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The Effects of Uniform Climate Change on International Cotton Prices and Production

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The Effects of Uniform Climate Change on International Cotton Prices and Production

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.

I. 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 CO₂ 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).¹

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. 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

¹ Table A5 of the SI Appendix of Schlenker and Roberts (2009).

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.

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.

II. Fiber Models of the U.S. and the World

In this section, we discuss, in turn, the U.S. and world fiber models used in the empirical analysis.

U.S. Cotton Model

Fundamental to the estimation of the effects of climate change in the U.S. on the world cotton market is the development of a structural econometric model of the U.S. cotton sector. This model incorporates the supply response of cotton, substitutability between cotton and manmade fibers, and linkage between the raw fiber and textile sectors in the different regions of the U.S. The U.S. model includes supply, demand, and market equilibrium for cotton and manmade fibers. The domestic supply of cotton is shown as the sum of production, beginning stocks, and imports. Production is further subdivided into areas and yields, while manmade fiber is derived from capacity and utilization. Overall cotton demand is derived from estimates of total fiber consumption which is subsequently allocated to cotton, wool and manmade fibers.

Fiber Supply Equations

To account for dissimilarities in growing conditions arising from climatic differences, water and other natural resource availability that influence crop mix, cotton-producing states in the U.S. are divided into four regions: (1) Delta (Mississippi, Arkansas, Missouri, Tennessee, and Louisiana); (2) Southeast (Georgia, Alabama, North Carolina, Florida, and Virginia); (3) West (Arizona, California, and New Mexico); and (4) Southwest (Kansas, Oklahoma, and Texas). The Southwest is further subdivided into irrigated and dryland production areas to account for substantial variation within this region. Cotton producers in the irrigated southwest may make considerable different acreage response decisions amidst a wider range of substitute crops than contiguous dryland producers. Competing crops are different across the regions, primarily soybeans in the Delta and Southeast, sorghum and wheat in the Southwest, and corn and wheat in the West. Figure 1 is a schematic representation of the U.S. cotton supply model.

Regional production is derived from separate estimates of harvested acreage and yield. Harvested acreage is a function of planted acreage, which, in turn, is conditioned on expected returns of cotton and competing crops, a time trend, program/policy variables, and in few occasions, lagged area:

$$(1) \quad a_{i,t}^c = f(p_{i,t}^c, p_{i,t}^s, t, a_{i,t-1}^c, z_{i,t}),$$

where $a_{i,t}^c$ is cotton acreage in the i th region at time t , $p_{i,t}^c$ and $p_{i,t}^s$ are i th region cotton and competing crop prices, respectively, and $z_{i,t}$ are other policy/program variables excluded in the computation of expected net returns (e.g. cotton insurance). Expected net returns for cotton and competing crops include both market and all program payments such as direct payments, marketing assistance and loan deficiency payments, and countercyclical payments. Producer assessment is subtracted from expected net returns.

Regional yield, $y_{i,t}$, is specified as a function of lagged prices of cotton and competing crops, time to account for technology effects, policy variables, and where available, rainfall amounts. Total cotton production, $TCP_{i,t}$, is the summation across regions of the product of harvested acreage and yield per hectare:

$$(2) \quad TCP_t = \sum_{i=1}^4 (a_{i,t}^c * y_{i,t})$$

While current capacity utilization decisions are based on current input and output prices, realized infrastructure production capacity is based on expected market prices of inputs and output several periods prior to completion of the construction of the infrastructure. As such, production capacity for manmade fibers is specified as:

$$(3) \quad MMFC_t = f(OP_{t-i}, PYP_{t-i}, MMFC_{t-1}) \quad i = 3, 4, \dots, 7$$

where $MMFC$ is manmade fiber production capacity, OP is crude oil price, PYP is the polyester price. The lag length is determined by using the minimum Akaike Information Criterion (AIC).

The utilization equation, in contrast, is a function of current prices and lagged utilization levels:

$$(4) \quad MMFU_t = f(PYP_t, OP_t, MMFU_{t-1})$$

where $MMFU$ is the capacity utilization of manmade fibers.

