Adoption of Water-Efficient Technology:
Role of Water Price Flexibility, Tenure Uncertainty and Production Targets in Uzbekistan

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The study investigates different institutional and economic factors that can induce farmers to adopt efficient irrigation technologies in the irrigated agriculture of Uzbekistan. To investigate the effect of different policies on the investment of efficient irrigation technology, we simulate different scenarios of institutional design of the cotton procurement policy and land tenure security using a farm-based optimization model that maximizes the total net benefit of a farmer. The results indicate that a flexible water price can increase the adoption rate of efficient irrigation technologies by 20% compared to fixed water price levels. However, the high water supply variability may nevertheless delay the adoption of an efficient technology. Likewise, the removal of the cotton yield-based target could increase the adoption rate of water-efficient technologies. Finally, farmers are likely to respond much stronger to flexible water pricing, when the risk of losing land is lower.

Keywords: water pricing, agricultural institutions, water-use efficiency, farm model

JEL codes: C61, Q12, Q15, Q16, Q18

1. Introduction

Irrigation water is becoming an increasingly scarce resource for the agricultural sector in Uzbekistan, Central Asia. The water scarcity at the user end is due not only to a poor irrigation infrastructure, but also to the wasteful irrigation practices resulting from poor implementation of water pricing mechanisms, lack of incentives to adopt advanced irrigation technology, and lack of water-use control and measurement (Wegerich, 2010; Oberkircher and Hornidge, 2011; Djanibekov et al., 2012c).

Recent studies showed that the water-use efficiency of the users in the Khorezm region of Uzbekistan is not more than 30% (Tischbein et al., 2012). The use of innovative irrigation technologies has been proposed as one of several possible solutions to increase the efficient use of the scarce water resources and reduce environmental degradation. Seckler et al. (1998) estimated that improvements in irrigation efficiency alone may meet one half of the increase in worldwide water demand until 2025. Similarly, through better and efficient use Uzbek farmers can save water that can then be re-allocated to products and services of higher value return in the water-scarce regions. This can take place without substantial investment in irrigation infrastructure. However, the relevant question is: What water-related policies in Uzbekistan can induce the increase in the efficiency of water use and maintenance of irrigated agricultural production while arresting and even reducing resource degradation in the irrigated areas?

It is often argued that water pricing is one way for inducing a higher adoption of efficient irrigation technology (Caswell et al., 1990; Sunding and Zilberman, 2001). It could promote water-use flexibility and establish a recognized water value, thus providing incentives for more efficient water use (Gardner, 1985; Shaliba and Bush, 1987). Water pricing that takes the increasing value of scarce supplies of irrigation water over time into account can be an option also for inducing a wider adoption of more efficient irrigation technologies and improving water-use efficiency. There is evidence that the introduction of water pricing is effective in increasing water-use efficiency in Uzbekistan (FAO, 1997).

However, in most cases, water charges are only a small fraction of the farmers' net income. Low collection rates for water charges and services in Uzbekistan are attributed to a lack of willingness to pay rather than by an inability to pay (Bhaduri and Kloos, 2013). Worldwide, the level of water fees remains low in order to motivate farmers to pay. But low water pricing often fails to meet the budget for cost recovery, and thus the incentive to pay more for water remains weak. This acts as a *vicious circle* of poorly managed water resources. Part of the failure can be attributed to a fixed water price. In Uzbekistan, water prices are fixed at a low

level and determined administratively (Djanibekov et al., 2012b), thus they reflect neither supply cost nor scarcity value. Moreover, when the scarcity value of water increases, it insulates the water economy from the market forces of demand and supply of water.

Bhaduri and Manna (2014) finds that a flexible water price, which depends on stochastic water and aggregate demand, can increase the adoption rate of efficient irrigation techniques by more than 20% if the farmer is risk averse. However, the implementation of a flexible water price also requires supporting institutional arrangements. It is often argued that volumetric water fees (together with incentives such as additional services that increase willingness to pay) may induce farmers to adopt efficient irrigation technology. Uzbekistan has shown considerable interest in implementing volumetric pricing, and even initiated it in some places on a trial basis (Veldwisch, 2008).

Other than water pricing, policies not related to water also influence the adoption of irrigation technologies in Uzbekistan. Pender et al. (2009) argue that despite their benefits on the experimental field level, in reality these technologies often fail to attract the farmers' attention, which is also due to the design of the cotton target policy.

Since the break-up of the Soviet Union, cotton production in Uzbekistan has remained strongly linked to the interests of the national export earnings. To ensure a certain amount of cotton production, the state determines that farms should allocate about half of their cropland to cotton cultivation and produce raw cotton at amounts assigned according to the soil-fertility levels of their fields. Failure to fulfill the cotton production target can constitute the grounds for losing a land lease. In addition, input supply to cotton production is prioritized by the state. For example, irrigation water is diverted to cotton fields before it is delivered to other crops. This water distribution policy has often neglected the water demand for production of other crops, especially rice, which is an important staple food holding a special position in the national cuisine of Uzbekistan, and which is among the most economically attractive crops for farmers in Khorezm (Veldwisch and Spoor, 2008). As a result, the effectiveness of water pricing mechanisms to induce the adoption of low-volume irrigation technologies may be limited because of these farm decision constraints (Djanibekov et al., 2012a).

