Ugandan GDP and Extreme Weather Events: An Exploratory Data Analysis

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Introduction

Climate change is impacting the production of agricultural goods across the planet, and Uganda is no exception. Uganda's agriculture sector is estimated to contribute between 25 percent and 40 percent of Gross Domestic Product (GDP), a common measure of national economic output, and employs around three quarters of the country's workforce. As a result, Uganda's economic performance is tied, in part, to the success of its agricultural production. We, therefore, expect that changes to agricultural production will impact national economic activity, as measured by the GDP.

This study is concerned with exploring this relationship between Uganda's agriculture sector and the country's GDP. In particular, it considers how extreme weather events may negatively impact agricultural production, thus negatively impacting the measure of GDP. We do this by exploring Uganda's quarterly GDP figures, as well as by creating an index of extreme weather stress, using aWhere's comprehensive database of global, localized weather conditions. As a result of our analysis, detailed below, we find that an index of extreme temperature and precipitation is cointegrated with agricultural GDP, and can, therefore, be used to explain some of the broader changes to GDP due to agricultural stress.

Methodology

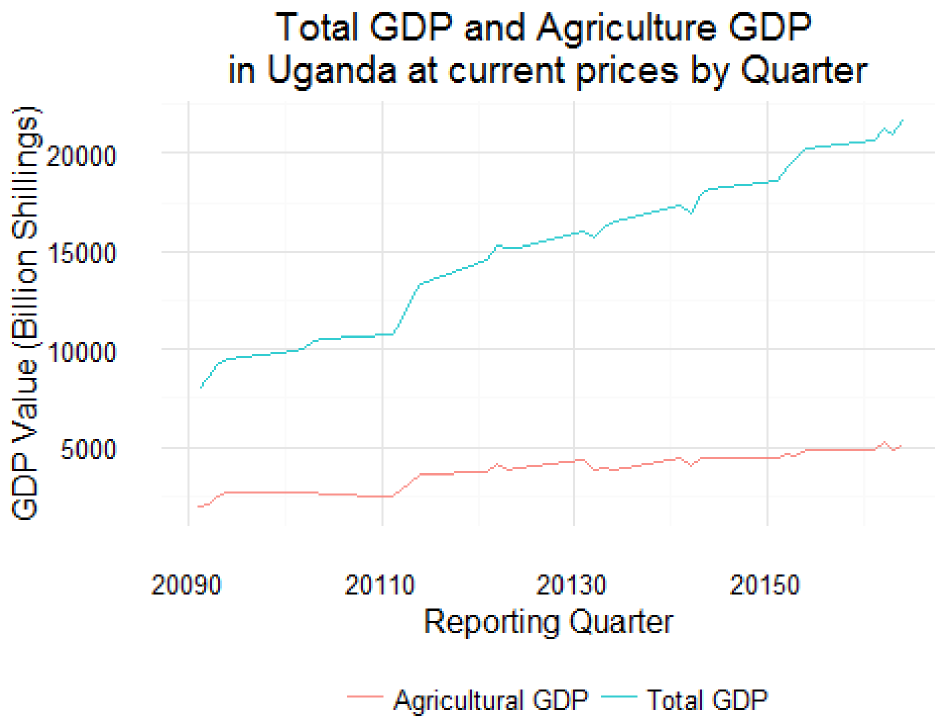
Using aWhere's global daily weather data, the historical Long Term Normal (LTN) weather is calculated across Uganda, every day for the past decade. This calculation is then used to determine if the weather on a given day was significantly different from the LTN. The index defines extreme conditions as those falling in the upper or lower tenth percentile of the historical record. The index was then calculated by taking the arithmetic mean of the following 3 indicators from the U.S. Climate Extremes Index:

- The percentage of Uganda with maximum temperatures much below or above normal.
- The percentage of Uganda with minimum temperatures much below or above normal.
- Twice the value of the percentage of Uganda with a much greater than normal proportion of total precipitation derived from extreme precipitation events. Extreme precipitation events are defined as being in the highest tenth percentile of precipitation amounts.

Each indicator has a threshold of 20 percent, above which the index is an indicator of abnormal weather events. This index is used as a measure of weather-related stress, which acts as a proxy for agricultural stress, to measure the impact of weather on agriculture, and thus ultimately on GDP. GDP figures are taken from the Uganda Bureau of Statistics.

