THE EFFECTS OF UNIFORM CLIMATE CHANGE ON INTERNATIONAL COTTON PRICES AND PRODUCTION

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Abstract

In this paper, we take the yield impacts of Schlenker and Roberts (2009), specifically on cotton, under a range of uniform temperature changes and apply it to a global fiber model to map changes in cotton production and prices. Although we use the 2011-2020 time period, the results should be viewed more as potential long-term market adjustments in the absence of new technology rather than a specific forecast. We find that in terms of extreme higher temperatures in the U.S. alone (+5°C) results in higher cotton prices as much as 17% against the baseline over the 2011-2020 projection period as production is cut back, on average, by 1.8%. Meanwhile, a 5°C increase in temperature in the U.S. and the rest-of-the-world (ROW) induces a price increase of as much as 135%, on average, throughout the projection period given a lower production of 20% from baseline levels that ignore temperature changes. More modest temperature changes (+1°C) result in much more modest (+6% in price and -1.3% in global production) changes in the cotton market.

Introduction

As the world's largest exporter and producer of agricultural commodities, the impacts of climate change in the U.S. could have broad ramifications for food /fiber supply and prices worldwide. But before one can investigate how prices will ultimately shift in response to climate change, it is critical to derive, initially, the correct relationship between weather and yields. However, most empirical studies link the average temperature over particular months or years to yields in linear regression models that fail to capture nonlinear temperature effects (Auffhammer, Ramanathan, and Vincent, 2006; Deschenes and Greenstone, 2007).

To assume that the marginal effect of temperature is constant when it is not results in inaccurate predictions based on non-marginal changes in temperatures that are expected under climate change (Schlenker and Roberts, 2008). Schlenker and Roberts (2009) use the whole distribution of temperatures within each day and across all days in the growing season for corn, soybeans, and cotton together with county-level yields to characterize the nonlinear and asymmetric relationship between temperatures and yields for these crops. In particular, yields increase until certain temperature thresholds and decline steeply above these thresholds: 29°C for corn, 30°C for soybeans, and 32°C for cotton. The results are robust after controlling for time-series or cross-sectional variations in temperatures and yields.

Schlenker and Roberts (2009) obtained monthly predictions of yield for minimum and maximum temperatures under four major emissions scenarios referred to as A1F1, A2, B1, and B2 for the years 1960-2099. A1F1 assumes continued use of fossil fuels which results in the largest increase in CO_2 concentrations and temperatures while B1 assumes the slowest rate of warming over the next century; B2 and A2 fall in between B1 and A1F1. In addition, Schlenker and Roberts (2009) also predicted yield impacts under a range of uniform temperature changes using a step-function. Table 1 reproduces a portion of Table 5A of Schlenker and Roberts (2009).

Table 1. Predicted Climate Change Impacts Under Uniform Climate Change for Cotton

Temperature	Impact (% change in yield)	Standard Error
+1°C	-2.59	1.57
+2°C	-8.34	3.08
+3°C	-16.30	4.54
+4°C	-25.48	6.01
+5°C	-35.61	7.36

Source: Table 5A of SI Appendix of Schlenker and Roberts (2009)

Two things are important to ultimately identify potential price changes as a consequence of climate change: an accurate relationship between temperature and yield growth, and a global cotton model that will funnel yield changes eventually to U.S. and world prices.

We find that much higher temperatures (+5°C) in the U.S. alone results in higher cotton prices as much as 17% against the baseline over the 2011-2020 projection period as production is cut back, on average, by 1.8%. Meanwhile, a 5°C increase in temperature in the U.S. and the rest-of-the-world (ROW) induces a price increase of as much as 135%, on average, throughout the projection period given a lower production of 20% from baseline levels that ignore temperature changes.

Methods

In this paper, we take the yield impacts in Schlenker and Roberts (2009), specifically on cotton, under a range of uniform temperature changes and apply it to a global fiber model to map changes in cotton prices (in response to varying changes in temperatures). Broadly, we examine the sensitivity of the world cotton price to rising temperatures from 2011 through 2020. Note that because the yield predictions of Schlenker and Roberts (2009) are made for 2020-2099, using yield predictions from any of the A1F1, A1, B1, B2 emissions scenario to predict price changes for years prior to 2020 (from 2011 through 2020), would grossly amplify climate change impacts in the immediate term. The yield effects under uniform temperature changes (uniform climate change), on the other hand, are more subdued and can be used to perform sensitivity analysis of price movements with respect to changing temperatures for years prior to 2020.

