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Agricultural risks and farm land consolidation process in transition countries: The case of cotton production in Uzbekistan

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Abstract

Cotton production substantially contributes to the GDP of Uzbekistan. It is produced under a state procurement policy, according to which farmers have to allocate half of their land for cotton, fulfill cotton output levels and sell the entire harvest of cotton to the state. Land is state owned and a land consolidation process is in place, where land allocated to a farm can be reduced if cotton production targets are not met. However, low production levels may not only arise due to bad management practices but also due to production risks, e.g., due to climatic variability or limited access to inputs such as irrigation water. In this study, we aim to assess policies that can improve cotton production levels and farm profits under land consolidation and agricultural risks. We use a recursive programming model, which considers risk-averse farmers and their farm size adjustments, together with irrigation water-crop yield response functions on different land productivity classes. We consider production, market and institutional risks and find that such risks affect resource allocation, production levels and thus also farm size developments. The farm land consolidation improves overall cotton output, yet, it reduces farm incomes as the state cotton procurement price is low. Under conditions of the state cotton procurement and land consolidation, increasing the cotton price can improve cotton production and farm profits and reduce farm size changes, but farm size changes still occur among farmers. Having secure land tenure together with land use flexibility and higher cotton prices allows farmers to improve incomes, reduce income disparity, diversify land uses, but results in lower cotton output than under the state cotton procurement policy.

Keywords: state target policies; institutional, production and market risks; farm heterogeneity; recursive programming.

1. Introduction

In 1990-1991, the Central and Eastern Europe and states of the former Soviet Union set out on the path from the centrally planned to market economies. Due to their high dependency on agricultural production, the agrarian reforms are one of the main characteristics of the transition process of these countries. Reforms in agriculture are aimed to improve rural welfare and agricultural production, and for these a series of policies, modifications in institutions and increase in incentives for rural population have been implemented (Lerman et al., 2004; Rozelle and Swinnen, 2004). The most important reforms were the abolishment of state planned production targets imposed on farmers as well as the land privatization and restructurization of large-scale collective farms into private farms and other types of market-focused agricultural enterprises (Lerman et al., 2004). Despite a common agenda for transition to market economy, post-Soviet countries follow different paths. For example, Azerbaijan, Armenia and Kyrgyzstan have made large reform steps towards market economy and have substantial land under farmers' ownership (Lerman, 2009). However, in some countries such as Belarus, Tajikistan, Turkmenistan and Uzbekistan, the functioning of agricultural policies has been continued with the pseudo-Soviet approach (Csaki et al., 2006). In Uzbekistan, for instance, most of the farmland is owned by the state and state imposes agricultural production quotas and state procurement policies on farmers. Especially, this is the case for cotton production, as it was also present during the Soviet Union.

Cotton output in Uzbekistan contributes about 13% to GDP through the export of cotton products (State Statistical Committee of Uzbekistan, 2010). To accomplish such high revenues from cotton the agricultural policies, institutions, infrastructure and farming practices are designed to ensure high levels of cotton production (Djanibekov et al., 2010). The main policy that determines the cotton production is the state cotton procurement policy, where farmers have to achieve the predetermined cotton output targets. Farmers have to sell the entire harvest to the state at the state determined price, which is lower than the potential (international) market prices. Moreover, the recent government program of farm restructuring, which is called the land consolidation/farm optimization and is in place since 2008, aims to optimize agricultural production by re-allocating land resources. The purpose of this program is especially maximizing cotton production, by adjusting farm sizes to utilize the economies of scale of farms. In contrast to European model of farm structural change and land consolidation with voluntary exchange of lands (e.g., see Van Dijk, 2003), in Uzbekistan this process is implemented by the state that reduces the area of inefficient farms and gives it in favor for increasing the area of more efficient farms. As a result of this policy, the number of farms was reduced by almost 80% between 2008 and 2012 (State Statistical Committee of Uzbekistan, 2010). More general, changes in agricultural policies can lead to the structural change of farms, where some farms may benefit whereas others may lose (e.g., see Happe et al., 2008). As a result, such process may lead to changes in the distribution of incomes and resources among agricultural producers (e.g., Feil et al., 2014; El Benni and Finger, 2013).

At the same time, farming in transition economies is subject to various sources of risks, such as production, market and institutional risks, that can affect agricultural output directly or indirectly (Pavlova et al., 2014; Balmann et al., 2015). For instance, Uzbek farmers face high crop price fluctuations for crops that are not under the state procurement policies. Another example is that the irrigation water supply for farming became more variable, for instance, because the frequency of drought years has increased (Müller, 2006). Moreover, cotton yields in Uzbekistan are volatile and climate change may increase yield variability further (Bobojonov and Aw-Hassan, 2014). Thus, cotton production below governmental production and performance goals can occur due to residual natural variability of cotton output, even though farmers may have adopted optimal management practices. The possibility that cotton output will be lower than target production levels will necessitate the state to change farm structure by re-allocation of land resources. Thus, the land area of farmers that fail to deliver the predetermined cotton amount is reduced and transferred to other farms. The design of cotton order-control mechanism and low procurement prices also disincentives farmers in growing cotton (Pomfret, 2008). Accordingly, to manage the risks of low cotton output the modifications of cotton procurement policy are required. Djanibekov and Khamzina (2016) show that the flexibility in cotton policy by lifting its area-based target and allowing farmers to diversify their land uses can reduce the effects of risks. Liberalization of marketing and improving cotton prices was argued to increase farm incomes and maintain cotton output (Guadagni et al., 2005).

Several previous studies analyzed farm size adjustments under policy changes (e.g., Balman, 1997; Berger, 2001; Freeman, 2009). For example, Storm et al. (2015) using an econometric model within the context of direct payments for farms in Norway, showed that the farm interdependencies significantly influence the farm structural change. Despite its usefulness to gain insights in underlying mechanisms, such ex-post estimations cannot evaluate the effects of possible new policies. Performing econometric estimations in our Uzbek case study is further complicated due to that in the transitional country settings the data is limited. In contrast, simulation models can account for ex-ante impacts using limited data. These models usually rely on the mathematical programming approach within the agent-based model that includes heterogeneous farms (Schreinemachers and Berger, 2006). In usual modeling applications, farm structure is assumed to change through the land markets of farms and modelled in recursive context by considering a dual value (i.e., shadow price) for land of farmers as a variable that leads to land purchase (e.g., Happe et al., 2006). In addition, several studies modelled the change in the structure of farms according to the Cochrane’s (1979) treadmill model (e.g., Berger, 2001). They implicitly assume that the policy and technological changes can lead early adopting farmers to absorb resources of laggard farmers that had to drive out of business due to reduced profits. However, these studies considered farm size change through the land markets by mostly using the deterministic model (e.g., Happe et al., 2011).