Through scenario analysis, we investigate the opportunities for higher flexibility of farmers' production decisions created through the modification of the cotton policy and improved tenure security, but directly addressing three interrelated questions in respect to the adoption of irrigation efficient technologies in agriculture o Uzbekistan:

1. Can flexible water pricing alone guarantee the adoption of efficient irrigation technology under higher variance in water flow?

2. Can tenure security support improvements in water-use efficiency?

3. Can a relaxation of the current cotton policy influence farmers' behaviour regarding efficient water use?

In the following section, we provide a brief overview of selected studies on the modification on cotton procurement policy in Uzbekistan. We then explain the method used in our study. The results from the different simulation scenarios are then presented, followed by a discussion. The last section offers conclusions.

2. Literature Review on Cotton Policy Modification in Uzbekistan

In this section we present summaries of nine selected studies on the modification on cotton procurement policy in Uzbekistan. While being diverse in the approaches, several studies focus on alternatives settings of the cotton procurement policy, while the largest set analyzes the effects of cotton policy liberalization. Using a simple partial equilibrium of Uzbek cotton market, Pomfret (2000) attempts to explain the difference of Uzbek procurement policy from the basic dual-pricing model, e.g. China, and concludes that the cotton policy causes major economy-wide distortions, deters output growth, diversification and innovation adoption in Uzbek agriculture. Guadagni et al. (2005) present a cost-benefit analysis to calculate that the cotton taxation makes 30% of farmer's gross cotton revenues and creates disincentives, and argue in favor of abolishing the cotton targets, liberalization of cotton marketing and exports. A cost-benefit analysis presented by Chertovitsky et al. (2007) focuses on the abolishment of only one element of the cotton procurement target, the area-specific production target. Their conclusion is that the cotton policy modification (not abolishment) can release 3% to 6% of farmland occupied by cotton for other purposes without affecting the production target. A meso-level cotton value chain analysis of changes along the cotton supply chain presented by Rudenko et al. (2009) shows that the structural changes and alternative (and liberalized) marketing channels for raw cotton can improve farm revenues. Using a static stochastic optimization scenario analysis of liberalization of cotton production, Bobojonov et al. (2010) concludes that the liberalization of cotton production can increase crop diversification and farmer income. The findings of the agronomic and economic analysis of N-fertilizer application to cotton (Kienzler et al., 2011) demonstrates that farmers follow recommended N-fertilizer application norms, but tend to under-apply fertilizer for cotton. A nominal rate of assistance estimation in the study by MacDonald (2012) shows once more (supports

arguments by Guadagni et al. (2005)) that the cotton taxation offsets subsidies for farms, and total net taxation increased after 2008 coincided with lower cotton yields. The study based on a dynamic farm-household model by Djanibekov et al. (2013b) analyzes a scenario of liberalization of the procurement policy for tree plantations at marginal lands. The authors conclude that diverting marginal lands from cotton production to tree plantation would improve farm and household revenues and reduce pressure on irrigation water resources. Djanibekov et al. (2013a) applied a bio-economic model of several cotton producers to simulate various adjustments in the procurement policy, including liberalization scenario as well as the one presented by Chertovitsky et al. (2007). Their results show that indeed the liberalization of cotton production can be the most economically attractive option among all possible sets of cotton policy modification, but it may also increase the pressure on irrigation water resources (e.g., via increased area of rice cultivation as in the case study of the Khorezm province of Uzbekistan).

3. Model

A farm-based model is structured where a farmer is assumed to maximize an instantaneous profit function by choosing the amount of water to apply to his crops and the area of land to be irrigated with improved irrigation technologies. The model considers that farmers cultivate j crops where j= cotton (c) and rice (r). Cotton and rice are considered in this analysis since these crops are the main competitors for users of irrigation water in the Khorezm province. Furthermore, one crop (cotton) represents the state-imposed policies, while the other (rice) is commercially the most attractive crop for local farmers. Each farmer is endowed with A^j amount of land, which can be used to cultivate both crops. A^c represents the area used to cultivate cotton and A^r represents the rice area, thus the total agricultural area per farmer over t years is defined as:

$$A_t^r + A_t^c = A_t$$

Consider the total applied water (gross) as w^j for j^{th} crop. Suppose there are two kinds of irrigation technologies: the inefficient, conventional furrow irrigation (*F*), and an efficient irrigation technology (*H*). For each irrigation technology *k*, irrigation effectiveness is denoted by e_k, where *k=F, H* and $e_H > e_F$.

Suppose the area covered under effective technology *H* at time *t* is *H(t)*.

The rate of change in area covered with efficient irrigation technology can be shown as:

$$\dot{H} = h - \delta_H H \tag{1}$$

where $H(t=0)=H_0$ and h are the amount of new area brought under efficient irrigation technology; δ_H represents the depreciation rate of the new technology. We assume that the per-unit cost of installing efficient irrigation technology is constant, and is denoted by c^H.

The net effective water applied can be represented as:

$$w^j{}_e = w^j \left[e_F (A^j - H^j) + e_H H^j \right] \tag{2}$$

The yields of the crops $y^j(w^j{}_e)$ are functions of respective effective water usage w_e.

We assume that the yield functions of both crops are concave in w_e with $y_{w_e} > 0$ and $y_{w_e w_e} < 0$. Given the institutional setup of agricultural production in Uzbekistan, the model considers the governmental assignment of a mandatory target yield and area for cotton, while rice is cultivated according to the farmer's decision.