To link the temperature-yield relationship to price, we use the world fiber model developed at the Cotton Economics Research Institute (CERI) at Texas Tech University (Pan and Hudson, 2011). By far, it is the most comprehensive world cotton model that consists of 24 cotton-producing and consuming countries/regions. Each country/region model includes supply, demand and market equilibrium for cotton and man-made fibers. As the world fiber model is a net trade, price equilibrium model that equilibrates the sum of all countries' net exports and imports, countries are linked to the world fiber model through their net trade in both cotton and manmade fiber. The sum of all countries' net trades is used to endogenously solve for the world price of cotton and polyester in the first round. These world prices feed back into the country models so that domestic adjustments in the cotton and manmade sectors can be made in response to world prices.

Results and Discussion

A ten-year projection period (2011-2020) is used to allow for comparison of short- and medium-term effects. That is, some effects, while they can be fairly consistent over a ten-year interval, can also be more pronounced in the short-term; still others slowly buildup in the medium-term. The baseline assumption assumes the continuance of current domestic and international policies, and is driven by a set of macroeconomic variables such as population growth, real GDP, exchange rates, the CPI, among others. Projections for these macroeconomic variables as well as those for acreage, yield, and prices for competing crops and crude oil prices were obtained from the *World and U.S. Agricultural Outlook* (FAPRI, 2010).

Scenario I: Uniform Climate Change in the U.S.

In this policy simulation, we use the relationship between uniform increases in temperature and yield changes developed by Schlenker and Roberts (2009) for the U.S. In this scenario, we successively scale down all baseline yield projections by +1°C (up until +5°C) and simulate the effects on world production and prices. Tables 2 and 3 summarize the estimated effects of a uniform climate change in the U.S. With higher temperatures affecting the

U.S. alone, world production is projected to contract by as much as 1.8% from baseline levels following a 5°C increase in temperature and as little as 0.1% if the temperature rises by 1°C. The order of the effects on world production is less than 1% for temperature increases of up to 3°C that correspond to price increases of 1.2% to 7.4% over that range. Cotton prices are projected to increase by 17% at +5°C.

Scenario II: Uniform Climate Change in the U.S. and Rest-of-the-World (ROW)

In the second scenario, the ROW's yield responses are assumed to mimic that of the U.S. We still use the temperature-yield relationships derived by Schlenkler and Roberts (2009) for the U.S. While the assumption of

Table 2. Effects of a Uniform Climate Change in the U.S. *only* on World Cotton Production

World Production (mn bales)	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020	Average
Baseline	126.8	125.9	127.6	130.3	133.2	137.2	140.1	143.6	145.6	147.2	135.8
+1°C	126.3	125.8	127.4	130.2	133.1	137.1	139.9	143.5	145.5	147.1	135.6
+2°C	126.2	125.7	127.4	130.1	133.0	137.1	139.9	143.4	145.4	147.0	135.5
+3°C	123.7	125.0	126.7	129.4	132.3	136.4	139.3	142.7	144.7	146.1	134.6
+4°C	122.0	124.4	126.3	128.9	131.8	136.0	138.8	142.2	144.1	145.4	134.0
+5°C	120.1	123.7	125.7	128.4	131.3	135.5	138.4	141.7	143.5	144.8	133.3
Change From Baseline (%)											
+1°C	-0.4	-0.1	-0.1	-0.1	-0.1	-0.1	-0.1	-0.1	-0.1	-0.1	-0.1
+2°C	-0.5	-0.1	-0.1	-0.2	-0.1	-0.1	-0.1	-0.1	-0.1	-0.2	-0.2
+3°C	-2.4	-0.7	-0.7	-0.7	-0.7	-0.6	-0.6	-0.6	-0.7	-0.8	-0.8
+4°C	-3.8	-1.2	-1.0	-1.1	-1.0	-0.9	-0.9	-1.0	-1.1	-1.2	-1.3
+5°C	-5.3	-1.7	-1.4	-1.5	-1.4	-1.3	-1.2	-1.3	-1.5	-1.6	-1.8

Table 3. Effects of a Uniform Climate Change in the U.S. *only* on the World Cotton Price