The product of manmade fiber capacity and utilization derives the total production of manmade fiber, $MMFP$:

$$(5) \quad MMF_t = MMFC_t * MMFU_t^2$$

Figure 2 is a schematic representation of the U.S. man-made fiber sector.

Fiber Demand Equations

Cotton and manmade fiber/textile demand consists of three equations: (a) fiber/textile consumption; (b) mill use, and (c) net imports. Cotton textile consumption is conditioned on advertising expenditures, the U.S. cotton textile price index, and real disposable income:

$$(6) \quad CTXCON_t = f(AD_t, CTPIUS_t, RDPI_t).$$

where $CTXCON$ is cotton consumption, AD is advertising expenditure, $CTPIUS$ is U.S. cotton textile price index, and $RDPI$ is personal disposable income in real terms.

Cotton mill use is estimated as a function of U.S. cotton textile price index, prices of cotton and polyester ($PCOT$ and $PYPY$, respectively), and non-agricultural research expenditures ($NARE$):

$$(7) \quad CMU_t = f(CTPIUS_t, PCOT_t, PYP_t, NARE_t).$$

² Equations (3), (4), and (5) are correspondingly estimated for two types of manmade fiber: cellulosic and synthetics. Rayon prices are used instead of polyester prices in estimating synthetics utilization and capacity equations.

Cotton textile trade (*CTT*) is specified as a function of U.S. cotton textile price index, the Chinese textile price index (*CTPICH*), and the trade-weighted Federal Reserve interest rate (*I*):

$$(8) \quad CTT_t = f(CTPIUS_t, CTPICH_t, I_t).$$

Similarly, manmade textile fiber consumption is specified by the same components only with corresponding non-cotton variables although absent from the corresponding manmade fiber trade equation is the Chinese price index.³

Ending stocks of cotton (*ES*) are estimated as a function of spot prices (*CSP*), total cotton production (*TCP*) and lagged ending stocks:

$$(9) \quad ES_t = f(CSP_t, TCP_t, ES_{t-1}).$$

Finally, the U.S. cotton farm price is solved endogenously in the model by equilibrating cotton supply (production + imports + beginning stocks) and cotton demand (mill use + exports + ending stocks). The U.S. polyester price (representative of world synthetic price) is solved in the model by equilibrating total supply (production) and demand (mill use). Likewise, the U.S. cotton textile price and non-cotton price indices are solved by equilibrating total supply (mill use + net imports) and demand (textile consumption). Figure 3 depicts these relationships.

World Fiber Model

The U.S. model is linked to a broader world fiber model that includes supply and demand models for the 23 other major producing and consuming countries and regions: (1) Asia (China, India, Pakistan, Taiwan, South Korea, Japan and Other Asia); (2) Africa (Egypt, Western Africa and Other Africa); (3) North America (Mexico, United States, and Canada); (4) Latin America (Brazil, Argentina, and Other Latin America); (5) Oceania (Australia); (6) Middle East (Turkey

³ This variable did not prove significant for this equation and was removed to enhance model performance.

and Other Middle East); (6) Former Soviet Union (Uzbekistan, Russia, and Other FSU); (7) Europe (European Union, Central and Eastern Europe, and Other Western Europe).

As shown in Figure 4, the representative country model includes supply, demand and market equilibrium for cotton and man-made fibers. Cotton production in each country and region defined in the model is derived from behavioral equations of area and yield. Generally, acreage equation is specified as a function of the expected net returns for cotton and competing crops whereas yield is dependent on expected cotton price and time trend to account for technological development. In some instances expected prices are used in lieu of expected return due to non-availability of cost of production data. For major players such as United States, China and India, cotton production is estimated in a regional framework to capture regional differences in climate, water availability and other natural resources that influence crop mix in different parts of the country.

Cotton demand is estimated using a two-step process. In the first step, total fiber demand (cotton, wool, the cellulosic and synthetic) are calculated by summing fibers demand in apparel, home furnishing and industrial sectors. In the second step, total fibers are divided among cotton, synthetic, cellulose and wool based on relative prices and other factors. Prices of man-made fibers are also endogenized in the model by having supply response for each of these sectors. Man-made fiber supply response, for both synthetic and cellulosic, is derived through the estimation of capacity and utilization equations for each market.