The target yield of cotton is defined by $\hat{y}^c$, while the target cotton area is defined by $\hat{A}^c$. Thus, the total cotton production target for a given farmer is defined as $\hat{y}^c . \hat{A}^c$.

We assume that the farmer can produce more than $\hat{y}^c$, and that this surplus can be realized at higher prices. If $\hat{y}^c \geq y^c$, then the surplus production is represented by $[\hat{y}^c \geq y^c] . \hat{A}^c$. To introduce the tenure uncertainty we assume that if a farmer fails to meet the cotton yield target for three consecutive years, his land tenure contract will be terminated.

Assuming uncertainty in water supply and other factors, yields may vary. In this respect, farmers have knowledge about the probability distribution of yields. The cumulative distribution of cotton yield is defined by $F(\hat{y}^c) = P[y^c < \hat{y}^c]$. It is also assumed that yield y_t^j, is a function of water usage per hectare w^j. Therefore, two situations are included, one depicts the probability of fulfillment of the cotton target yield and thus defines the cotton produce surplus, and the second one is the cotton production target failure:

$$y^c \geq \hat{y}^c, \text{ where } \quad P[y^c \geq \hat{y}^c] = 1 - F(\hat{y}^c) \text{ and}$$
$$y^c < \hat{y}^c, \text{ where } P[y^c < \hat{y}^c] = F(\hat{y}^c) \tag{3}$$

The model considers water supply W to be stochastic and follow a log-normal distribution with mean μ and standard deviation σ.

The price of water is denoted by p. The price of the water evolves over time and is a function of the aggregate excess demand of water:

$$dp/dt = \lambda \left[\sum_l^N w - W \right] \tag{4}$$

where λ is a constant and reflects the price sensitivity to excess demand function. It is assumed that there are *N* homogeneous farmers who can influence water demand and the price of water.

The expected net benefit of the farmer for a given period can be expressed as:

$$V = E(NB) = [1 - F(\hat{y}^c)].P^c * [E(y^c) - \hat{y}^c] \widehat{* A^c} + (P^r - C^r).E(y^r).(A - \hat{A}^c) -$$
$$c^H h - pw \tag{5}$$

where P^j and C^j are the price and marginal cost of jth crop $j = c, r$.

Considering the probability of fulfilling the cotton quota in three consecutive years as $\pi = 3.P[y^c < \hat{y}^c] = 3.F(\hat{y}^c)$, discount factor as δ, and terminal time period as *T*, the present discounted value of net benefits can be represented as:

$$PDV = V + \delta V + \delta^2 V + (1 - \pi)\delta^3 V + (1 - \pi)^2 \delta^4 V + \dots + (1 - \pi)^{T-2}\delta^T V \tag{6}$$

Using a numerical analysis, the net benefit is maximized as expressed in eq. (6) with respect to gross water usage *w* as well as investment in efficient irrigation techniques in terms of area. The @ Risk software package was used to simulate the model employing the Latin Hypercube sampling technique. Table 1 illustrates the scenario definitions and Table 2 the parameter values of the model, distribution function and the crop-water response functions. The key variable used in the simulation is the water flow *W*. Using Best Fit Software and empirical data, the distribution function of the water flow of the Khorezm region was determined. Simulation results suggest that the stochastic factor ε_t is best fitted with a log-normal distribution with mean 15,000 m^3 per hectare of cultivated area and a constant variance $\sigma = $ 8,000 m^3 per hectare of cultivated area.

<Table 1>

<Table 2>

Different scenarios were formulated based on water pricing, institutional design of the cotton policy and the land tenure insecurity to investigate the effect of different policies on the investment in efficient irrigation technology. *Scenario 1* represents the baseline scenario under which the investment path of efficient irrigation technology was simulated. In this scenario, the price of water used for rice production is fixed at US$ 5 per 1000 m^3 of water according to the average values of the shadow price of water presented in Djanibekov (2008). Furthermore, the farmer produces cotton under the so-called *cotton target system* according to

which the cotton area annually occupies on average about 55% of the land. The cotton target yield is determined by the government at 2.5 t ha^{-1} (Djanibekov 2008, Farm Survey 2010). Under this scenario, if the farmer fails to fulfill cotton production targets for three consecutive years, the land use contract is terminated, which will act as a disincentive. *Scenario 2* pursues a similar situation to that in *Scenario 1* but assumes a flexible water pricing scheme where the water price depends on the excess demand of water. *Scenarios 3* and *4* simulate conditions with land tenure uncertainty. The latter two scenarios describe the situation where the farmer enjoys tenure certainty even if he does not fulfill the cotton target. *Scenarios 5* and *6* depict situations where there is neither a cotton yield target nor a restriction on the area for cotton production under fixed and flexible water price regimes, respectively.

4. Results and Discussion

Figure 1 shows the optimal time path of investment in efficient irrigation technology under different scenarios[1].