To our knowledge, no studies have addressed the change in farm sizes due to the state policies (e.g., state planned farm restructuring for optimizing production quota of crop) under conditions of agricultural risks. We aim to fill this gap by addressing the farm land consolidation, state cotton procurement policy, cotton production and farm incomes in Uzbekistan. We also add a particular focus on agricultural risks, including a unique combination of institutional, market and production risks, as well as risk-aversion of farmers. To this end, we develop a recursive programming model combining heterogeneous farms depicted with farm-level modules that are interlinked via land-transfer mechanisms. We simulate several scenarios to analyze different options to modify the state cotton procurement policy for improving cotton production and farm incomes under conditions of variability in agriculture. The model relies on data from farm surveys and secondary sources.

Within this context, the objectives of this study are to: (1) analyze the effects of change in land possession due to the cotton procurement policy, i.e., failure to deliver to the state the cotton output of one farmer leads to its land area reduction and the transfer of this land to another farmer, on farm incomes under agricultural variability; and (2) identify policies that can lead to the improvement of cotton production and incomes of farmers.

2. Methods

2.1 Background on cotton procurement policy and cotton-growing farming

The case study area of our analysis is the Khorezm region and southern districts of the Autonomous Republic of Karakalpakstan, namely Beruniy, Turtkul and Ellikkala. Irrigated agriculture accounts for about 35% of the region’s GDP. Cotton and winter wheat (hereafter referred to as wheat) are the major crops cultivated (occupy about 40 and 25% respectively of arable land), and are also subject to a state procurement policy. Other main crops are rice, vegetables and maize.

The main agricultural producers in our case study region are farmers (about 88% of arable land), followed by small-scale semi-subsistence rural households (about 11% of arable land) and agricultural enterprises (about 1% of arable land, usually owned by the state and private companies). The main farm types are cotton-grain farms that occupy about 85% of arable land that is in possession of farms. The remaining farmland belongs to other farm types such as livestock, horticulture, sericulture, fishery and poultry. The farmland is owned by the state and farmers lease land from the state, i.e., they have usufruct rights for land. The cotton-grain farms have to fulfill the cotton production levels, and the state is a monopsonist of cotton produced by farmers. To fulfill the state cotton procurement policy, cotton-grain farmers each year have to i) allocate half of their land for cotton cultivation (area-based target), ii) produce a certain cotton output (quantity-based target), which is in the study area is about 2.4 t ha^{-1} multiplied by the half of the farmland allocated for cotton[1], and iii) sell the entire cotton harvest to the state at the state determined prices (Djanibekov et al., 2015). Cotton procurement price is about 227 USD t^{-1} (as of 2009; Djanibekov et al., 2013) and is lower than in neighboring countries such as Kazakhstan (550 USD t^{-1}) and Kyrgyzstan (450 USD t^{-1}) (Pomfret, 2008). Half of the wheat output is purchased by the state at a price below the local market price, while the remainder can be traded by farmers in local markets. Farmers receive input subsidies from the state for cotton and wheat production (Djanibekov et al., 2010)[2].

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[1] The cotton output level differs by regions of Uzbekistan and is assigned by the state to each farmer according to her/his land productivity levels and climate conditions (Djanibekov et al., 2012). However, during the farm survey, we were not able to reveal farmers' cotton procurement output target levels (see section 2.5 for survey description) and hence we assumed that the quantity-based target level includes the cotton yield level of 2.4 t ha^{-1} (i.e., average cotton yield in study area in 2010) multiplied by the half of the farmland allocated for cotton.

[2] Most of the state subsidies for cotton production are in the form of loans for farmers at an interest rate of 3%, which is lower than bank interest rate. Also, subsidies include the operation and maintenance costs and state budget payments to irrigation pumping stations (Djanibekov et al., 2010).

Since 1991 the *kolkhoz* and *sovkhoz* lands were distributed among private farms and their number has been increasing[3]. However, since the introduction of the governmental program on farm restructuring in 2008, the numbers of farms started to reduce significantly. Fig. 1 shows the change in farm numbers and size in Uzbekistan between 1997 and 2010. This development also holds for our study area, where in 2012 the number of farms was almost one fifth than in 2008. The decrease of farm numbers led to an increase in the size of other farms, hence the released land resources were re-allocated. The reduction in farm numbers is mainly observed in relatively smaller farms (i.e., with area of up to 40 ha), while larger farms have experienced increases of farm acreage. This recent decrease in farm numbers was triggered by the state's farm optimization policy, i.e., land consolidation process, which is aimed to increase agricultural productivity by reducing the area of inefficient farms while increasing the land area of efficient farms (Djanibekov et al., 2012). Due to that the state is the sole owner of farmland and farmers only lease land, the state can impose the agricultural production targets on farmers and adjust farm sizes for meeting such targets. In particular, cotton-grain growing farms experienced substantial changes in their farm size since the land consolidation process in 2008 (State Statistical Committee of Uzbekistan, 2012). Although, over the last years the number and size of farms has not changed substantially the farms will be subject to farm optimization again[4].

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[3] After independence in 1991, *kolkhoz* and *sovkhoz* lands in Uzbekistan were redesigned to the collective farms and part of their land was distributed to the private farms. From 1998 to 2007 the land of the collective farms was distributed to the private farms and their number has been increasing (Djanibekov et al., 2012).

[4] Uzbekistan will implement the policy for improving the efficiency of farms during 2018-2021 that also includes adjustments in farm sizes (see in Russian http://prezident.uz/ru/lists/view?id=1119)