Apart from supply and demand models for cotton and other fibers, the model also includes behavioral equations for ending stocks and trade. Border policies tariffs, quotas and tariff-rate-quotas are incorporated into the trade equations. As shown in Figure 5, Cotton A-index and

polyester prices are solved in the model by equalizing world exports and imports. For interested readers, a full documentation of the world fiber model is presented in Pan and Hudson (2011).

A stylized model specification for a representative country is presented in Table 2. The model specifies per capita fiber consumption as a function of the fiber and non-fiber prices and per capita income. In the second stage, total fiber production is allocated among various fibers based on relative prices. In the supply side, cotton acreage generally is specified as a function of own and competing crop expected net returns or prices and cotton yield is dependent on cotton price and time trend to capture technological change. For man-made fibers, capacity and utilization are modeled separately to estimate production and generally specified as function of past five years' man-made fibers and crude oil prices. Finally, export and import equations are specified as a function of domestic and international prices. For import equations, international prices are calculated by converting world price in domestic currency equivalent after adding appropriate tariffs. Similarly, for export equations, international prices are calculated by converting world representative price into domestic currency equivalent.

As the world fiber model is a net trade, price equilibrium model that equilibrates the sum of all countries' net exports and imports, the U.S. and other country sub-models are linked to the world fiber model through its 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 U.S. model as well as to other country sub-models so that domestic adjustments in the cotton and manmade sectors can be made in response to world prices.

II. Data and Parameter Estimates

Annual data for the period 1970 to 2004 were obtained from several sources.

Macroeconomic data such as gross domestic product (GDP), disposable income, Consumer Price Index (CPI) were sourced from the Food, Agriculture and Policy Research Institute (FAPRI). Cotton data on total U.S. acreage, yield, production, mill use, ending stocks, and trade were collected from the Foreign Agricultural Service of the U.S. Department of Agriculture. U.S. cotton farm, spot and mill prices, and regional acreage, yield and production were obtained from the *Cotton and Wool Situation and Outlook Yearbook* published by the Economic Research Service (ERS), U.S. Department of Agriculture (2008). Prices of competing crops were derived from various yearbooks for different crops published by the ERS as well. Data on consumption and trade of textile and manmade fiber as well as manmade fiber production capacity and utilization were sourced from various issues of *Fiber Organon* published by the Fiber Economic Board.

Parameter estimates of the behavioral equations of the U.S. model as well as for other countries, along with the regression statistics are reported in Pan & Hudson (2011). After estimating all equations, the model was solved simultaneously using the PROC MODEL routine in SAS. Historical simulation of the model's equations was used to validate the estimated model using the components of the mean squared error (MSE) and Theil inequality coefficients. In Pan and Hudson (2011), a significant portion of the bias and regression components' values are close to 0 which indicates that simulated values closely track actual values. The disturbance components for most variables are close to 1 which suggests that most of the errors in the simulated values relate to the randomness in the actual data series. Theil inequality coefficients that are close to 0 also reinforce the model's good performance.

IV. Policy Simulation

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 3 and 4 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 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 5 and 6 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 6 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 7 shows how world production is adversely affected for every 1°C increase in temperature relative to baseline levels.

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 7 presents the results of the 'shift in share' analysis for the top cotton-producing countries in the world.

As shown in Table 7, 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?

V. 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.⁴ 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.

⁴ Average global consumption of cotton (mill utilization plus ending stocks) over the period 2011-2020 under the baseline is 186.9 million bales.