<Figure 1>

According to the results of *Scenarios 1* and *2*, even when the price of water is fixed at a higher value, compared to the cases with flexible water price schemes it can be seen that (i) the rate of adoption will be much slower, and (ii) the aggregate level of adoption of efficient irrigation technologies will be lower. The results of *Scenarios 3* and *4* imply that tenure security also determines the adoption rate of irrigation technologies. If the farmer's land tenure is secure and not related to the performance of cotton yield, then the difference between the adoption rates of efficient irrigation technology under flexible and fixed water price regimes will be more pronounced during the early periods. In such case, as far as adoption is concerned, a farmer is more likely to response to a flexible water price regime compared to a fixed water price. Hence, to motivate farmers to early adoption of efficient irrigation technologies, a series of frame conditions could be conducive such as flexible water pricing combined with tenure security for agricultural farmland. The results of *Scenarios 5* and *6* also indicate that removal of the cotton policy regarding the fulfillment of yield targets and the area of production could encourage farmers to adopt efficient irrigation technologies. However, in the initial years the rate of adoption is likely to be lower, as a farmer has to

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[1] Here the aggregate adoption of efficient irrigation technology will decrease if the existing irrigation technology is depreciating and the representative farmer is no longer making new investments in irrigation technology.

account for costs of land and other fixed variables. However, recurring higher profits from cotton without a rigid cotton policy would provide greater opportunities for adopting irrigation technology in the following period and at a faster pace.

The model results show that the price of water may play a significant role in inducing a farmer to adopt efficient irrigation techniques. This in line with the findings of Oberkircher (2011), which show that when the cotton production targets are deregulated and the duration of land lease becomes more certain farmers' investments in efficient irrigation technology will increase. On the other hand, although the famers may invest in efficient irrigation technology (e.g., sprinkler), in all cases the timing of the adoption of the technology is likely to depend on the design of institutional arrangements (e.g., cotton production targets and/or land tenure security). In fact, farmers who face a short planning horizon because they risk losing their farmland do not consider sustainability as a priority (Oberkircher, 2011). In this respect, the recent farm consolidation process, which involved the risk of losing farmland, has also reduced the farmers' interest in any agricultural technology (Djanibekov et al., 2012a).

Figure 2 shows how optimal investment amounts could respond to different levels of water supply variability.

<Figure 2>

In the numerical analysis, it is assumed that the coefficient of variation changes from 0.55 to 0.80 indicating that the magnitude of the irrigation water supply increases over the years. The findings indicate further that the aggregate investment in efficient irrigation technology would be lower under higher variability in water supply. This result may hold if the decline in optimal water consumption has a lower impact on crop yield and the farmer adjusts his activities to the variability of the water supply.

Contrary to the prediction of the economic theory that resource use efficiency improves with its scarcity, irrigation water use is becoming less and less efficient while water is becoming scarcer (Saleth and Dinar, 2004). This is particularly relevant for the case of Uzbekistan, where water scarcity conditions do not influence farmers directly to use water more efficiently. In 2010, farmers in Khorezm paid only US\$ 2.5 per 1000 m^3 in form of water service fees, which barely covered the expenses of the Water User Association (Farm Survey, 2010). Bobojonov (2008) has shown that farmers in the study region would need to be charged at least US\$ 5 per 1000 m^3 to cover operation and management expenses for the

existing water management organizations and to achieve a water use efficiency of about 67%. The findings of this study, however, indicate that water prices of US$ 5 per 1000 m^3 of water can induce the farmer to irrigate the majority (80%) of his land with efficient irrigation technology. However, if water prices are fixed, for example determined administratively and thus ignoring the water supply level, they reflect neither the supply cost nor the scarcity value of water, and the adoption rate of efficient irrigation technology is likely to be lower.

The duration and frequency of irrigation water scarcity in Khorezm has increased since 1980 (Müller, 2006). It is expected that it will continue to negatively impact agricultural production in the Khorezm region. Together with climate change, this will have even greater negative impacts on agricultural incomes particularly in the downstream areas of the main river basins (Siegfried et al., 2012). The results indicate that water variability will have a stronger negative effect on the farmers' decision to invest in efficient irrigation technology during the early stages of adoption, and particularly under a fixed rather than under a flexible water price regime. Combined with high variability in the water supply, a fixed water pricing is likely to delay the adoption of efficient irrigation technology during the initial period. In such a case, the farmer may even prefer to buy water at a fixed price rather than to invest in irrigation technology. However, a consistently recurring variability in the water supply will in the end lead the farmers to invest in irrigation technology.

The findings of the study are consistent with the general view that water pricing is a valid tool for increasing the efficiency of water use. The theoretical validity of flexible water pricing, however, has been constrained by several factors. First, the effective application of this economic instrument requires that a strong institution is established, which owns and manages the physical infrastructure, monitors the allocation of water, assures water delivery, and provides the forum for conflict resolution, and thus alleviates the inefficiencies of public water management. In many instances, the absence of strong institutional arrangements often makes it difficult to implement water pricing. Second, the majority of the farmers in Uzbekistan may find it difficult to adopt efficient irrigation technology, especially when induced by water pricing. Under the existing state targets, the introduction of water pricing for creating water saving incentives can be limited due to the financial constraints of agricultural producers (Bobojonov et al., 2010). Another issue is that opportunities and constraints with respect to adopting efficient technologies vary between different groups of farmers who are different with regard to land characteristics and form of production (Veldwisch, 2008; Oberkircher, 2011). Hence any water pricing approach must be sensitive to match the farmers' unique characteristics of low capital availability.