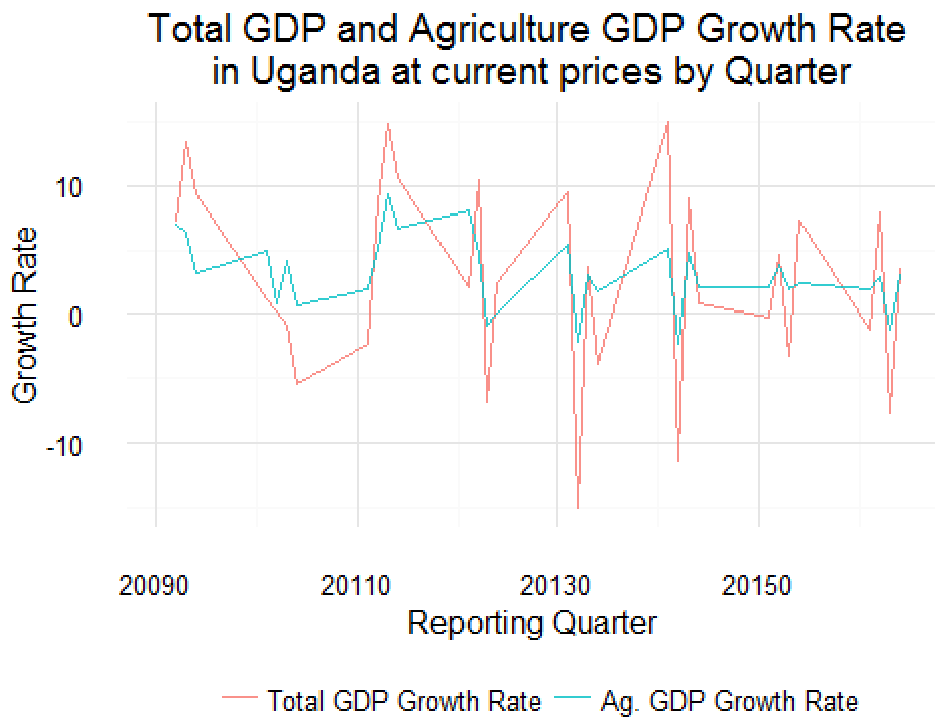
Gross Domestic Product (GDP)

We begin with an examination of Uganda's quarterly GDP figures, both for total economic activity and for agricultural output.



The above plot shows how the overall GDP and the agricultural GDP move together in Uganda.

```
#Correlation between Total GDP and Agricultural GDP
cor(uganda_gpd$t_gdp, uganda_gpd$ag_gdp)

## [1] 0.9812421
```



The above plot shows how GDP growth and growth in agricultural GDP also mirror each other in Uganda.

```
#Correlation between Change in Total GDP and Change in Agriculture GDP
cor(uganda_gdp_change$gdp_rate, uganda_gdp_change$aggdp_rate, use = "complete
.obs")

## [1] 0.8145724
```

Looking at the time series plots of both Uganda's overall GDP and agicultural GDP, one can see that the two series are correlated. This is supported by our calculations of correlation for the series. We expect there to be a high correlation between agricultural GDP and total GDP as the agriculture sector is a significant portion of Uganda's economic activity. This preliminary analysis serves as a check to ensure our assumptions are supported by the data. Given these results, we proceed to test our hypothesis that the rise in the rate of extreme weather events due to climate change, and the expected negative impact on the country's agricultural economy, will have an impact on the overall rate of economic growth in Uganda.

Constructing a Weather Index

To test our hypothesis, we construct an index of extreme weather to act as a proxy for agricultural stress. We do this first by using aWhere's global and robust weather data to construct a temperature index, based on the U.S. Climate Extremes Index. We then expand our analysis by using the same data to construct a precipitation index. These indices are graphed and compared against GDP figures to test the relationship of the data series.