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)

Table 2. Standard Specifications of Behavioral Equations

Variable	Behavioral Equation
Per capita fiber consumption	$PC_f = \alpha_0 + \alpha_1 P_f + \alpha_2 I$
Share of cotton mill use	$DS_c = \beta_0 + \beta_1 (P_c / P_s)$
Share of man-made fiber mill use	$DS_m = \beta_0^m + \beta_1^m (P_c / P_s)$
Cotton supply	$S_{c,t} = \kappa_0 + \kappa_1 (P_{c,t-1})$
Man-made fiber supply	$S_{m,t} = \kappa_0^m + \sum_{k=1}^5 \kappa_1^m (P_{m,t-k}) + \sum_{k=1}^5 \kappa_2^m (P_{g,t-k})$
Cotton imports	$I_c = \phi_0 + \phi_1 (P_c / WP_c (1+T))$
Cotton exports	$E_c = \phi_{e0} + \phi_{e1} (P_c / WP_c (1-\tau))$
Cotton price linkage	$P_c = \gamma_0 + \gamma_1 WP_c$
Polyester price linkage	$P_m = \gamma_0 + \gamma_1 WP_m$

Note: The capital letter PC, S, D, DS, P, WP, I and E represents per capita consumption, supply, share of mill use, domestic price, world price, imports and exports respectively. The subscripts f, c, m, w represents fiber, cotton, man-made fiber, and world respectively. $t, t-1, t-k$ represent current time period, one lag, and k lags. T, τ represent tariffs rate and export subsidy rate.

Table 3. 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 4. 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 5. 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 6. 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

Table 7. Shift in Shares of World Cotton Production

<i>Country and Temperature Change</i>	<i>Actual Production (^{'000} bales)</i>	<i>Production Under Constant Baseline Share of World Production (^{'000} bales)</i>	<i>Change Due to Decline in World Production (%)</i>
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

