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APPROACHES TO OPTIMIZE UZBEKISTAN'S INVESTMENT IN IRRIGATION TECHNOLOGIES

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Abstract

For many decades, Uzbekistan has been one of the largest cotton producers in the world. The irrigation water needed for these high production levels has been delivered by the massive diversion of the Amu Darya and Syr Darya rivers, which naturally flowed into the Aral Sea. This diversion for agriculture was the main cause of the rapid decline of the Aral Sea, which is at only 10% of its original size today. The traditional method of irrigation, which relies on simple open canal systems, is highly inefficient for managing the region's critical and limited water resource. It has been qualitatively estimated, for example, that irrigation water lost to evaporation and system inefficiencies is quite large. With the future availability of water at risk for agriculture in Central Asia, primarily due to the loss of glacial volume from global warming, along with declines in seasonal snowpack, it is clear that new approaches to water management are needed. Any serious efforts to restore the Aral Sea and its ecological services would also reduce supplies of irrigation water for Uzbekistan. While regional conflict over water is unlikely, it must be considered since Uzbekistan is a downstream country among several that rely on the Amu Darya and Syr Darya rivers for most of their water supplies. To insure against these risks to cotton production and the underlying economy, better irrigation technologies are needed across Uzbekistan. However, these technologies can be quite expensive, especially given that water is still nearly free. In this case study we explore the use of real options analysis (ROA) to look for optimal investment strategies in efficient irrigation technologies in light of variable climate and policy uncertainties.

Keywords: real options analysis, drip irrigation, climate change, water resources, glaciers.
JEL: Q150, Q540, Q250.

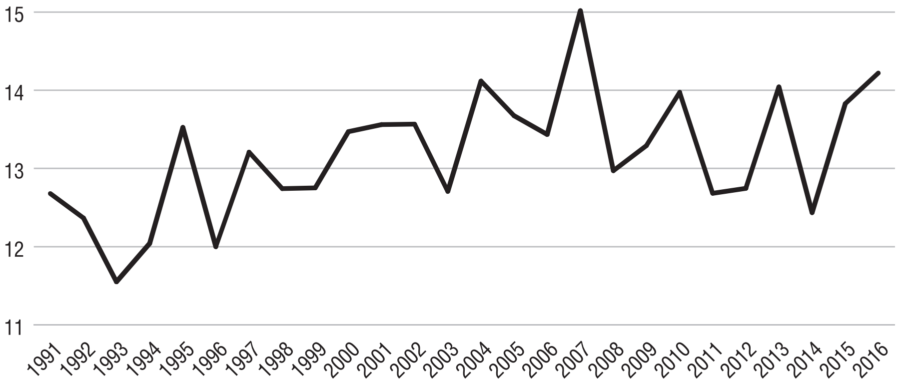
Introduction and Background

Uzbekistan is located in Central Eurasia, within the Amu Darya and Syr Darya River basins, and is completely landlocked [McKinney, 2003]. Its current population is about 33 million and its 2018 GDP was about US$ 47.9B[1].

Climate of Uzbekistan

The climate of Uzbekistan is continental, characteristic of Central Asia, with both large seasonal and daily variations in air temperature. It is quite arid, with a long summer. Normally, the hottest month is July, with average mean monthly air temperatures from 37°C in the south to 32–33°C in the north. The absolute maximum air temperature reaches 48–50°C in the south, and 44–46°C in the northern areas. In winter, the average temperature for January, which is the coldest month, is about −10°C in the lower reaches of the Amu Darya, and in the south it is +2 to +3°C[2].

From 1950 to 2013, the increase in temperature averaged 0.27°C for every 10 years, which is higher than the global rate. The average annual temperatures over the last 25 years can be seen in Fig. 1 and overall are increasing. The number of days with air temperatures above 40°C has been rising. The number of days with frost has been decreasing significantly, by about 4–5 days on average every 10 years.



Source: Centre of Hydrometeorological Service at Ministry of Emergency Situations of the Republic of Uzbekistan (Uzhydromet). https://www.meteo.uz/#/en/open-data.