Cotton A-Index (U.S. cents/lb)	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020	Average
Baseline	100.4	93.2	91.8	93.1	93.6	93.9	93.6	94.1	94.1	94.0	94.2
+1°C	103.2	94.5	93.0	94.2	94.7	94.9	94.5	94.8	94.6	94.4	95.3
+2°C	104.0	95.0	93.4	94.6	95.0	95.2	94.7	95.0	94.7	94.5	95.6
+3°C	118.1	102.4	99.4	100.5	100.7	100.2	98.8	98.2	97.0	95.9	101.1
+4°C	128.4	108.3	104.0	104.9	105.0	103.9	101.8	100.5	98.7	97.4	105.3
+5°C	139.8	115.5	109.6	109.9	109.9	108.2	105.2	103.3	101.1	99.4	110.2
Change From Baseline (%)											
+1°C	2.8	1.5	1.3	1.2	1.2	1.0	0.9	0.7	0.5	0.4	1.2
+2°C	3.6	1.9	1.6	1.6	1.6	1.4	1.1	0.9	0.7	0.5	1.5
+3°C	17.7	9.9	8.2	8.0	7.7	6.7	5.5	4.4	3.1	2.0	7.4
+4°C	27.9	16.3	13.3	12.7	12.2	10.6	8.7	6.8	4.9	3.5	11.8
+5°C	39.3	23.9	19.3	18.1	17.4	15.1	12.3	9.8	7.5	5.7	17.0

Table 4. Effects of a Uniform Climate Change in the U.S. + ROW on World Cotton Production

World Production (mn bales)	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020	Average
Baseline	126.8	125.9	127.6	130.3	133.2	137.2	140.1	143.6	145.6	147.2	135.8
+1°C	123.7	124.3	126.0	128.8	131.7	135.7	138.5	142.0	143.9	145.3	134.0
+2°C	122.7	123.8	125.5	128.3	131.2	135.3	138.0	141.4	143.3	144.6	133.4
+3°C	106.9	114.9	117.4	120.1	123.1	127.2	129.7	132.5	134.1	135.2	124.1
+4°C	95.6	107.4	111.1	113.8	116.8	120.8	123.1	125.7	127.1	127.8	116.9
+5°C	83.1	97.7	103.2	106.3	109.2	113.1	115.2	117.5	118.6	119.1	108.3
Change From Baseline (%)											
+1°C	-2.5	-1.2	-1.2	-1.2	-1.1	-1.1	-1.1	-1.2	-1.2	-1.3	-1.3
+2°C	-3.2	-1.6	-1.6	-1.6	-1.5	-1.4	-1.5	-1.5	-1.6	-1.8	-1.7
+3°C	-15.7	-8.7	-8.0	-7.9	-7.6	-7.3	-7.4	-7.7	-7.9	-8.2	-8.6
+4°C	-24.6	-14.7	-12.9	-12.7	-12.3	-11.9	-12.1	-12.5	-12.8	-13.2	-13.9
+5°C	-34.5	-22.4	-19.1	-18.5	-18.0	-17.6	-17.7	-18.2	-18.6	-19.1	-20.2

Table 5. Effects of a Uniform Climate Change in the U.S. + ROW on the World Cotton Price

Cotton A-Index (U.S. cents/lb)	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020	Average
Baseline	100.4	93.2	91.8	93.1	93.6	93.9	93.6	94.1	94.1	94.0	94.2
+1°C	115.4	101.9	99.6	100.4	100.5	99.8	98.4	97.9	96.5	95.5	100.6
+2°C	120.2	104.7	102.1	102.7	102.6	101.7	99.9	99.0	97.3	96.1	102.6
+3°C	206.3	159.9	148.5	145.0	141.7	134.8	127.4	121.9	115.7	110.7	141.2
+4°C	275.2	211.4	190.4	182.2	176.0	164.2	152.0	142.4	132.5	124.4	175.1
+5°C	357.0	282.1	248.8	233.0	223.0	205.4	186.8	171.6	157.1	144.9	221.0
Change From Baseline (%)											
+1°C	15.0	9.3	8.5	7.9	7.4	6.3	5.1	4.0	2.6	1.5	6.8
+2°C	19.8	12.4	11.2	10.4	9.7	8.2	6.7	5.2	3.4	2.2	9.0
+3°C	105.6	71.6	61.6	55.8	51.4	43.5	36.0	29.6	23.0	17.8	49.9
+4°C	174.2	126.9	107.3	95.7	88.1	74.8	62.3	51.3	40.9	32.3	85.9
+5°C	255.7	202.8	170.9	150.3	138.3	118.6	99.5	82.4	67.0	54.1	134.6

other countries having the same yield response to temperature changes is unrealistic amidst varying cultivars, agro-climatic conditions across countries, the value of the exercise lies not in the projections, or the accuracy of the projections, but rather in showing how world cotton prices shift to varying levels of temperature change. Specifically, increments of 1°C (up to 5°C) are added to Scenario I for all regions/countries (in addition to the U.S.) to evaluate the sensitivity of world cotton prices. Tables 4 and 5 summarize the estimated effects of a uniform climate change on world cotton production and prices. With higher temperatures affecting all the cotton producing countries within the world fiber model, world production levels can shrink by about a fifth from baseline levels with resultant cotton prices more than doubling following a 5°C increase in temperature. At the lowest end at +1°C, production is projected to decline by only 1.3% and price to increase by 6.8%.