Water use improvement potential and financial feasibility of efficient irrigation technologies have an inverse relationship: The more efficient technology is also more capital intensive (Bekchanov et al., 2010). In this respect, to fit the low capital availability among farmers, cheaper but less water efficient options such as double flow, short and alternate dry furrow techniques may have the highest potential for adoption (Bekchanov et al., 2010). Among the technologies, the use of laser leveling has proven to increase water use efficiency and crop yields in many countries (Humphreys et al., 2005). Laser leveling could be extremely suitable for the region, as 70% of the total cropped area is only poorly (unevenly) leveled in Uzbekistan (UNDP, 2007). Proper leveling would allow a more equal distribution of water in flood and furrow irrigation and, therefore, decrease the amount of water needed for irrigation (Bobojonov et al., 2010). Laser-leveled fields have proven to reduce water demand by as much as 20% compared to traditionally leveled fields. Laser-leveled fields are, however, 10% less effective than sprinkler irrigation. The expense of leveling one hectare of land was estimated to be only 8% of the cost of sprinkler irrigation.

The deregulation of the cotton production targets at the current stage may increase the pressure on irrigation water resources, as farmers would opt to cultivate more profitable, albeit more water-intensive, crops such as rice (Djanibekov et al., 2013a). Additional policy measures will be required for promoting crops that require less irrigation water. On the other hand, the increasing variability of water supply stemming from climate change may also induce farmers to cultivate less water-intensive crops such as potatoes, vegetables and maize instead of cotton and rice as an alternative to introducing water pricing, and to adopting the efficient irrigation technologies for these crops (Bobojonov et al., 2010).

5. Conclusions

The study attempts to answer the question whether or not water pricing can induce farmers to adopt efficient irrigation technologies. The results show that a flexible water price, which depends on stochastic as well as aggregate water demand, can increase the adoption rate of efficient irrigation technologies (exemplified here by sprinklers) by more than 20%. Overall, the results indicate that the negative effect of water variability on investment in efficient irrigation technology would be more prominent during the early stages of adoption, and particularly under a fixed rather than flexible water price regime. Fixed water price levels in combination with considerable variability in water supply are likely to delay the adoption of efficient irrigation technology during the initial periods. However, while even a flexible water price cannot guarantee its earlier adoption, under the increasing water supply variability as a

result of climate change farmers are likely to decide to adopt efficient irrigation technology in the later stages.

Based on the current cotton target policy and tenure insecurity of farmland, according to which farmers bear the risk of losing their land lease if they do not achieve the production target, the results show that these aspects of Uzbekistan's agriculture are important factors influencing farmers' decisions to adopt efficient irrigation technology. With secure land tenure, farmers are likely to react more strongly to flexible water price regimes compared to fixed water regimes with regard to investment in irrigation technology. The farmers' aggregate adoption of efficient irrigation technology would be also greater if the minimum cotton yield targets were to be abolished. However, in such case, farmers would have to bear the full costs of cultivation of cotton, which in turn would restrict investment capacities during the initial periods. As a consequence, the adoption of efficient irrigation technology can be delayed.

References

Bekchanov, M., Lamers, J.P.A., Martius, C., 2010. Pros and cons of adopting water-wise approaches in the lower reaches of the Amu Darya: A socio-economic view. *Wate*, 2, 200-216.

Bhaduri, A., Kloos, J., 2013. Getting the water prices right using an incentive-based approach: An application of a choice experiment in Khorezm, Uzbekistan. *European Journal of Development Research* 25, 680-694.

Bhaduri A., Manna, U., 2014. Impacts of water supply uncertainty and storage on efficient irrigation technology adoption. *Natural Resource Modeling* 27, 1-24.

Bobojonov, I., 2008. Modelling crop and water allocation under uncertainty in irrigatedagriculture: a case study on the Khorezm region, Uzbekistan. Ph.D. diss., ZEF, Bonn University, Germany, 141 p.

Bobojonov, I., Franz, J., Berg, E., Lamers, J.P.A., Martius, C., 2010. Improved policy making for sustainable farming: a case study on irrigated dryland agriculture in Western Uzbekistan. *Journal of Sustainable Agriculture* 34, 800-817.

CAWATERinfo, 2011. Amudarya River Basin. Online data of the BWO Amudarya. Available at: http://www.cawater-info.net/amudarya/index_e.htm#

Caswell, M., Lichtenberg, E., Zilberman, D., 1990. The effects of pricing policies on water conservation and drainage. *American Journal of Agricultural Economics* 72, 883-890.

Chertovitsky, A., Akbarov, O., Yahshilikov, Y., 2007. Relaxing control over the cropping structure: the next step for land reform in Uzbekistan. In *Paper Presented at the Joint IAAE-104th EAAE Seminar 'Agricultural Economics and Transition: What was expected, what we observed, the lessons learned'* Budapest, Hungary, 6-8 September 2007.

Djanibekov, N., 2008 A Micro-economic Analysis of Farm Restructuring in the Khorezm Region, Uzbekistan. Ph.D. thesis, ZEF, University of Bonn, Bonn, Germany, 180 p.

Djanibekov, N., Van Assche, K., Bobojonov, I., Lamers, J.P.A., 2012a. Farm restructuring and land consolidation in Uzbekistan: new farms with old barriers. *Europe-Asia Studies* 64, 1101-1126.

Djanibekov, N., Hornidge, A.-K., Ul-Hassan, M., 2012b. From joint experimentation to laissez-faire: transdisciplinary innovation research for the institutional strengthening of a water users association in Khorezm, Uzbekistan. *Journal of Agricultural Education and Extension* 18, 409-423.