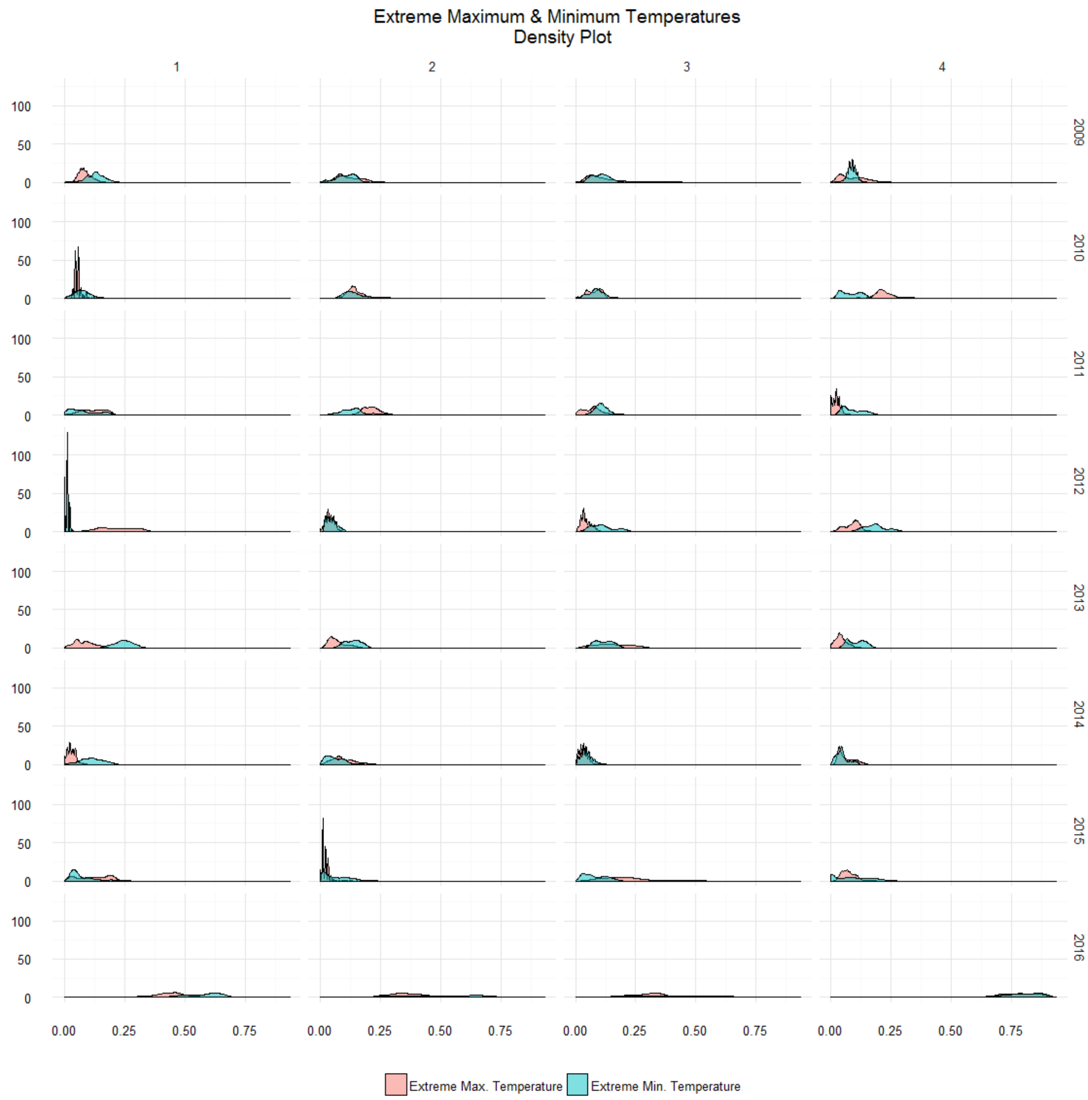
Temperature

To construct our temperature index, we compare Uganda's annual temperature data to the long-term normal (LTN) data. We did this for each of aWhere's nearly 3,000 virtual weather stations across Uganda. To do this, we calculate the range of normal maximum and minimum temperatures (10% - 90%) for each location in the country, every day of the year. Next, we compare those derived daily values to the maximum and minimum temperatures observed in the same locations, to determine if any values were abnormal enough to be labeled "extreme."

The table below shows preliminary results from our analysis for one location in Uganda. This table suggests that in 2011, this particular location experienced "extreme" temperature conditions only in the second quarter, when maximum temperatures exceeded LTN values significantly.