Fig. 1. **Average Annual Temperature in Uzbekistan** (°C)

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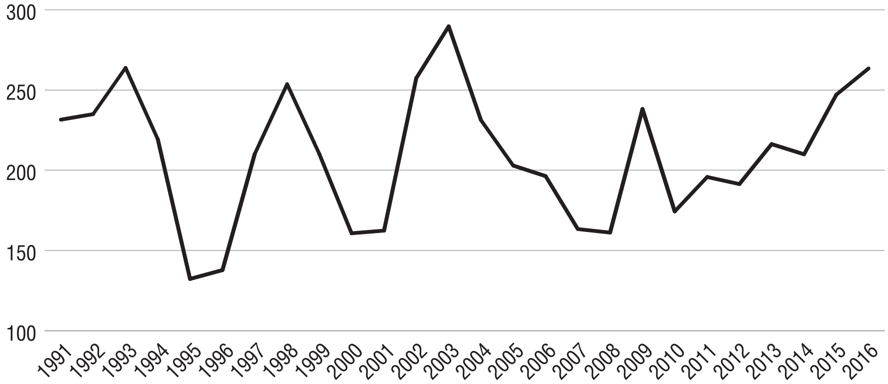
[1] Uzbekistan Country Overview. World Bank, 2019. https://www.worldbank.org/en/country/uzbekistan/overview.

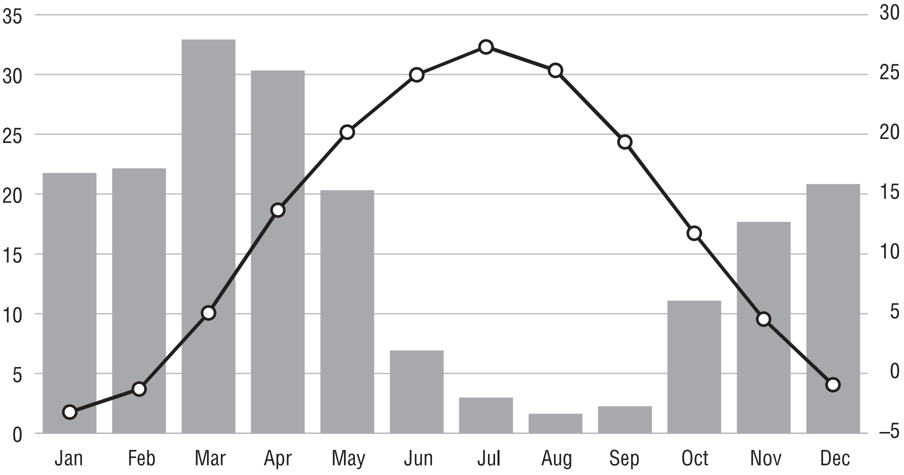
[2] Third National Communication of the Republic of Uzbekistan Under the UN Framework Convention on Climate Change. UzHydroMet, Tashkent, Section 4.1, 2016, pp. 88-89. https://unfccc.int/sites/default/files/resource/TNC%20of%20Uzbekistan%20under%20UNFCCC_english_n.pdf.

Annual precipitation in millimeters (mm) from 1991–2016 is shown in Fig. 2, and while it is quite low in general, there is a fairly significant interannual variability. Precipitation falls predominantly in winter and spring, and rainfall is extremely sparse from June to August. March and April typically have the highest rainfall. The monthly temperature and precipitation patterns can also be seen in Fig. 3[3].



Source: Centre of Hydrometeorological Service at Ministry of Emergency Situations of the Republic of Uzbekistan (Uzhydromet). https://www.meteo.uz/#/en/open-data.

Fig. 2. **Average Annual Precipitation in Uzbekistan** (mm)



Source: Climate Change Knowledge Portal.

Fig. 3. **Historic Monthly Averages for Temperature** (line with points, right bias) **and Rainfall** (bars, left bias) **in Uzbekistan, 1901–2016**

The hottest month of the year is July, in the middle of the growing season, and has been steadily warming, as illustrated in Fig. 4. This has serious implications to evapotranspiration and irrigation water loss.