Figure 1. Schematic Representation of U.S. Cotton Supply Model

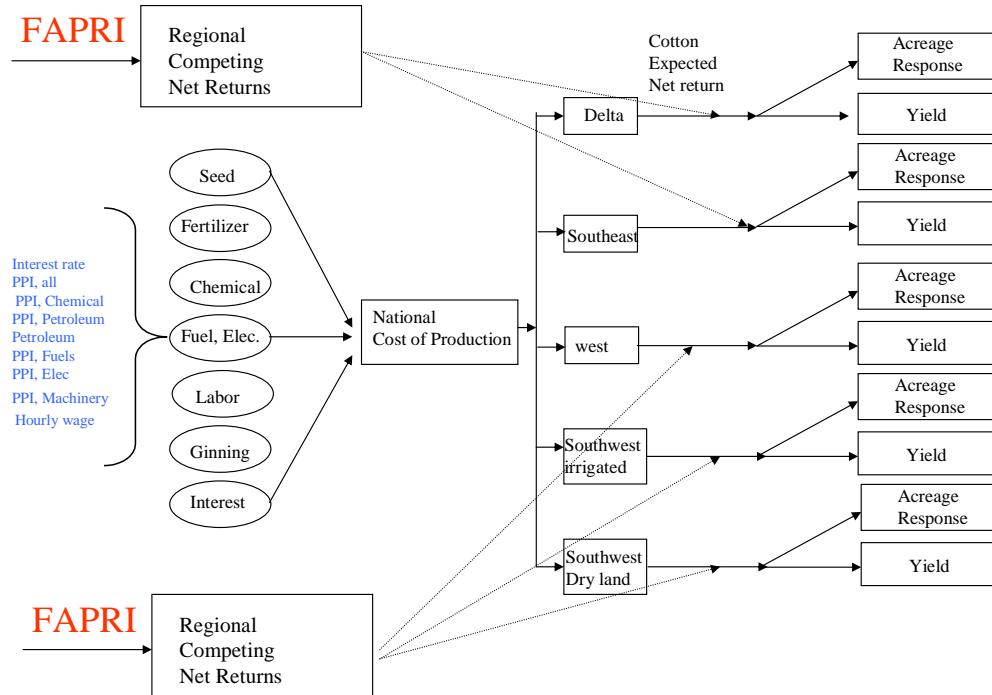


Figure 2. Schematic Representation of the Man-made Fiber Model

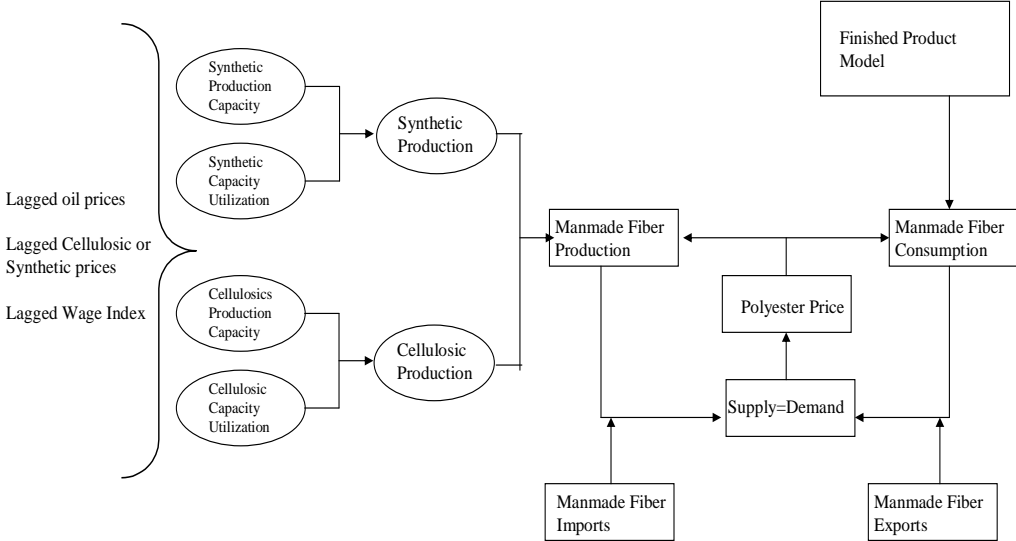


Figure 3. U.S. Cotton and Non-Cotton Textile Models