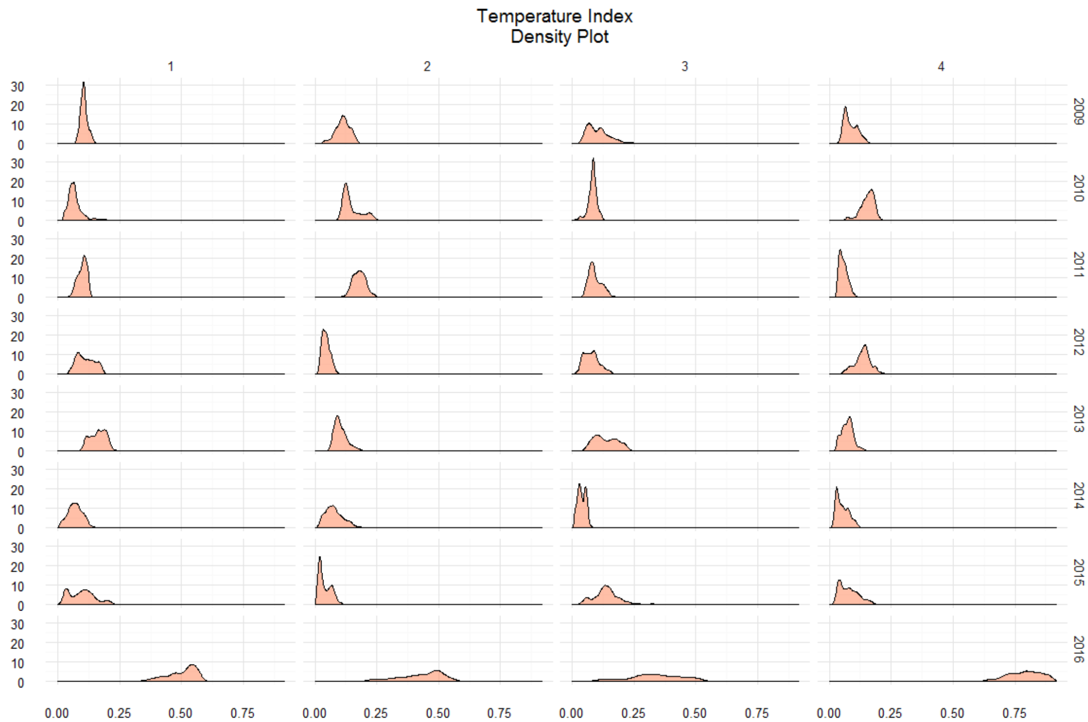
```
## # A tibble: 4 × 4
##   year_quarter percen_extreme_max percen_extreme_min index_temperature
##          <int>              <dbl>              <dbl>             <dbl>
## 1        20111         0.18181818         0.01136364        0.09659091
## 2        20112         0.26373626         0.12087912        0.19230769
## 3        20113         0.12087912         0.13186813        0.12637363
## 4        20114         0.03296703         0.04395604        0.03846154
```

After running a similar analysis for the remaining 2,835 locations monitored across Uganda, we can produce histograms using data from all of the locations, aggregated by quater, to take a closer look at the frequency of abnormal temperature events on a quarterly basis.



The above figure shows the share of locations across Uganda that experienced extreme maximum or minimum temperatures. All regions above the 0.2 threshold (shown on the x axis) are considered to be experiencing extreme conditions.

Our index, plotted by year and quarter above, suggests that temperatures in Uganda has predominantly been stable, without obvious or significant movement far enough from the mean to be considered extreme. The exception appears to be 2016, in which several locations in Uganda have experienced both maximum and minimum temperatures above our threshold of 0.2. By combining these two series, we can view one index of temperature extremes, on either end of the spectrum, comprising both maximum and minimum temperatures.