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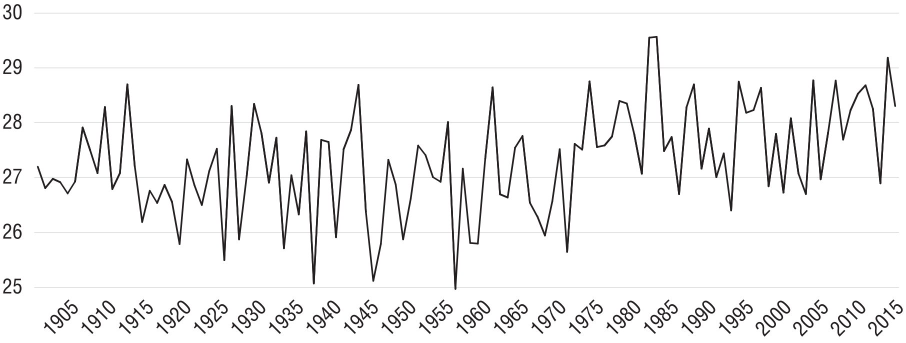
[3] Climate Change Knowledge Portal, World Bank, 2019.



Source: Climate Change Knowledge Portal.

Fig. 4. **Average Annual July Temperatures in Uzbekistan** (°C)

Water for Irrigation

Water resources come mainly from the runoff of the Amu Darya and Syr Darya rivers (55%) that traditionally filled the Aral Sea, plus the runoff of small rivers (33%). These two rivers are mainly formed in Tajikistan and Kyrgyzstan. Only about 10% of the Syr Darya and Amu Darya flows start within Uzbekistan. Their flows are managed through reservoirs with a complicated irrigation system consisting of a large number of canals, pumping stations, drains and drainage collectors[4].

1. Cotton and the Uzbek Economy

Cotton production has played a very important role in the Uzbek economy for at least 20 years, with Uzbekistan usually being the fifth, or in some years the sixth, largest producer of raw cotton lint in the world[5]. Up until Uzbekistan became a significant exporter of natural gas in the early 2000s, cotton was the country's major export. While cotton has fallen behind the export of energy products in value, it still remains an important contributor to the Uzbek economy[6].

Annual raw cotton production has averaged about 1,133,500 metric tons during the period 1992–2016[7]. Cotton yield can be seen in Fig. 5.

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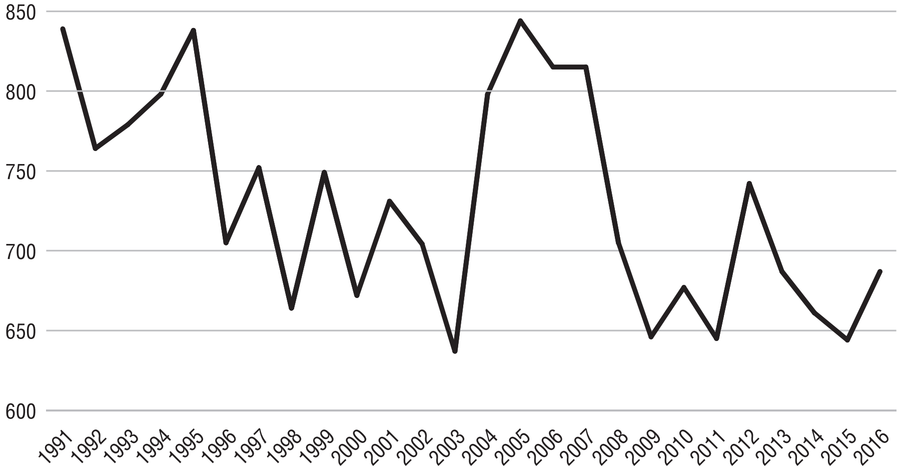
[4] Third National Communication.., pp. 88-89.

[5] Food and Agriculture Organization Corporate Statistical Database (FAOSTAT), 2019. http://www.fao.org/faostat/en/#data.

[6] Index Mundi 2019. Uzbekistan Economy Profile 2018. https://www.indexmundi.com/uzbekistan/economy_profile.html.