Figure 1 plots the movement of world cotton price (on average over 2011-2020) for every 1°C increase in temperature relative to the baseline under the two scenarios. Figure 2 shows how world production is adversely affected for every 1°C increase in temperature relative to baseline levels.

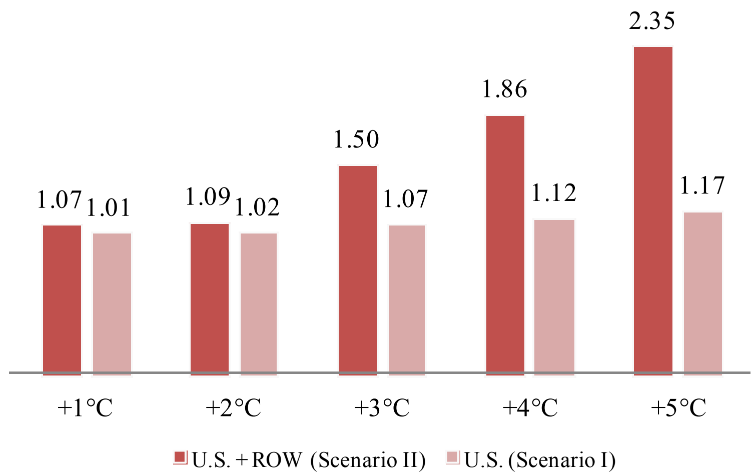

Figure 1. Cotton A-index Relative to Baseline Levels (Baseline=1)

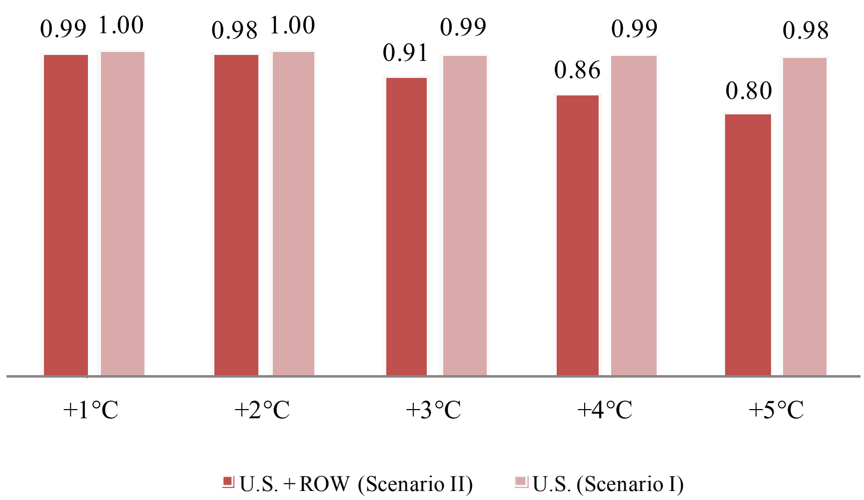

Figure 2. World Cotton Production Relative to Baseline Levels (Baseline=1)

Locational Effects

We apply the 'shift in share' analysis by Krueger (2000) to examine changes in production across cotton-producing countries included in the model. Using the average 2011-2020 production without an increase in temperature as a base, the share of each country's domestic production to world production is calculated. The shares so calculated are then applied to world production in the +1°C, +2°C, +3°C, +4°C, and +5°C scenarios to estimate what each country's production would have been had its share of world cotton output been unaltered. The difference between that number and the actual production is then taken as the 'shift' in country production due to lower world output arising from higher temperatures that result in lower yields. Table 6 presents the results of the 'shift in share' analysis for the top cotton-producing countries in the world.