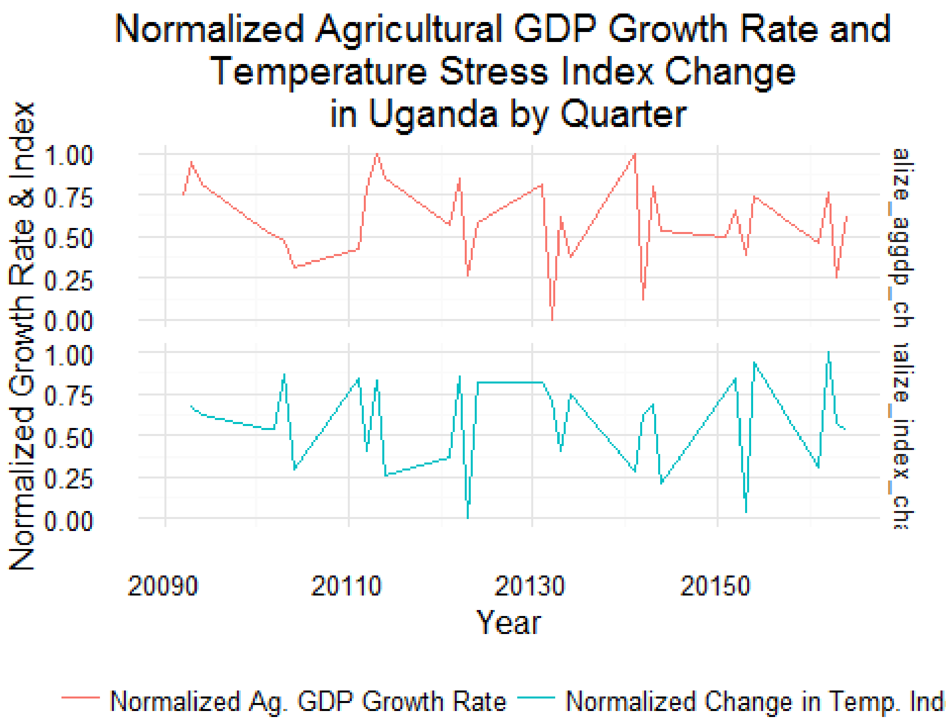


The above figure shows the number of locations across Uganda that experienced an abnormal temperature index value, on either end of the spectrum.

Combining the temperature extremes into one index further confirms the observation that temperatures are relatively stable, and therefore not likely to lead to extreme or sudden impacts on agricultural production in a given quarter.

Temperature and GDP

To compare agricultural GDP and our temperature index, we normalize both series and chart them here.



As the line chart does not identify a clear pattern or relationship, we calculate the cointegration of the two series using the Johansen test, as well as the correlation of the series.

```
#Cointegration using the Johansen Procedure
library(urca)
cointegration <- temp_index %>% ungroup() %>%
  group_by(year_quarter) %>%
  summarise(mean_index = mean(index_temperature, na.rm = T)) %>%
  inner_join(mutate(uganda_gpd, aggdp_rate = (ag_gdp - lag(ag_gdp)) / ag_gdp)
, by = "year_quarter") %>%
  mutate(index_change =  (mean_index - lag(mean_index)) / mean_index) %>%
  mutate(index_change_prev = lag(index_change)) %>%
  select(index_change_prev, aggdp_rate) %>%
  ca.jo(., type="trace",ecdet="none",spec="longrun")
summary(cointegration)

##
## ######################
## # Johansen-Procedure #
## ######################
##
## Test type: trace statistic , with linear trend
##
## Eigenvalues (lambda):
## [1] 0.6726150 0.2770622
##
```

```
## Values of teststatistic and critical values of test:
##
##           test 10pct  5pct  1pct
## r <= 1 |  9.08  6.50  8.18 11.65
## r = 0  | 40.35 15.66 17.95 23.52
##
## Eigenvectors, normalised to first column:
## (These are the cointegration relations)
##
##                        index_change_prev.l2 aggdp_rate.l2
## index_change_prev.l2               1.000000       1.00000
## aggdp_rate.l2                      3.348182     -12.49477
##
## Weights W:
## (This is the loading matrix)
##
##                       index_change_prev.l2 aggdp_rate.l2
## index_change_prev.d             -1.8002967   -0.23875874
## aggdp_rate.d                    -0.1393655    0.05271927
```