Djanibekov, N., Bobojonov, I., Djanibekov, U., 2012c. Prospects of agricultural water service fees in the irrigated drylands, downstream of Amudarya, in Martius, C., Rudenko, I., Lamers, J.P.A. and P.L.G. Vlek, eds., *Cotton, water, salts and soums - economic and ecological restructuring in Khorezm, Uzbekistan*. Springer, Dordrecht Heidelberg London New York, pp. 389-411.

Djanibekov, N., Sommer, R., Djanibekov, U., 2013. Evaluation of effects of cotton policy changes on land and water use in Uzbekistan: Application of a bio-economic farm model at the level of a water users association. *Agricultural Systems* 118, 1-13.

Djanibekov, U., Djanibekov, N., Khamzina, A., Bhaduri, A., Lamers, J.P.A., Berg, E., 2013. Impacts of innovative forestry land use on rural livelihood in a bimodal agricultural system in irrigated drylands. *Land Use Policy* 35, 95-106.

Farm Survey, 2010. Socio-economic survey of commercial farms in Khorezm province, June-August 2010.

FAO, 1997. Uzbekistan. FAO's Information System on Water and Agriculture URL: http://www.fao.org/nr/water/aquastat/countries/uzbekistan/index.stm.

Gardner, R.L., 1985. The potential for water markets in Idaho. *Idaho Economics Forecast* 7, 24-34.

Guadagni M., Raiser, M., Crole-Rees, A., Khidirov, D., 2005. Cotton taxation in Uzbekistan: Opportunities for reform. ECSSD Working Paper No 41. Europe and Central Asia Region, World Bank, Washington DC.

Humphreys, E., Meisner, C., Gupta, R., Timsina, J., Beecher, H.G., Lu Tang Yong.,Singh, Yadvinder., Gill, M.A., Masih, I., Jia, G., Thompson, J.A., 2005. Water saving in rice-wheat systems. Irrigated Rice-Based Systems, Special issue proceedings of the Fifth Asian Crop Science Conference.

Kienzler, K.M., Djanibekov, N., Lamers, J.P.A., 2011. An agronomic, economic and behavioral analysis of N application to cotton and wheat in post-Soviet Uzbekistan. *Agricultural Systems* 104, 411-418.

MacDonald, S., 2012. Economic policy and cotton in Uzbekistan. United States Department of Agriculture, Report from Economic Research Service CWS-12h-01, 26 p.

MAWR, 2001. Ministry of Agriculture and Water Resources of Uzbekistan, Guide for Water Engineers in Shirkats and WUAs. Scientific production association Mirob-A, Tashkent.

Müller, M., 2006, A general equilibrium approach to modelling water and land use reforms in Uzbekistan. Ph.D. thesis, ZEF, University of Bonn, Bonn, Germany, 170 p.

Oberkircher, L., 2011. On pumps and paradigms: Water scarcity and technology adoption in Uzbekistan. *Society & Natural Resources* 24, 1270-1285.

Oberkircher, L., Hornidge, A.-K., 2011. 'Water is life' - farmer rationales and water saving in Khorezm, Uzbekistan: A lifeworld analysis. *Rural Sociology* 76, 394-421.

Pender, J., Mirzabaev, A., Kato, E., 2009. Economic analysis of sustainable land management options in Central Asia. IFPRI/ICARDA Final Report for ADB, 146 pp.

Pomfret, R., 2000. Agrarian reform in Uzbekistan: Why has the Chinese model failed to deliver? *Economic Development and Cultural Change* 48, 269-284.

Pomfret, R., 2008. Tajikistan, Turkmenistan and Uzbekistan, in K. Anderson and J. Swinnen, eds., *Distortions to Agricultural Incentives in Europe's Transition Economies*. World Bank, Washington DC.

Rudenko, I., Lamers, J.P.A., Grote, U., 2009. Can Uzbek farmers get more for their cotton? The *European Journal of Development Research* 21, 283-296.

Saleth, M., Dinar, A., 2004. *The Institutional Economics of Water - A Cross Country Analysis of Institution and Performance*. Edward Elgar, Cheltenham, UK.

Sekler, D., Amarsinghe, U., Molden, D., de Silva, R., Barker, R., 1998. World water demand and supply, 1990-2025: Scenarios and issues. Research Report 19, IWMI: Colombo.

Shaliba, B.C., Bush, D.B., 1987. *Water Markets in Theory and Practice: Market Transfers, Water Values, and Public Policy*. Westview Press, Boulder, Colorado.

Siegfried, T., Bernauer, T., Guiennet, R., Sellars, S., Robertson, A.W., Mankin, J., Bauer-Gottwein, P., Yakovlev, A., 2012. Will climate change exacerbate water stress in Central Asia? *Climatic Change* 112, 881-899.

Sommer, R., Djanibekov, N., Müller, M., Salaev, O., 2012. Economic-ecological optimization model of land and resource use at farm-aggregated level, in C. Martius, I. Rudenko, J.P.A. Lamers and P.L.G. Vlek, eds., *Cotton, Water, Salts and Soums - Economic and Ecological Restructuring in Khorezm, Uzbekistan*. Springer, Dordrecht Heidelberg London New York, pp. 267-283.

Sunding, D., Zilberman, D., 2001. The agricultural innovation process: Research and technology adoption in a changing agricultural sector, in L.G. Bruce and G.C. Rausser, eds., *Handbook of Agricultural Economics*, Volume 1, Part A, Elsevier, pp. 207-261.

UNDP, 2007. Water – Critical Resource for Uzbekistan's future. UNDP Tashkent, pp. 38-60.