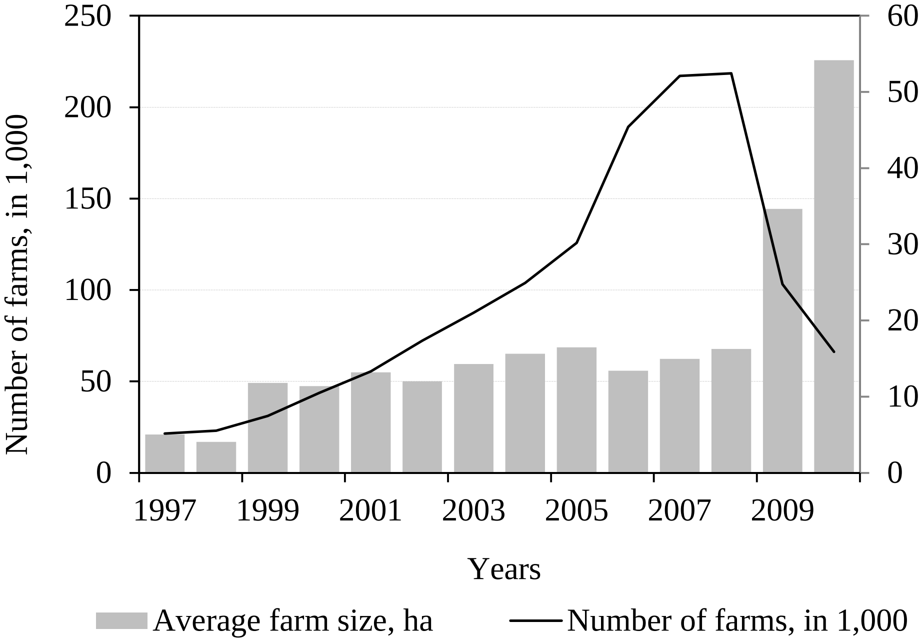

Fig. 1. Dynamics in number and average size of farms in Uzbekistan.

Source: State Statistical Committee of Uzbekistan (2012).

In the study area, irrigated agricultural production is subject to various risks. For instance, yields are uncertain as a result of irrigation water variability, crop diseases and unfavorable weather conditions. About 20–30% of regional croplands have low production potential for crops (MAWR, 2010). The land productivity is influenced by several factors such as agricultural practices, soil salinity, slope of land, and groundwater table and salinity. In addition, crop yields are affected by varying irrigation supplies (MAWR, 2010). Farmers also face price fluctuations (Mori Clement et al., 2015), except the state procurement prices for cotton and wheat (concerns half of the harvest that is under the state procurement). Such uncertainties may lead to the failure in fulfillment of the state cotton procurement targets. Considering the state cotton procurement policy, substantial reduction in numbers of cotton-grain farms and that farmers lease land from the state, it can be assumed that the area of cotton-grain farms that have lower production than the targeted cotton output may reduce, and as a result the area of those farms that meet the targeted level may increase (although such process is not explicitly defined in the legislation). Note that we are aware that changes in farm sizes can also be influenced by other external factors (e.g., networks, farmers' bargaining power). The fact that particularly larger farms benefit from this new policy might be due to economies of scale, but might also be caused by the lower crop yield variability at larger farms because a wider spatial allocation of production sites implies on-farm hedging effects, where there is a non-perfect correlation of yield levels at each field (e.g., see Marra and Schurle, 1994; Finger, 2012). Also, it might happen that all of the farms are 'inefficient' agricultural producers and in such case other external factors might influence farm size change and land redistribution.

2.2 The model

We develop a model that includes decision making of and the interaction between heterogeneous cotton-growing farmers that integrates the Uzbek cotton procurement policy and market, production and institutional risks. The model allows us to investigate the effects of different policies on the dynamics of farm size changes, land uses and farm profits. Considered land uses include cotton, wheat, rice, maize and vegetables.

The production risks comprise the variability in yields of crop main products (hereafter crop yields) due to the variability of irrigation water supply and other factors (e.g., weather, pests). Both risk sources are generated using multivariate normal distributions and accounting for interdependencies across the random variables. It is assumed that the distribution of simulated parameters on crop yields and irrigation water is not influenced by the model outcome in one period, and hence the probability distribution of crop yields and irrigation water are identical over the period of analysis. Market risk includes price variability of crops that are generated using a geometric Brownian motion with drift to examine the effects of fluctuations in crop prices over time. The Brownian motion has independent increments and the change in the process in any period is normally distributed with a variance that increases with time (Dixit and Pindyck, 1994). As the cotton price is set by the state, it is assumed to be deterministic. Institutional risk may occur to farmers due to their failure to fulfil the cotton production target level set by the state and their land is expropriated and transferred to another farm that fulfils cotton output levels. Hence, we generated multivariate normal distribution and stochastic process for analysed farm types. We consider 10 simulations of crop yields and irrigation water availability and 10 paths for prices, which give in total 100 simulations in each period. This number of simulations is chosen as it allows an efficient balance between computational requirements and stability of the model results. Information on drift and volatility of crop prices, observed crop yields and irrigation water availability and simulated crop net present values are given in Table A.1, Appendix A and Tables B.1-2, Appendix B.

The model is programmed in GAMS[5]. In the model, we assume that cotton-growing farmers face the problem of selecting crop cultivation to achieve the highest annual present values under agricultural variability. We develop a recursive programming model to address dynamics in farm planning and maximization of profits under different states of nature. The recursive programming model optimizes farmers' decisions for each year sequentially and thus assumes that farmers' are myopic and do not have perfect foresight of the future to make long-term planning (Blanco-Fonseca et al., 2011). This also implies that farmers do not consider in long-term planning the future farm size changes due to failure to meet the state cotton production target level. The model is normative that is a prescriptive type of model used to determine the variable levels in order to optimize the objective function. Farmers' objective to maximize present values in each year is formalized as:

$$Max\ Z_{sft} = \sum_{j=1}^{J} \sum_{l=1}^{L} \frac{\bar{p}_{jst}\bar{y}_{jslft}X_{jslft} - c_{jsft}X_{jslft}}{(1+d)^{t}} \tag{1}$$

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[5] http://www.gams.com/

where Z is the objective value of the model, index f denotes farms comprising 3 farm types (i.e., A, B, C), s represents the states of nature (s_1, s_2, …, S) with S equal to s_{100} and is the number of states of nature, t is the period of analysis (1, 2, …, T) with T equal to 10 years and results of period t influence the initial model settings in period $t+1$, j is the annual crop types, l is the soil productivity levels (i.e., low, average, good and high) that are constant over years, $\bar{p}$ is the varying crop output prices, $\bar{y}$ is the varying crop yields, X is the area allocated to crops by each farm under different states of nature where crop cultivation follows the seasonal calendar, c is the deterministic input costs of crop cultivation and transaction costs incurred from receiving additional land that are assumed to vary for each farm depending on states of nature, d is the discount rate of 14% that represents the difference between the nominal interest rate and the consumer price index in Uzbekistan (Djanibekov and Khamzina, 2016). Although in the model we do not consider the long-term activities and planning decisions, we include the discount rate to reflect possible profits over time.