[7] Sirtioglu I. Uzbekistan — Republic of, Cotton and Products Update 2017. *United States Department of Agriculture (USDA)*, 2017, GAIN Report Number TR7053. Pp. 1-4. https://apps.fas.usda.gov/newgainapi/api/report/downloadreportbyfilename?filename=Cotton%20and%20Products%20Update_Tashkent_Uzbekistan%20-%20Republic%20of_11-30-2017.pdf; World Agricultural Production. Foreign Agricultural Service. *United States Department of Agriculture (USDA)*, Circular Series, WAP 3–19, March 2019, Table 17 Cotton Area, Yield, and Production. P. 31. https://www.fas.usda.gov/data/world-agricultural-production.



Source: Index Mundi.

Fig. 5. **Cotton Yield** (kg/ha)

2. Drip Irrigation

There exists a range of estimates of initial installation costs of drip irrigation systems in Uzbekistan. Costs significantly depend upon the existing conditions of the land; whether or not it has already been levelled; and whether other land improvements have already occurred or not. Estimates of installation costs (including materials and labor) on existing irrigated areas varied between US$ 2,300 and 3,500/hectare (ha)[8]. Other cost estimates range from about $3,000/ha [Larson et al., 2015] to as high as $5,000/ha [Niyazmetov, Rudenko, 2013].

Water savings of 20–40% have been reported with drip irrigation in Uzbekistan and increases in cotton yield of about 30% [Djumaboev et al., 2019]. Other studies have reported yield increases averaging 40%, and occasionally as high as 70%, along with fertilizer savings of 30–40%[9]. The energy savings associated with drip irrigation can also be significant since this technology requires considerably less pumping of water from canals to fields. In traditional canal irrigation systems, approximately 5,000 m^3 of water must be pumped at a cost of about US$ 105/ha/season (authors' calculation), assuming the State electricity price of US 2.4 cents/kilowatt-hour (kWh).

Although the benefits of transitioning to drip irrigation are substantial, the potential costs are very large. At 1.18 million hectares of cotton production[10], the higher-end cost estimates for the conversion of all this

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[8] Food and Agriculture Organization Corporate Statistical Database.

[9] Ibid.

[10] World Agricultural Production.

area to drip irrigation could range from US$ 2.7 billion to US$ 5.9 billion. These numbers represent about 5.5 percent to nearly 12 percent of Uzbek GDP for 2018[11]. It is important to understand that there is significant variability in these numbers, due to the small scale of these pilots, uncertain labor costs, and the fact that some lands are already too salinized for drip irrigation. Nonetheless, the scale of these costs (upwards of 10 percent of GDP) is the major obstacle to large-scale adoption of drip technologies.

3. Methods

Real Options Analysis

Real options analysis (ROA) applies option valuation techniques to uncertain and high-risk capital budgeting and investment decisions. A real option is the right—but not the obligation—to undertake certain business initiatives, such as deferring, abandoning, expanding, staging, or contracting an investment project. Real options are investments in real tangible assets, not financial assets. In this specific context, these real assets could be technologies, such as high-efficiency drip irrigation systems, that address environmental and economic problems [Golub, Brody, 2017].

ROA can also guide analyses and investments in water resource management. This method can be used to promote reasonable current investments while also creating incentives for future investments as water policies in Uzbekistan change and long-term effects of climate change on the water resources there become clearer. ROA can help decision makers understand the value and costs of irreversible investment decisions and weigh the costs of delay versus early actions. Advanced option pricing can provide consistent metrics to price risk and uncertainty in technology investments for complex problems such as climate adaptation [Anda et al., 2009].

4. Results

In this case study, drip irrigation is considered as an alternative technology for delivering irrigation water for cotton production. Drip irrigation technology has the potential to mitigate some of the risks associated with water shortages and corresponding fluctuations in cotton yield. This technology may also help minimize the impacts of rising electricity costs associated with pumping (water to fields) and any future fees levied on water allocations.

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[11] Uzbekistan Country Overview; World Development Indicators. World Bank, 2019. https://data.worldbank.org/country/uzbekistan.