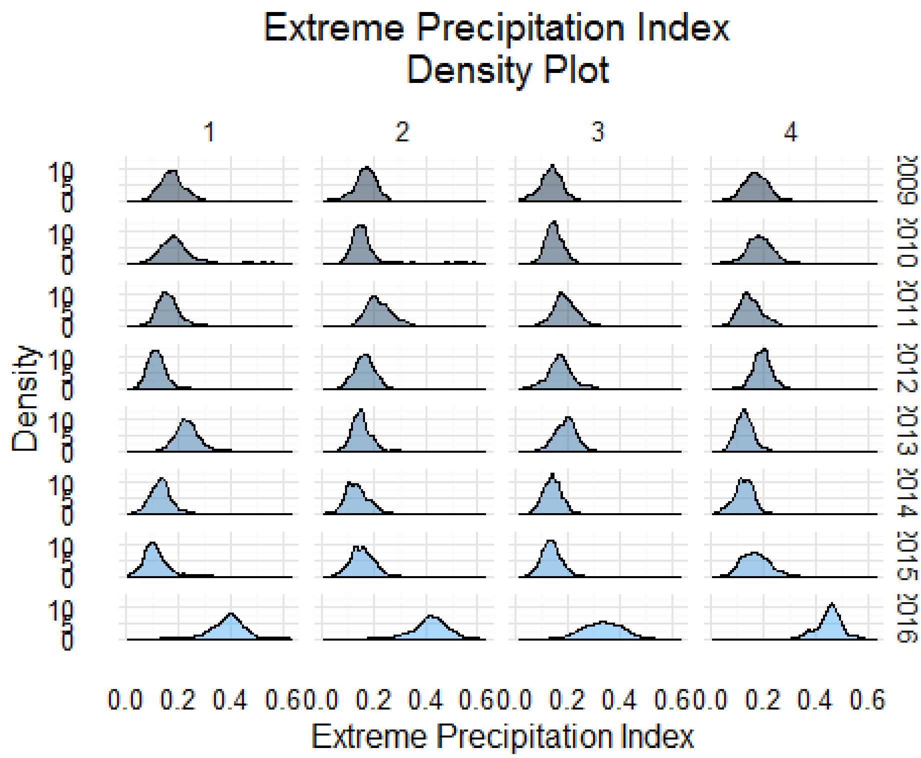
```
#Correlation between change in the temperature index and change in the Uganda
n agricultural GDP
cor(x=table$index_change_prev, y=table$aggdp_rate, use = "complete.obs")

## [1] 0.2012303
```

The correlation alone does not suggest a strong relationship between the series. However, using a null hypothesis of no cointegration between the two series, the Johansen test shows the test statistics for r = 0 at the 1%, 5% and 10% level will reject the null hypothesis of no cointegration. However, the test statistics for r <= 1 does not lead us to reject the null hypothesis at all confidence levels. This suggests we can confidently reject the null hypothesis of no cointegration between the change in agriculture GDP and the change in our temperature index. However, we cannot conclude that the temperature index change rate is cointegrated with the GDP change rate. This suggests that there might be another factor to look at if we want to conclude that agriculture GDP change is cointegrated with extreme weather index. Below, we'll calculate a precipitation index to see if abnormal precipitation levels have a larger impact on agricultural GDP.

Precipitation

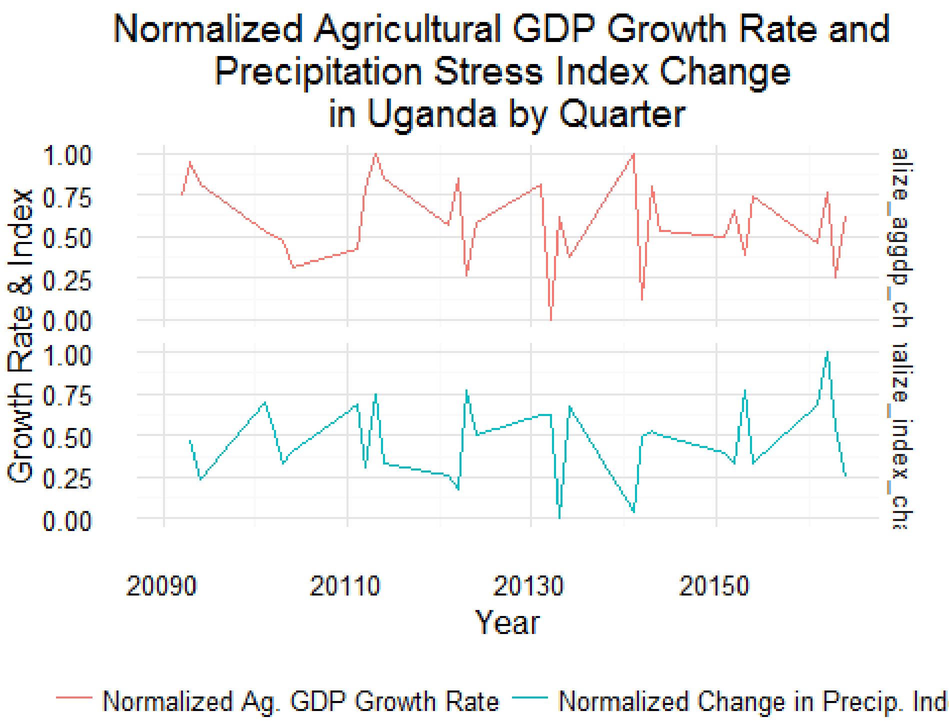
Having explored our temperature index above, we now conduct a similar exercise for precipitation figures in Uganda, to assess the impact of excess precipitation on GDP. This index is calculated using the number of days in which the precipitation in Uganda was significantly higher than normal (in the 10th percentile), multiplied by two.