We assume that farmers are risk-averse and focus on downside risks and downside risk aversion. To model the downside risk aversion of farmers, we apply the safety-first approach (e.g., see Briner et al., 2012; Haley, 2012). In the safety-first approach, farmers avoid resource allocation decisions that imply the possibility of having profits lower than the certain critical threshold. Such threshold values can reflect the minimum income levels allowing survival of the farm and household or the re-payment of debt capital. In our model, this is implemented as an additional constraint, where annual discounted profits should not fall below a critical threshold:

$$\sum_{j=1}^{J}\sum_{l=1}^{L}\frac{\bar{p}_{jst}\bar{y}_{jslft}X_{jslft}-c_{jsft}X_{jslft}}{(1+d)^{t}} \geq \tag{2}$$

$$u\frac{\left(\sum_{s=1}^{S}\sum_{j=1}^{J}\sum_{l=1}^{L}\frac{\bar{p}_{jst}\bar{y}_{jslft}X_{jslft}-c_{jsft}X_{jslft}}{(1+d)^t}\right)}{S}$$

where u shows the percentage value of the expected discounted profits from different states of nature. We assume u=0.7, as such threshold value is considered as 'extreme' loss in the agricultural insurance literature (e.g., Conradt et al., 2015). In the right-hand side of the equation, we multiply the threshold value (u) with the discounted expected profits of farmers.

The farm land area is the constraint that restricts farmers' crop cultivation activities and changes every year depending on fulfillment of cotton procurement policy. For the first year of analysis, we consider the initial state of farm sizes based on our observations (Eq. 3). In subsequent periods the size of each farm can be adjusted as a result of re-allocation of land (Eq. 4). The following equations are land area constraints in the model:

$$a_{lft} \geq \sum_{j} X_{jslft} \qquad \text{where } t = 1 \qquad (3)$$

$$\bar{A}_{slft} \geq \sum_{j} X_{jslft} \qquad \text{where } t > 1 \qquad (4)$$

where a is the initial land size of farms, i.e., farmland area in year one, $\bar{A}$ is the size of farms under different states of nature after year one.

The model output on land use at farms allows us to analyze how diverse are farming practices. Diversification at farm is a sustainable land use practice and can generate higher profits under conditions of variability (Baumgärtner and Quaas, 2010). We use the Herfindahl index calculated over land use[6] as measure for farm-level diversification, where a lower index shows that farmer is more diversified.

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[6] For each farm, we calculate the sum of squared ratio of the area under crop *j* to the total farm land use area.

The model determines the area of farms every year through the fulfillment of cotton procurement policy by each farm. Reflecting current cotton procurement policy, farmers have to allocate 50% of their land for cotton cultivation according to the area-based target. In the model, we include the area-based target by considering the equality constraint for 50% of farmland cultivated with cotton. According to the quantity-based target of the cotton procurement policy farmers have to produce 2.4 t ha^{-1} on 50% of land allocated for cotton. However, in the model we do not include the constraint equation for cotton production levels, because cotton yields are volatile due to production risks and hence farmers might fail to produce the required amount of cotton. We consider in the model the quantity-based target of cotton output by assuming that the state changes farms' sizes according to the fulfillment of the cotton output level. The farms that do not meet the cotton output target are considered as 'inefficient' by the state and part of land consolidation. To meet the cotton output levels the state reduces the land allocated to such farms and transfers this land to the farm that complied with the cotton procurement targets. Accordingly, in the model the reduction in farm area occurs when the cotton output is lower than the expected cotton production level (i.e., lower than the 2.4 t ha^{-1} multiplied by the half of farmland size). Produced cotton affects the farm size in the next year. In addition, we assume that farmers do not adjust their cotton production decisions to maintain the farm size, but instead farmers meet the area-based target of cotton and focus on producing there cotton with uncertain yields. The following are equations for cotton area constraint (Eq. 5), the reduced area of farmland (Eq. 6) and the size of farm after the land transfer (Eq. 7):

$$q\sum_{l}\bar{A}_{slft}=\sum_{l}X_{jslft} \qquad \text{where } j\text{=cotton} \qquad (5)$$

$$\frac{q\ \acute{y}_j\ \bar{A}_{slft} - \sum_l \bar{y}_{jslft}\ X_{jslft}}{\frac{q}{\acute{y}_j}} = R_{lsft} \qquad \text{where } j\text{=cotton} \tag{6}$$

$$\bar{A}_{slft} = \bar{A}_{slft-1} \pm R_{slft-1} \tag{7}$$

where $\bar{A}$ includes the size of farms in the initial (i.e., initial land size parameter a) and subsequent years, q is equal to 0.5 and represents the half of the farmland allocated for cotton cultivation (i.e., area-based target), $\acute{y}$ is equal to 2.4 and represents the average per hectare cotton yield required from each farm (i.e., 2.4 t ha^{-1} multiplied by half of the farmland area allocated for cotton results in the quantity-based target for cotton output), and R is the area of farm that is reduced or increased as a result of respectively lower than or meeting/exceeding the state target cotton output. The variable R in Eq. 7 is subtracted from farms that lose land or added to the area of farms that meet the cotton production levels and thus respectively farms can have decrease or increase in size. In case only one of the farmers has not produced required amount of cotton, part of his/her land is transferred to the farmer that produced the largest amount of cotton. If all exemplary farm considered in the model are not complying with target production levels, their land is reduced and is considered to be transferred to a residual farm land area. Such residual land user can represent other farm types (e.g., livestock, horticulture) or other agricultural producers (e.g., agricultural enterprises) or abandonment of land. We do not consider other external factors that might be influencing the farm size change, e.g., networks, bargaining power of farmers (see e.g., Djanibekov et al., 2012).

An increase in farm size implies also an increase in labor requirements to monitor and manage agricultural production. Therefore, the increase in farm size can increase farmer's transaction costs for operating the farm. To reflect these transaction costs, we assume that when the farm size increases farmer hires additional labor to manage the land. For each additional hectare of land farmer pays hired labor a wage of 27 USD ha^{-1} $month^{-1}$. This value was observed during the surveys and is the monthly average wage paid by farmers to hired labor for managing 1 ha of cropland (for information on surveys see Section 2.5).

Farmers apply irrigation water to produce crops and irrigation water availability at farms is limited. Hence, the model comprises crop water-yield response functions and a constraint on irrigation water availability. The irrigation water supply level to farmers is organized by the state and depends on many conditions such as climate and irrigation water releases by upstream countries. Irrigation water available for crop cultivation is varying, affects crop yields and accordingly farmers adjust their land use activities. Due to absence of information on spatial water distribution to different fields and farms, we assume the amount of irrigation water available to be homogeneously distributed for each farm based on its size. Irrigation water supply for each farm changes proportionally with respect to farm size. Farmers allocate arable lands with crops at respective irrigation rates that cannot exceed the variable irrigation water supply to farms:

$$\sum_{j}\sum_{l} k_j\, X_{jslft} \leq \sum_{l} \overline{w}_s\, \overline{A}_{slft} \tag{8}$$

where k is irrigation rates for crops, $\overline{w}$ is the varying irrigation water availability, and $\bar{A}$ is the size of farms under different states and includes also the initial farm size (i.e., initial land size parameter a).