However, installation of this technology requires significant upfront capital as well as resources for long-term maintenance. These investments, in turn, are exposed to other major risks related to cotton price volatility. Additionally, drip irrigation may be exposed to currency exchange risks if any of the material components are imported. However, for a first-level analysis, we assume that labor costs are the same for both technologies. While this assumption may be a little weak, labor costs in Uzbekistan are not very transparent. To compare the two irrigation technologies, we calculated risk-adjusted benefits and costs for both, by applying the real options methodology described in [Golub, Brody, 2017; Golub et al., 2019]; see Table 1.

Table 1

Risk-Adjusted Benefits and Costs for Traditional and Drip Irrigation

	Conventional Irrigation	Drip Irrigation	Calculation
Cotton price volatility	Exposed	Exposed	Based on cotton futures market
Productivity shocks (yield) due to variability of water supply	Exposed	Very unlikely, assumed to be zero	Historical data of yield/ha in Uzbekistan
Cost of water and electricity	Exposed	Exposed, but drip irrigation may use as little as 30% of water needed for traditional irrigation	Focus on price of electricity (elimination of subsidies and social cost of carbon)
Cost of capital	Assume zero other than maintenance costs	High exposure	Country-specific cost of capital

5. Risk-Adjusted Value of Output

Based on historical data (1991–2019), the average price of cotton is about \$1.5/kg[12]. As with other commodities, cotton is mainly traded on the futures market. The volatility of futures markets is the best method to characterize the exposure of cotton revenues to market volatility. As in [Cooke, Golub, 2019], we use an ETF (exchange traded fund) with tracker BAL[13] that represents a portfolio of futures contracts on cotton with different expiration dates. An implied volatility of BAL is about 30%. We use this value to calculate risk-adjusted revenue from a kilogram of cotton. For a productivity shock risk, we use historical yield data/ha. An average yield is 730 kg/ha and yield volatility is about 10%. Assuming that the yield in Uzbekistan and the global market price are independent random variables, the combined standard deviation

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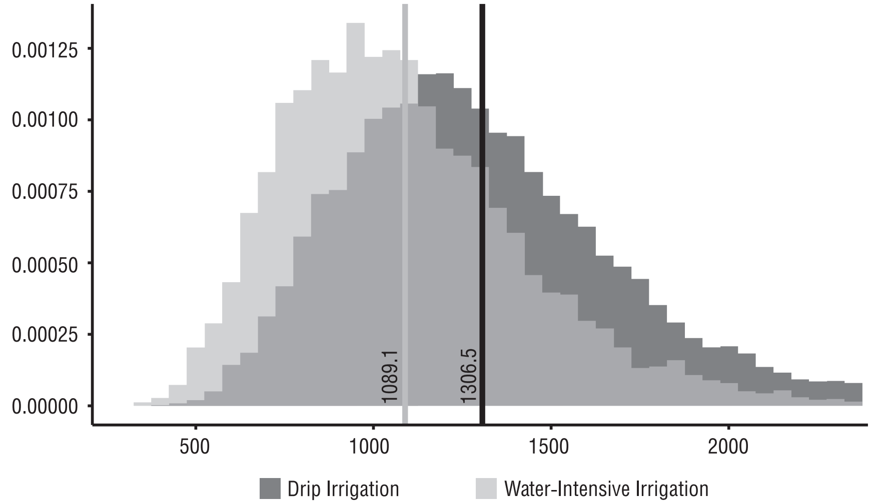
[12] Macrotrends 2019. https://www.macrotrends.net/2533/cotton-prices-historical-chart-data.

[13] BAL is the iPath Dow Jones-UBS Cotton Subindex Total Return. The index to which this ETN is linked consists of a single futures contract on cotton.

