16.89
      temp_sq_td |    -1032     -14.39
   -------------------------------------
     pre_temp_td |     -42.4     -12.06
    popln_den_td |    292.9       15.7
   -------------------------------------
    manure_hec_td |     1.019      9.875
   human_l_hec_td |    -401.1     -6.622
   -------------------------------------
   bullock_hec_td    |      3214      16.13
   tractor_hec_td    |     -3133     -8.866
-------------------------------------
```

## Appendix E: STATA Do File

```
log using "E:\paper_1.smcl"
import excel "E:\new_data.xls", sheet("Sheet1") firstrow
xtset district year
sum
xtsum
sum preci temp, detail
xtregn_revenueprecipre_sq temp
temp_sqpopln_denmanure_hechuman_l_hecbullock_hectractor_hecp_humanlaborf_s, fe
outreg2 using E:\output.doc
xtregn_revenuepre_temppopln_denmanure_hechuman_l_hecbullock_hectractor_hecp_humanlab
orf_s, fe
outreg2 using E:\output.doc, append
xtregn_revenueprecipre_sq temp
temp_sqpopln_denmanure_hechuman_l_hecbullock_hectractor_hecp_humanlaborf_s, fe
estimates store fixed
xtregn_revenueprecipre_sq temp
temp_sqpopln_denmanure_hechuman_l_hecbullock_hectractor_hecp_humanlaborf_s, re
hausman fixed ., sigmamore
xtregn_revenuepre_temppopln_denmanure_hechuman_l_hecbullock_hectractor_hecp_humanlab
orf_s, fe
estimates store fixed
xtregn_revenuepre_temppopln_denmanure_hechuman_l_hecbullock_hectractor_hecp_humanlab
orf_s, re
hausman fixed ., sigmamore
xtregn_revenueprecipre_sq temp
temp_sqpopln_denmanure_hechuman_l_hecbullock_hectractor_hecp_humanlaborf_s, fe
xttest3
xtregn_revenuepre_temppopln_denmanure_hechuman_l_hecbullock_hectractor_hecp_humanlab
orf_s, fe
xttest3
xtunitrootllcn_revenue if district, demean lags(aic 5) kernel(bartlettnwest)
xtcsd, pesaran show
xtglsn_revenueprecipre_sq temp
temp_sqpre_temppopln_denmanure_hechuman_l_hecbullock_hectractor_hecp_humanlaborf_s ,
igls panels (heteroskedastic)
estimates store hetero
xtglsn_revenuepre_temppre_temppopln_denmanure_hechuman_l_hecbullock_hectractor_hecp_h
umanlaborf_s , igls panels (heteroskedastic)
estimates store hetero
xtpedronin_revenueprecipre_sq , full notest
xtpedronin_revenue temp temp_sq, full notest
xtpedronin_revenuepre_temppopln_den  , full notest
xtpedronin_revenuemanure_hechuman_l_hec , full notest
xtpedronin_revenuebullock_hectractor_hec, full notest
log close
```



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