Another constraint is related to the machinery available at farm, where machinery use and endowments are measured in diesel equivalents. In this constraint, it is assumed that crops have different diesel (i.e., machinery use) requirements but their yields are not responsive to diesel use:

$$\sum_{l} i_j X_{jslft} \leq m_f \tag{9}$$

where i_j is the diesel requirement for crop j and m_f is diesel available in farm. We assume that farmers cannot purchase additional machinery and hence machinery available at farm is constant over the period of analysis.

For information on main model parameters see Table B.1 and Table B.2, Appendix B. The model was validated by comparing the land use pattern of surveyed farms with the business-as-usual model results (in Table S.1 in Supplementary material; for scenario description see section 2.4). The model validation shows that the model results do not differ substantially with the observed land use pattern of surveyed farmers in the study area, except for vegetables and wheat cultivation. The large difference in vegetable cultivation can be due to that we considered the gross margins and did not account for the undeveloped infrastructure that restricts vegetable production in the region (e.g., storage and processing, marketing channels). Wheat has high area in the study area due to that it contributes to food self-sufficiency and its by-products are used as feed for livestock, which were not considered in the model. Also, we do not consider in the model other crops cultivated at farms such as fruit orchards and fodder crops.

2.3 Heterogeneous farms

From our survey, we isolated three types of cotton-grain farms (denoted as Farms A, B and C), which differ in their size, soil productivity level (i.e., low, average, good, and high productive lands), machinery available and variability of crop yields (Table 1) (for description of the farm survey see section 2.5). We assume that Farm C has advantage over Farms A and B as it has larger land area, share in area of more productive soils, more machinery available and less varying crop yields. As discussed above, larger farms are assumed to face, at the farm-level, lower yield variability because on-farm hedging effects (e.g., see Marra and Schurle, 1994; Finger, 2012). Thus, in the model the yield variability is lower the larger is farm size, i.e., Farm C has the lowest yield variability. The smallest farm type is Farm A, which is also the most disadvantaged farm in land area, productivity level and machinery available and has the highest variability of crop yields. Heterogeneous farms are interlinked to each other through the land transfer arrangements initiated by the land consolidation process. This process implies that the land of farms that are inefficient in terms of cotton output is taken away and given to farms that fulfil cotton output level. In addition to resource endowments, each farm is subject to policies that set the boundaries of crop production activities.

An alternative modeling approach for our study would be the use of an agent-based model. Such approach allows modelling the entire population of farmers in the region and their interactions, and thus can show in detail the change in size, number and typology of farms (e.g., see Happe et al., 2008). We opted, however, against such modeling approach because we lack sufficient agent specific information in our case study area.

Table 1. Farm characteristics.

	Farm types		
Attributes	A	B	C
Farm size, ha	15	40	87
Area of land by productivity type, ha			
Low	5	8	10
Average	5	16	35
Good	5	15	40
High	0	1	2
Machinery available, in diesel m^3	11	12	30

Coefficient of variation of crop yield			
Cotton	0.16	0.12	0.08
Wheat	0.15	0.11	0.08
Rice	0.22	0.17	0.11
Maize	0.16	0.12	0.08
Vegetables	0.11	0.08	0.06

Source: Coefficients of variation of crop yields are adapted from MAWR (2010) and State Statistical Committee of Uzbekistan (2010).

2.4 Policy scenario settings

We assume five scenarios that modify cotton procurement policy and land consolidation to observe the changes in cotton output, farm sizes and incomes (Table 2):

- In the business-as-usual (BAU) scenario, farms have to follow the current state cotton procurement settings, where they allocate half of their land for cotton (i.e., area-based target) and have to produce certain amount of cotton that in average is 2.4 t ha^{-1} from land allocated for cotton (i.e., quantity-based target). Farmers sell the entire cotton harvest to the state at the price of 227 USD t^{-1}. According to the realized cotton production amount the farm area is determined as described in section 2.2;
- Flexible area-based target scenario (Flexible) assumes a slight modification of the first scenario: the area-based target of cotton cultivation is abolished and farmers are flexible in deciding how much area to allocate for cotton cultivation. However, farmers still have to meet the quantity-based target of cotton policy according to their total farm size (i.e., 2.4 t ha^{-1} multiplied by the half of farmland size). The land area in possession of farmers changes according to their cotton output. Hence, in this model scenario, Eq. 5 is not included. The state cotton procurement price is 227 USD t^{-1};

- Cotton procurement price increase scenario (Cotton price) assumes increase in farm-gate price of cotton, i.e., state cotton procurement price. We applied this scenario due to the fact that the current state purchase price of cotton can be insufficient to incentivize farmers towards the optimal management to achieve the highest potential cotton yields. The modified cotton price in the model is derived based on dual value of cotton, i.e., minimal increase in cotton price that would lead to cultivation of this crop. We obtain the dual values of cotton for each state of nature, i.e., based on variabilities in crop yields and prices, and irrigation water availability. When identifying dual values for cotton, we assume that there is no farm size change. Furthermore, as cotton procurement price do not differ depending on soil and farm types and farm risk perceptions, we assume the dual values of cotton cultivation to be their average values on four soil productivity levels at three modelled farms that are risk-neutral (i.e., $u=0$ in Eq. 2). Accordingly, depending on the state of nature the dual values of cotton are between 212 and 489 USD t^{-1}, which result in cotton price to be within the range of 439 to 716 USD t^{-1}. For comparison, the world cotton price in 2010 was 748 USD t^{-1} (MacDonald, 2012), and the cotton price producers received in Kazakhstan and Kyrgyzstan were 550 and 450 USD t^{-1} respectively (Pomfret, 2008). We assume in this scenario that farmers have the opportunity to directly sell cotton on markets and that the new buyers of cotton (e.g., private ginneries) might be entering the market. In this modified cotton procurement policy, farmers still have to meet quantity- and area-based targets of cotton policy. Farms’ size changes according to cotton output level;
- Secure land tenure rights scenario (Tenure) reflects that farmers still have to allocate a specified area of their land for cotton production (area-based target). However, land possession of farmers is fixed and does not change depending on crop output. Thus, the area of farms is constant over years and because of that we assume that the state cannot

negotiate the cotton production amount and set the quantity-based target to farmers. In this scenario, Eqs. 6-7 are not considered in the model. The state cotton purchase price is assumed to be fixed at 227 USD t^{-1};

- Liberalized scenario (Liberalized) considers that farmers have the full flexibility in land use decision-making and thus do not have to meet the cotton procurement policy and can sell in the market the raw cotton output with the increased farm-gate prices ranging between 439 and 716 USD t^{-1}. Also, we assume that farmers own the land and there is no land consolidation procedure.