Once the precipitation index has been calculated across Uganda, we can view the results by quarter and by year via a density plot. As above, the threshold for our precipitation index is 0.2, with figures above that threshold considered extreme. Reviewing the plots below suggests that the first and third quarters of 2015 saw predominantly normal precipitation patterns, while 2016 has been more irregular.



Precipitation & Temperature vs. GDP

We now combine both our extreme temperature and extreme precipitation indices into one index, to see if both together show a relationship to agriculture GDP. We have again normalized the figures for easier viewing.



Once again, the relationship is unclear from the chart alone, so we use the Johansen test and correlation figures to further examine the proposed relationship between the two data series.

```
#Cointegration using the Johansen Procedure
cointegration <- table %>% select(aggdp_rate, index_change_prev) %>%
ca.jo(., type="trace",ecdet="none",spec="longrun")
summary(cointegration)

##
## ######################
## # Johansen-Procedure #
## ######################
##
## Test type: trace statistic , with linear trend
##
## Eigenvalues (lambda):
## [1] 0.4700850 0.3686635
##
## Values of teststatistic and critical values of test:
##
##           test 10pct  5pct  1pct
## r <= 1 | 12.88  6.50  8.18 11.65
## r = 0  | 30.66 15.66 17.95 23.52
##
## Eigenvectors, normalised to first column:
## (These are the cointegration relations)
```

```
##
##                       aggdp_rate.l2 index_change_prev.l2
## aggdp_rate.l2              1.000000           1.00000000
## index_change_prev.l2       1.225051          -0.03971099
##
## Weights W:
## (This is the loading matrix)
##
##                      aggdp_rate.l2 index_change_prev.l2
## aggdp_rate.d          -0.04903851            -1.089909
## index_change_prev.d   -1.03323363             1.277109
```

```
#Correlation between change in the precipitation index and change in the Ugan
dan agricultural GDP
cor(table$aggdp_rate, table$index_change_prev, use = "complete.obs")

## [1] -0.3150912
```

As above, the correlation figure does not provide evidence of a clear relationship, so we look at the Johansen test results. For this test we can conclude the two time series are cointegrated at all confidence levels. Compared to the test results from the temperature index alone, adding abnormal rainfall events brought up the test statistics to be sufficient to reject the null hypothesis of no cointegration at all confidence levels, for both r = 0 and r <= 1. With these results, we can conclude that the extreme weather index, as a combination of extreme minimum and maximum temperatures and abnormal precipitation, is cointegrated with Ugandan agriculture GDP change.

These results support our hypothesis that when there are more extreme weather events, in the terms of temperature and precipitation, in Uganda, the agriculture GDP is impacted. With the strong correlation between Uganda's agriculture GDP and total GDP, we can further conclude that extreme weather events in Uganda can be expected to negatively impact GDP growth.

Conclusion

In this study, we tested our hypothesis that changes in agricultural GDP, modelled using an extreme weather index, are linked to changes in total GDP. Our tests concluded that an index of extreme temperature and excess precipitation in Uganda is cointegrated with changes in agricultural GDP. This supports our hypothesis that when there are more extreme weather events the agriculture GDP growth rate slows. Of course, there are many other factors that impact agricultural production, including subsidies, seed type, fertilizer application, among others. Future work might seek to account for these factors in an analysis, to further understand the link between weather and agricultural GDP, and ultimately on total GDP.