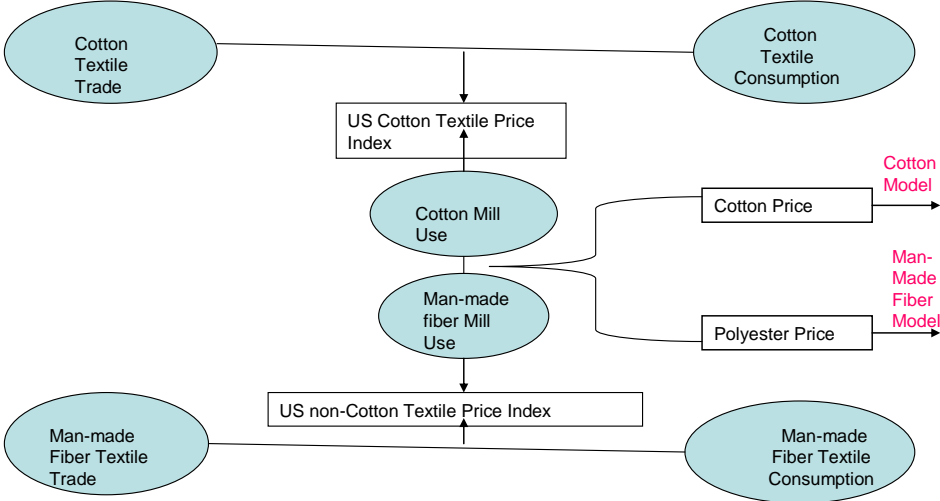


Figure 4. Representative Country Model

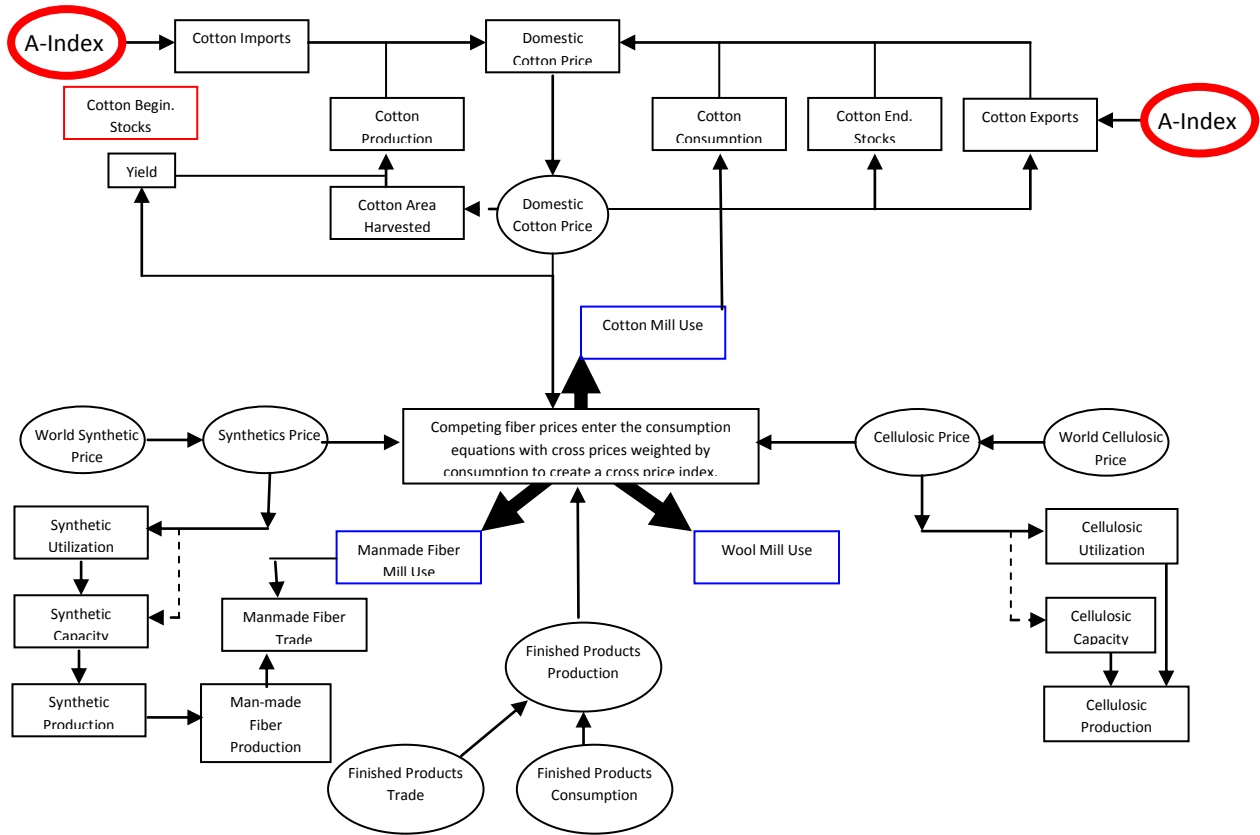


Figure 5. World Fiber Price Solving Mechanism

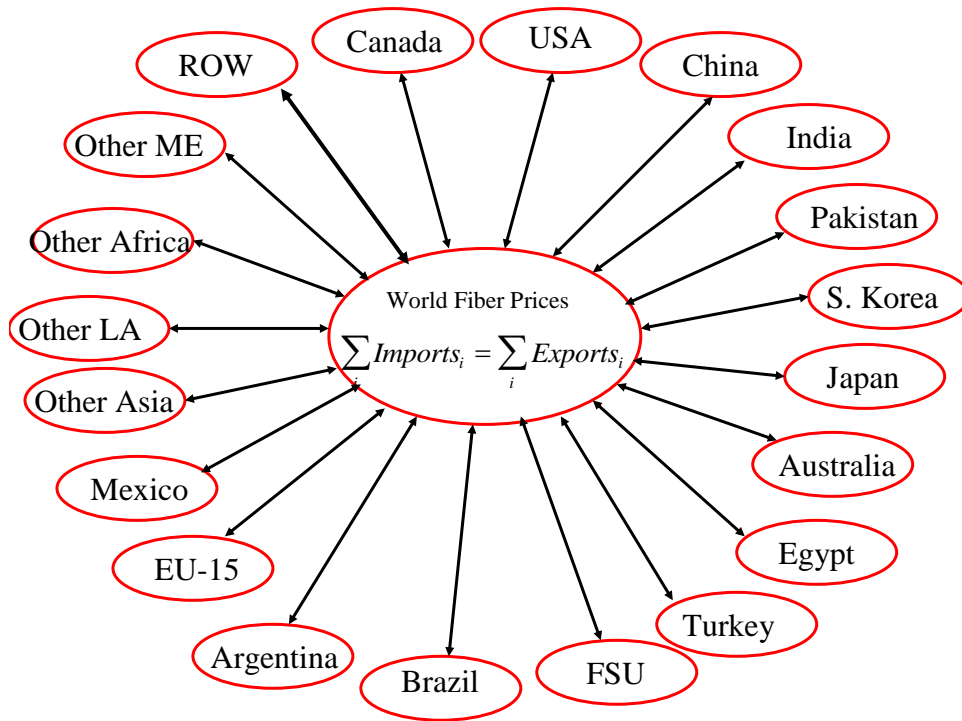