Table 2. Description of model scenarios.

Policy designs	Scenarios				
	BAU	Flexible	Cotton price	Tenure	Liberalized
Cotton procurement price, USD t^{-1}	227	227	439–716	227	439–716
Area-based target, % of farm area	50	0	50	50	0
Quantity-based target, t ha^{-1}	2.4	2.4	2.4	0	0
Farm size adjustments	Yes	Yes	Yes	No	No

2.5.Data sources

The data on farm characteristics considered in our analysis is obtained from Djanibekov et al. (2013) and Djanibekov and Khamzina (2016). This data includes 80 surveys of cotton-grain farms that were conducted in the study area during June 2010 and March 2011. The farmers were randomly selected from the cross-sectional data on farmers in the study area, and the questions were addressed to the farm owner or manager. The surveys provided information on farm cropping pattern, crop input and output prices, and crop production technologies. Information on farm characteristics also consists of data from the official statistical departments (State Statistical Committee of Uzbekistan, 2010). Prices of commodities also include data collected during weekly market surveys. To specify variability of crop yields and prices and irrigation water availability, we used the information on average and standard deviation of crop output prices and yields and irrigation water availability based on data reported between 2001 and 2010 (State Statistical Committee of Uzbekistan, 2010; MAWR, 2010). Crop yields are estimated according to water-yield response functions using official irrigation rate recommendations for four classes of land productivity, i.e., low, average, good, and high (MAWR 2001; Land Resources 2002). Water-yield response functions were derived based on recommendations provided by MAWR (2001). According to these norms, highest yields of cotton, wheat, rice, maize and vegetables can be reached with irrigation amounts of 5612, 5497, 28216, 5311 and 8572 m^3 ha^{-1} respectively. In these norms, yield of rice changes with respect to irrigation level and is the same for all land productivity classes. The water-yield response functions take into the account the variability of crop yields and water availability.

3. Results

3.1 Farm size

The model results show that the land consolidation under conditions of uncertainty affects size of all three modelled farms over years under continuation of current settings, i.e., in the BAU scenario. Mainly the low and average productive lands are expropriated from farms that fail to meet the cotton output target (Tables S.2 in Supplementary material). As a result of expropriation of low productive lands the share of well productive lands increases and farmers can have higher yields from such lands. In the states of nature when none of the farmers meet the cotton production target their land is assumed to be transferred to other farmers (e.g., livestock, horticulture) or to other agricultural producers (e.g., agricultural enterprises, which can also produce cotton) and is expressed as ‘Residue’ (Fig. C.1 in Appendix C). The farm size changes increase over the simulated period of time as a result of drift in Brownian motion and its effect on increase of profit variability.

Under different states of nature and policy scenarios the land transfer is found to be induced in different directions as well as in different magnitudes (Fig. 2). The variability of possible farm size changes is found to be substantial, in a range from -60 to +75%. The Flexible scenario leads to larger changes in farm sizes than the BAU scenario due to low cotton returns and myopic nature of farmers’ decisions in the model and thus they are interested in maximizing profits in the current year and cannot predict the cotton output levels to maintain the farm sizes over time (Fig. 2b). In the Tenure and Liberalized scenarios, no farm size changes are occurring as farmers have secure land tenure.

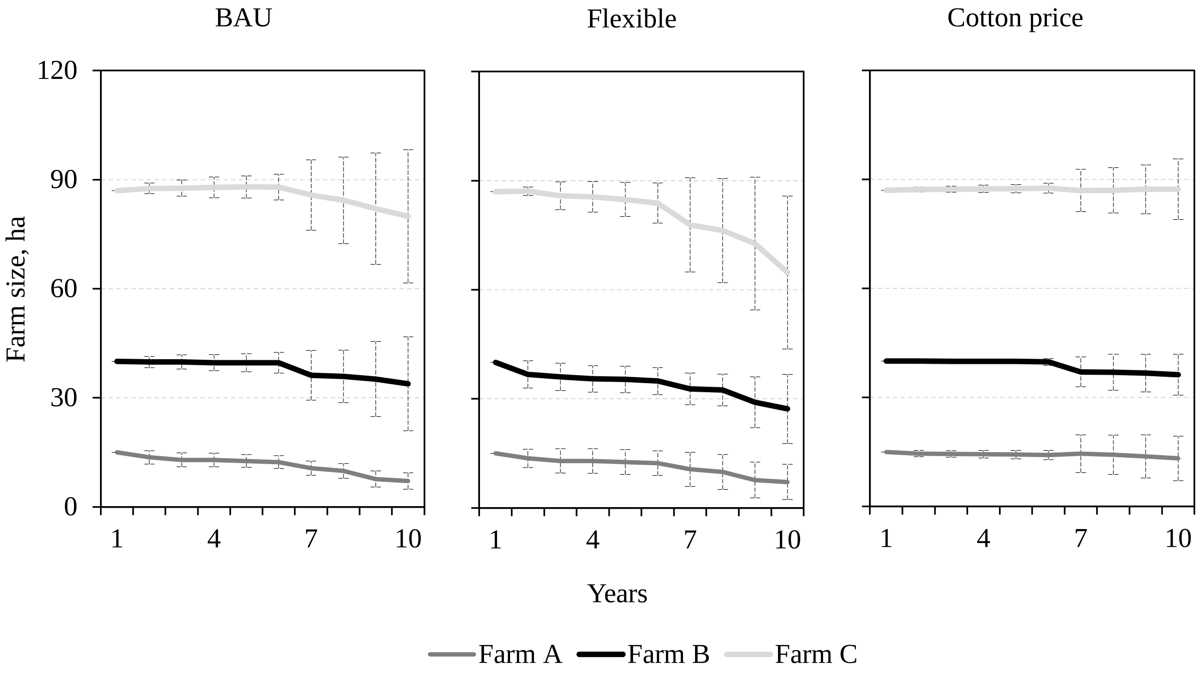

Fig. 2. Average and standard deviations of sizes of farms A, B and C in the business-as-usual (BAU), Flexible and Cotton price scenarios.