Veldwisch, G.J., 2008. Cotton, rice and water: Transformation of agrarian relations, irrigation technology and water distribution in Khorezm, Uzbekistan. Ph.D. thesis, ZEF, University of Bonn, Bonn, Germany, 219 p.

Veldwisch, G.J., Spoor, M., 2008. Contesting rural resources: emerging 'forms' of agrarian production in Uzbekistan. *Journal of Peasant Studies* 35, 424-451.

Wegerich, K., 2010. *Handing Over the Sunset - External Factors Influencing the Establishment of Water User Associations in Uzbekistan: Evidence from Khorezm Province*. CuvillierVerlag, Göttingen, 169 p.
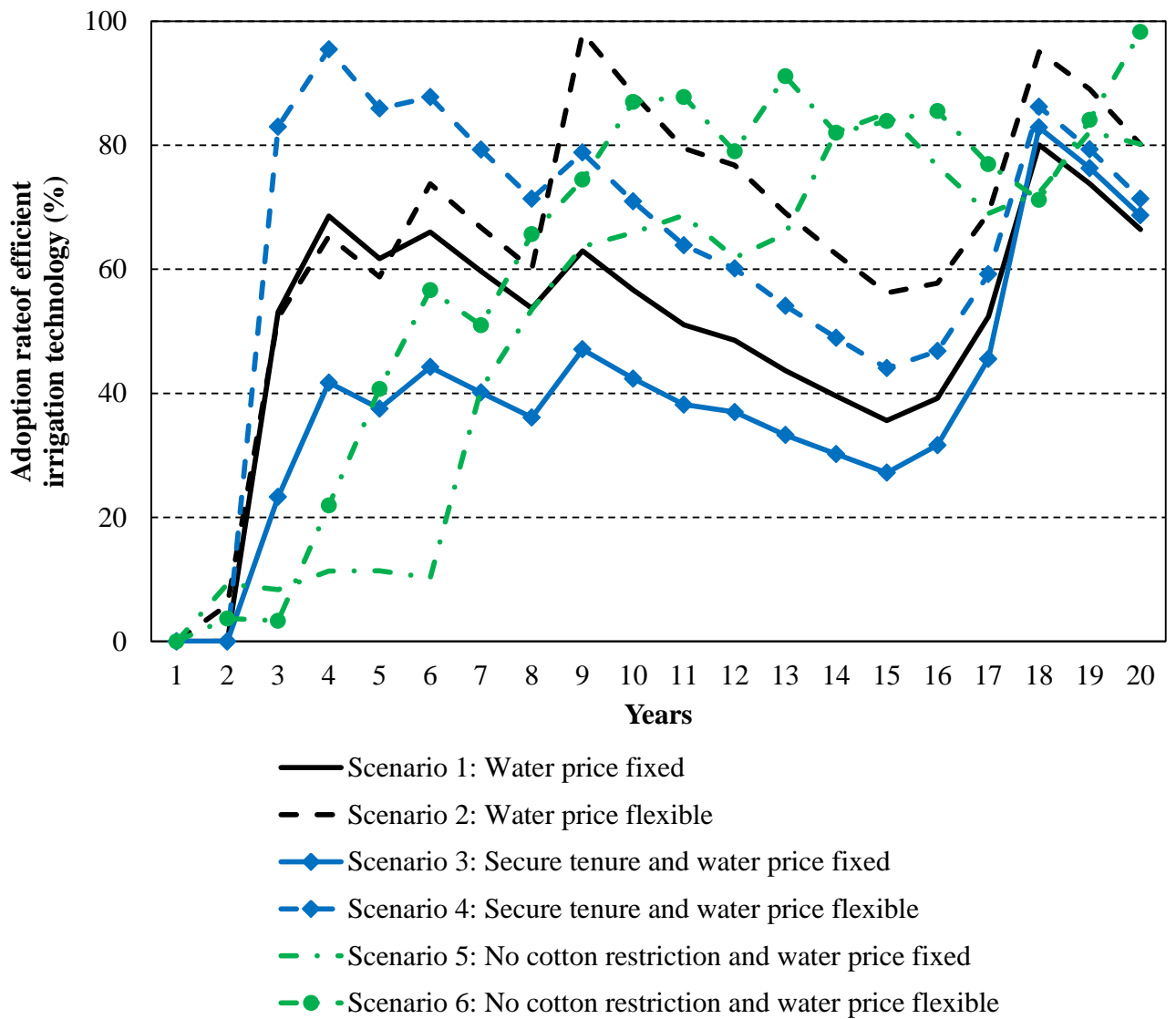
Table 1: Model scenarios

Attribute	Scenario 1 Water price fixed	Scenario 2 Water price flexible	Scenario 3 Secure tenure and water price fixed	Scenario 4 Secure tenure and water price flexible	Scenario 5 No cotton restriction and water price fixed	Scenario 6 No cotton restriction and water price flexible
Water price	Fixed	Flexible	Fixed	Flexible	Fixed	Flexible
Land tenure based on performance	Yes	Yes	No	No	No	No
Cotton yield and area restriction	Yes	Yes	Yes	Yes	No	No