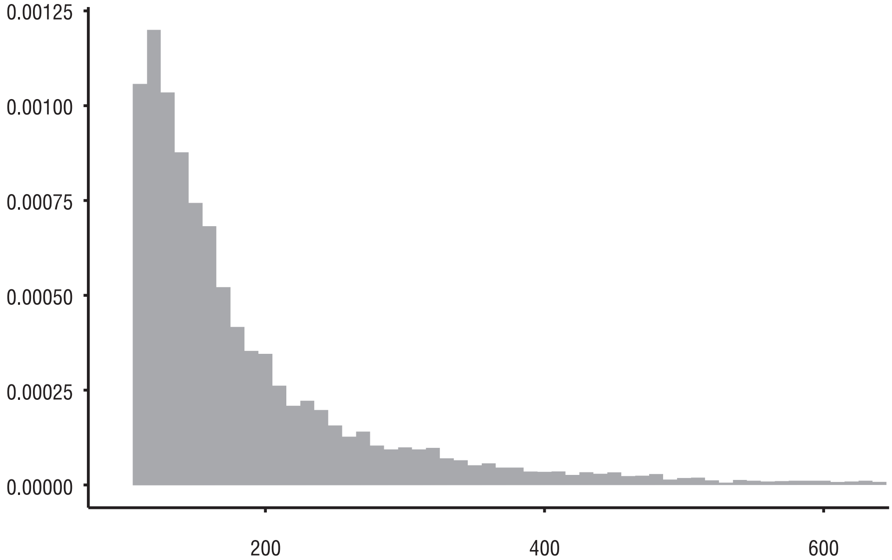
of output is about $350/ha. Drip irrigation is exposed to price risk only (not yield risk) and exhibits about 20% higher yield[14].

Fig. 6 presents annual production for conventional and drip irrigation technologies. All costs and benefits are calculated per 1 hectare.



Source: Macrotrends 2019.

Fig. 6. **Gross Revenue of Cotton for Alternative Irrigation Technology** ($/ha)



Source: Macrotrends 2019.

Fig. 7. **Potential Increase in the Cost of Water for Irrigation** ($/ha)

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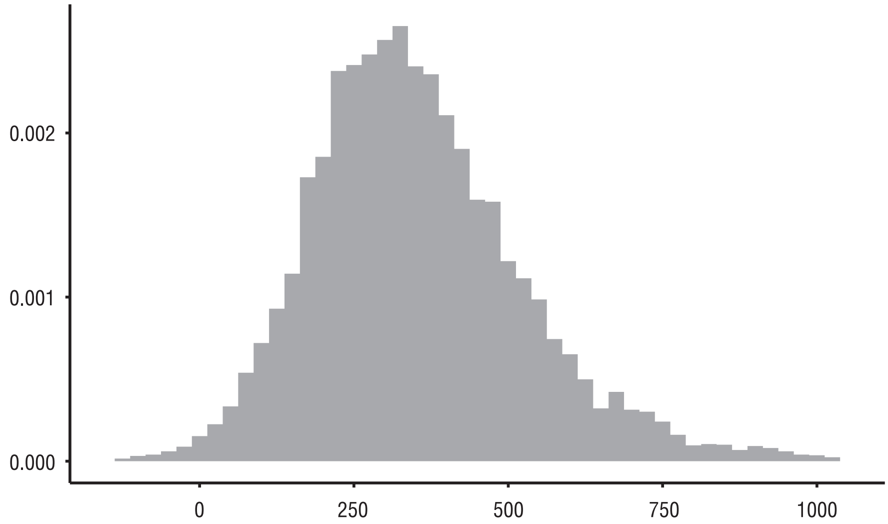
[14] This increase is assumed to be uncertain, and for Monte Carlo simulation we assume it to follow a symmetric betaPERT distribution with maximum 1.4 and minimum 1. Cotton price is described by a log-normal distribution, and yield for conventional irrigation technology is described by a normal distribution.

The risk premium of moving to drip irrigation is about $75/ha (we apply the Bachelier option pricing formula) on top of an expected savings of $360/ha. We apply conservative estimates for the cost of water increases for the water-intensive traditional irrigation technology (Figs. 7 and 8).



Source: Macrotrends 2019.

Fig. 8. **Benefit of Switching to Drip Irrigation** ($/ha)

The risk-adjusted savings of switching to drip irrigation would be $435/ha.