Note: bars represent standard deviations; in the Tenure and Liberalized scenarios no change in farm size takes place.

3.2 Cotton production and land use

The change in farm sizes is conditional on fulfillment of cotton procurement target. The farm area reduction is caused by farms producing less cotton than the state target level, i.e., lower output than the half of the total farm area multiplied by 2.4 t ha^{-1} of cotton yield. While a farm that is endowed with better productive lands and lower yield variability can have a better cotton output performance (Fig. 3), yet under continuation of current settings, i.e., BAU scenario, still might not be able to fulfill the cotton target level. The Flexibility scenario, results that farmers allocate on average insufficient area and other resources to fulfill the cotton output target. In the Tenure and Liberalized scenarios, we find that farmers still produce cotton, but result in lower overall cotton production levels than in the BAU scenario. In addition, such policies result in high variability of cotton production, due to high opportunity cost and absence of the quantity-based target for cotton as well as omitting the land transfer option to farms that have advantages in cotton production, i.e., more resource endowments and lower agricultural production variability. In the Cotton price scenario, improvement in cotton prices leads that farmers increase cotton production on half of their land allocated for this crop. Consequently, in many states of nature of this scenario, farmers can meet their cotton production targets. This results in fewer cases of farm size changes than in the BAU case.

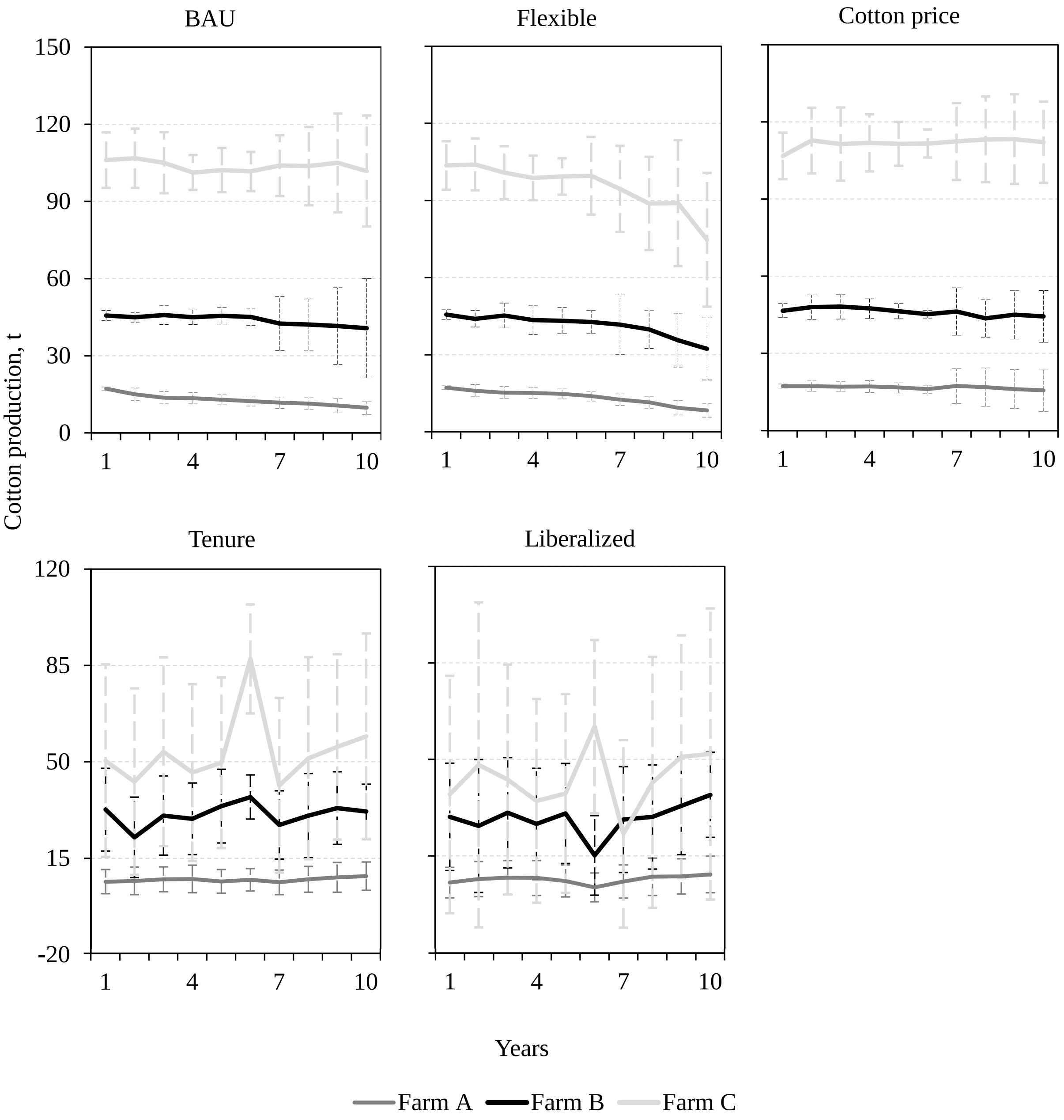

Fig. 3. Average and standard deviations of cotton production at farms A, B and C in the business-as-usual (BAU), Flexible, Cotton price, Tenure and Liberalized scenarios.
Note: bars represent standard deviations.

Production pattern of other crops at farms do not differ substantially in the BAU, Cotton price and Tenure scenarios (Fig. 4). In the initial years of these scenarios, cotton and vegetables are the main crops preferred by farmers. Eventually, farmers increase the cultivation area of wheat and maize at the expense of reduced area of vegetables. Due to the presence of the cotton procurement policy the land uses are highly concentrated (Table 3). Improving the land tenure and removing the cotton quantity-based target, i.e., Tenure scenario, results in the less diversified land use pattern than in other scenarios. In this scenario, farmers allocate half of their land for cotton, while having low cotton gross margins and not being able to reduce the area of low productive lands. The most diversified land use pattern is observed in the Liberalized scenario. Also, with such policy, farmers maintain their land use pattern over time as there is absence of land consolidation and farmers have the full flexibility in land use decision-making and can sell the cotton output at higher prices than in the BAU settings. Larger farm size is found to have a more diversified land use pattern than smaller farm.