Table 2: Parameters and values used in numerical analysis

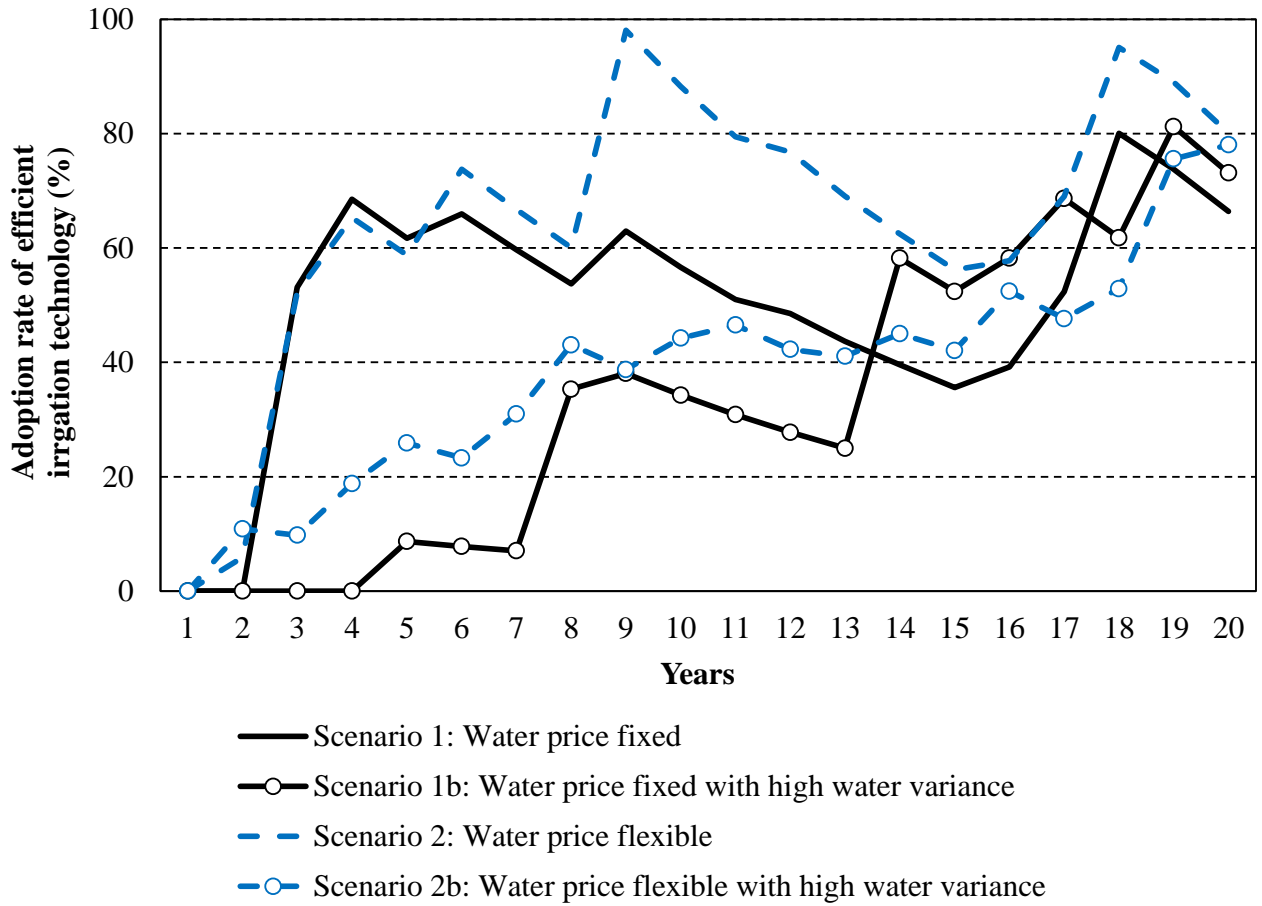| Parameter (unit)	Value	Source
Depreciation rate (%)	10	Bhaduri and Manna (2014)
Cost of investment in irrigation technology (sprinkler) (US dollar per ha, c^H)	973	
Initial price of water (US$ per 1000 m^3)	10	Djanibekov (2008)
Discount rate (%)	10	
Efficiency of furrow irrigation e_F (%)	55	Bhaduri and Manna (2014)
Efficiency of sprinkle irrigation e_H (%)	80	
Price of water (US$ per 1000 m^3)	5	Djanibekov (2008)
Water price sensitivity to excess demand (coefficient)	0.1	Bhaduri and Manna (2014)
Price of cotton (US$ per ton)	234	Farm survey 2010
Price of rice (US$ per ton)	1000	Farm survey 2010
Per unit cost of cotton (US$ per ton)	180	Farm survey 2010
Per unit cost of rice (US$ per ton)	600	Farm survey 2010
Average cotton target yield (tons per ha)	2.5	Farm survey 2010
Share of farmland under cotton target area (%)	55	Farm survey 2010
Water supply mean (1000 m^3 per ha)	15	CAWATERinfo (2011)
Water supply variance (1000 m^3 per ha)	8	CAWATERinfo (2011)
Yield function – cotton	$2.135*w_e{\char`\^}(1/4)$	Estimated based on MAWR (2001)
Yield function – cotton	$1.723*w_e{\char`\^}(1/3)$	Estimated based on MAWR (2001)

Note: Exchange rate of 1 US$ = 1,319 UZS as of 2009 according to Sommer et al. (2012).

Figure 1: Adoption of efficient irrigation technology under different scenarios

Source: Model results.

Figure 2: Adoption of efficient irrigation technology under different water price regimes and supply variability

Source: Model results.