Table 6. Shift in Shares of World Cotton Production

Country and Temperature Change	*Actual Production ('000 bales)*	*Production Under Constant Baseline Share of World Production ('000 bales)*	*Change Due to Decline in World Production (%)*
China			
+1°C	36096.7	36238.7	-0.4
+2°C	35898.3	36086.9	-0.5
+3°C	33570.6	33570.6	-3.0
+4°C	29958.3	31625.8	-5.3
+5°C	26766.8	29291.7	-8.6
India			
+1°C	32584.3	32618.9	-0.1
+2°C	32436.7	32482.2	-0.1
+3°C	29893.9	30217.3	-1.1
+4°C	27865.5	28466.7	-2.1
+5°C	25390.4	26365.8	-3.7
U.S.			
+1°C	19043.8	18933.2	0.6
+2°C	18999.1	18853.9	0.8
+3°C	18310.6	17539.2	4.4
+4°C	17809.7	16523.1	7.8
+5°C	17227.9	15303.7	12.6
Pakistan			
+1°C	10133.6	10251.2	-1.1
+2°C	10055.0	10208.3	-1.5
+3°C	8780.9	9496.5	-7.5
+4°C	7864.9	8946.3	-12.1
+5°C	6844.1	8286.0	-17.4
Brazil			
+1°C	9228.3	9179.8	0.5
+2°C	9205.9	9141.3	0.7
+3°C	8866.9	8503.9	4.3
+4°C	8633.2	8011.3	7.8
+5°C	8367.1	7420.0	12.8
Uzbekistan			
+1°C	4611.4	4610.8	0.0
+2°C	4592.0	4591.4	0.0
+3°C	4250.7	4271.3	-0.5
+4°C	3974.4	4023.8	-1.2
+5°C	3639.6	3726.9	-2.3
Australia			
+1°C	4446.9	4394.7	1.2
+2°C	4444.8	4376.3	1.6
+3°C	4402.2	4071.1	8.1
+4°C	4348.9	3835.3	13.4
+5°C	4256.4	3552.2	19.8
Turkey			
+1°C	2731.8	2733.1	0.0
+2°C	2720.1	2721.6	-0.1
+3°C	2529.8	2531.8	-0.1
+4°C	2387.5	2385.2	0.1
+5°C	2220.1	2209.1	0.5
W/C Africa			
+1°C	1914.5	1925.3	-0.6
+2°C	1903.2	1917.2	-0.7
+3°C	1720.9	1783.5	-3.5
+4°C	1588.5	1680.2	-5.5
+5°C	1438.4	1556.2	-7.6
Other Asia			
+1°C	1907.8	1927.5	-1.0
+2°C	1893.7	1919.5	-1.3
+3°C	1667.0	1785.6	-6.6
+4°C	1504.8	1682.2	-10.5
+5°C	1324.2	1558.0	-15.0

As shown in Table 6, notwithstanding lower world cotton output, China, India, Pakistan, Uzbekistan, West and Central Africa, and Other Asia are likely to see diminished world shares as a result of temperature rises. In contrast, the U.S., Brazil, Australia and Turkey (in part) are projected to gain higher production shares as temperatures rise. Given these notable location effects, it is curious to ask whether the cotton types grown in the first set of countries are not well-suited to higher temperatures as opposed to those grown in the second set of countries?

Summary and Conclusions

The simulation results over the period 2011-2020 suggest that a large increase in temperature is expected to have rather dramatic effect on world cotton production levels and prices in the absence of any technology to address production under higher temperatures. For example, a 5°C increase in temperature across all cotton producing countries in the world under uniform climate change is likely to shave off as much as 20% of the world's current (baseline) cotton production followed by a more than doubling of cotton prices. Under a more modest temperature increase of +1°C, production is projected to decline by only 1.3% and prices to increase by 6.8%.

Interestingly, this model provides a rough approximation of the economic value of technology that will address production under higher temperatures. Holding global consumption constant, the difference in average price from the baseline to each scenario times global consumption provides the cost increase to global consumers, which ranges from $90B to $198B. [Average global consumption of cotton (mill utilization plus ending stocks) over the period 2011-2020 under the baseline is 186.9 million bales.] Accordingly, investment in technology to address production under higher temperatures could be as much as this amount and consumers would be at least as well off. But, this should be viewed as a lower bound because global demand will likely increase as population grows, thereby putting more upward pressure on price, and thereby value of technology, *ceteris paribus*.

The analysis presented here only represents a first attempt at understanding the potential economic impacts of temperature increases on global cotton markets. Understandably, there are a number of important caveats. First, we are applying both temperature changes and yield changes uniformly across the globe. This is not realistic, but necessary given the complexity of the global climate and the plethora of cultivars used around the world. Second, we are modeling a much shorter period, which does not necessarily correspond with the time period for expected climate change, and the modeled temperature changes are assumed constant throughout the forecast period. Thus, the model results should be viewed as an average impact of a shift in temperatures to a new steady-state equilibrium rather than a model of the transition in the market. With these caveats, we reiterate that the model results should be viewed more as a guidepost for understanding the potential aggregate effects rather than a specific forecast of annual changes.

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