Capital costs per hectare of drip irrigation cited in this paper range from $2,300 to $5,000/ha ($3650/ha on average). The break-even cost of capital should then be around 9 percent (borrowing at 9 percent is zero profit). Given the risks described in this paper, and that the actual cost of capital in Uzbekistan is no doubt significantly higher than 9 percent, it is unlikely to be profitable to borrow to install drip irrigation. In Russia's energy sector, for example, the implied cost of capital was estimated around 45% [Golub et al., 2019].

Discussion and Conclusions

There are many serious issues related to Uzbekistan adopting efficient drip irrigation technology. The total potential cost of this change might approach 10% of GDP. It is unlikely that this conversion could happen overnight, and it is more likely to take as long as 10–20 years. Every year, each farmer is facing the risk of delaying conversion; and should value the lost opportunities of this conversion.

By delaying conversion to efficient drip irrigation technology, a cotton producer is losing the risk-adjusted benefits of conversion at the money call option (expected return is 9 percent) plus the risk premium ($75/ha) which may be underestimated due to our assumptions about the costs of water and energy. If a producer can secure a loan with interest payments below break-even, then they should convert to drip irrigation. However, there are groups of risks that create a relatively high cost of capital. These include overall country risk such as exchange rate risks, and high transaction costs at the London Commodity Exchange. Exchange rates affect costs of borrowing or importing in dollars, and the actual profits of any Uzbek producer that works in local currency but receives prices in dollars. Additionally, market prices of cotton are determined by the aggregate production of cotton in all major producing countries, not just Uzbekistan.

There are risks associated with outdated government policies that could be addressed to create incentives for change. These include the need for absolute land ownership guarantees with complete decision-making autonomy and removing subsidies throughout the economy, especially those given for water and energy costs, which would create incentives to adopt drip irrigation. There may be a role for incentives for best agricultural practices to help encourage these practices. There may also be financial benefits to producers by waiting to adopt the new technology should the prices come down in the future with larger scale-adoption.

In addition to capital and policy uncertainties, the most serious unavoidable long-term risk to Uzbekistan's water resources and cotton production is climate change. Climate modeling suggests that nearer-term spring and summer flows from snow and glacial melt might actually increase in the next phases of warming. However, climate change is also expected to produce increases in monthly maximum temperatures across Uzbekistan. The Intergovernmental Panel on Climate Change's (IPCC's) estimate of warming under the highest emission pathway (RCP 8.5) is an average temperature increase of 2.4°C by mid-century and nearly 5°C by end of the century. The number of hot days in Uzbekistan is projected to increase by 28.6 days by 2040–2059, under the RCP 8.5 scenario. The number of tropical nights (minimum temperature above 20°C) is projected to increase by over 31 days by 2040–2059, as well, under the RCP 8.5 scenario.

The country is also likely to experience high variability of rainfall across different agroecological and climatic zones. Across the country, however, there have been some spatial differences in precipitation trends, with annual precipitation declining between 50 and 100 mm in some central and eastern districts and moderately increasing in areas surrounding the Aral Sea. Increased heat and precipitation variability will lead to increased evapotranspiration in summer months, resulting in increased water demand under any river flow regime. Projections suggest that glacial melting (glaciers in Central Asia have shrunk by 25% and are expected to shrink by another 25% over the next 20 years) will affect water availability in Uzbekistan in both the short and the long term[15].

When considered together—the potential for future yield shocks due to water supply variability, policy shifts and regional instabilities, along with uncertain future costs of water and electricity, compounded by global warming—it is clear that Uzbekistan's cotton industry is exposed to multiple, significant risks[16].

Under the IPCC's three warming scenarios associated with representative concentration pathways (RCPs) of greenhouse gases (low RCP 4.5, medium RCP 6.0, and high RCP 8.5), depending on the region, potential crop losses are estimated to range from a low of 3% in one region to potentially 50% losses in cotton production under the high warming scenario. The majority of the projected losses range from 10 to 30%.

In the longer term it would seem that conversion to drip irrigation will be an absolute necessity; in the meantime, the government could reduce the financial risks of an earlier conversion by changing its water, energy and land policies and incentivizing lower cost-management practices to improve soil water retention.

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