Figure 6. Cotton A-index Relative to Baseline Levels (Baseline=1)

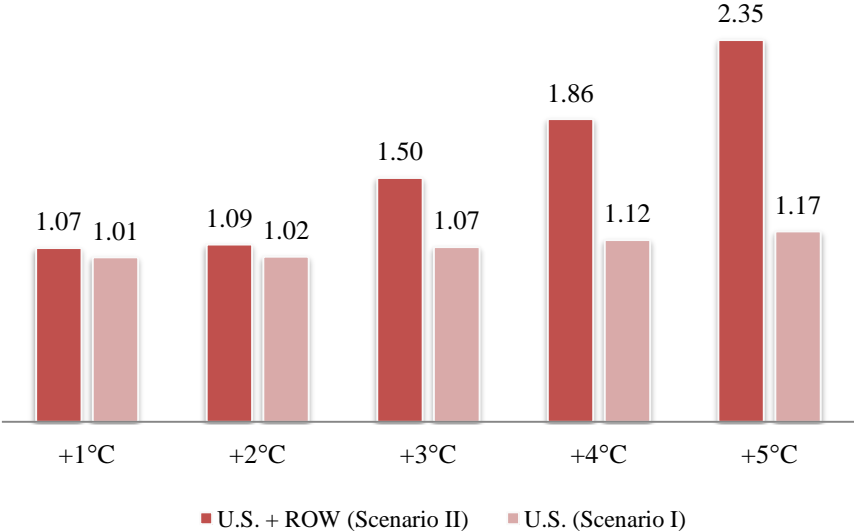
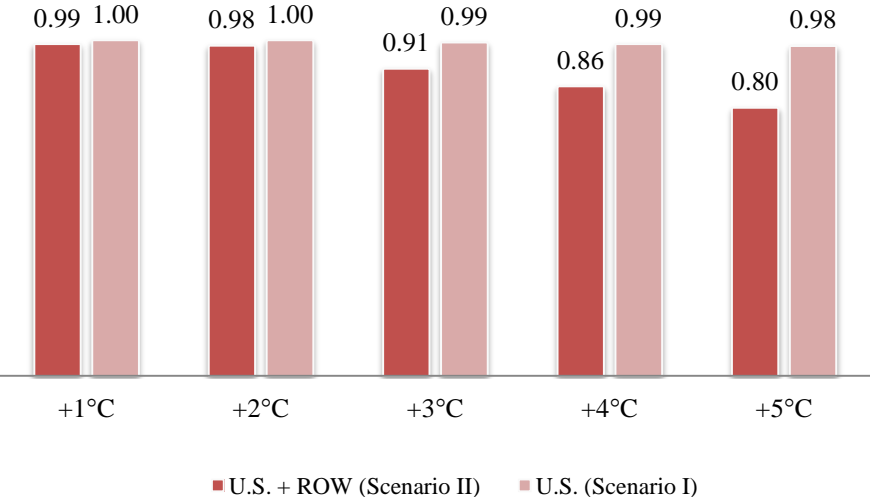


Figure 7. World Cotton Production Relative to Baseline Levels (Baseline=1)



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