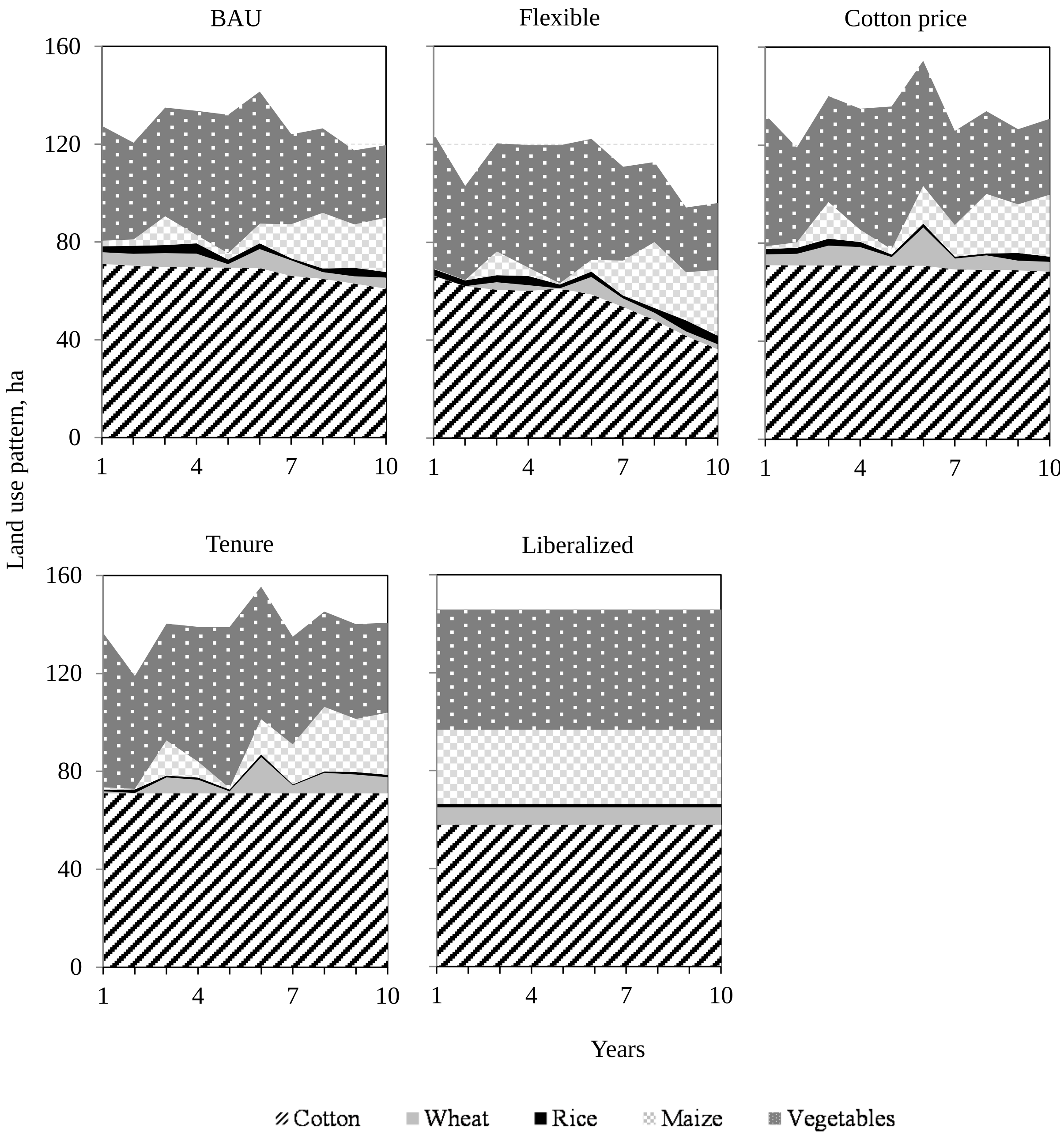

Fig. 4. Combined land use pattern of farms A, B and C in the business-as-usual (BAU), Flexible, Cotton price, Tenure and Liberalized scenarios.

Table 3. Averaged over 10 years the Herfindahl index on land use diversity for farms A, B and C in the business-as-usual (BAU), Flexible, Cotton price, Tenure and Liberalized scenarios.

Farm type	Scenarios				
	BAU	Flexible	Cotton price	Land tenure	Liberalized
Farm A	0.385	0.401	0.413	0.424	0.332
Farm B	0.405	0.399	0.407	0.411	0.370
Farm C	0.409	0.404	0.401	0.401	0.308

3.3 Farm incomes

Farm size changes also affect farmers' profits (Table 4). Profits are found to be the lowest in the BAU scenario, especially caused by cotton area-based target and land consolidation process. If the cotton policy is modified and allows farmers to have the full flexibility in land use allocation, i.e., Flexibility scenario, farm profits are slightly higher than in the BAU scenario, despite substantial farmland expropriation. Largest profits are generated in the Liberalized scenario (profit increases by almost twofold in comparison to the BAU case), which allows farmers to gain substantial profits from cotton price increase, secured land tenure and land use flexibility. Especially, the substantial increase in profits occurs for Farm C, which is better resource endowed farm. At the same time, we find the highest farm profit fluctuations occur in the Liberalized scenario, while it is lowest in the BAU scenario.

The highest profit difference across farms is observed under the BAU scenario (Tab. 4). In contrast, in the Liberalized scenario, this difference is lowest and substantially smaller than in the BAU scenario.

Table 4. Mean and standard deviation (SD) of net present values over 10 years of farms A, B and C in the business-as-usual (BAU), Flexible, Cotton price, Tenure and Liberalized scenarios under the 14% discount rate, in 1000 USD per farm.

Scenarios	Farm A		Farm B		Farm C	
	Mean	SD	Mean	SD	Mean	SD
BAU	69	20	268	45	653	103
Flexible	69	20	267	45	663	106
Cotton price	95	23	336	55	820	113
Tenure	87	20	284	45	678	127
Liberalized	140	27	440	82	1059	198

4. Discussion

The transition from planning to market economies in post-Soviet countries changes agricultural structure. In Uzbekistan, some of the features of Soviet economy have remained. The most important ones are the cotton procurement policy and the state ownership of farmland. After the break-up of the Soviet Union, cotton production is still a large sector generating export revenues (Zettelmeyer, 1999). Agrarian policies, institutions and infrastructure are designed to fulfill the state cotton procurement policy by farmers and the entire cotton production has to be sold only to the state. Dismantling of large-scale *kolkhozes* and *sovkhozes* during the farm restructuring process resulted in smaller farm units that receive production targets, procedures and spatial boundaries with the aim to increase cotton production (Müller, 2006). Although, it is considered important to distribute the land among rural people to alleviate the poverty (Lerman, 2005), the state policies recently started to support farm land consolidation for optimizing agricultural production and mainly cotton output. Implementation of land consolidation in post-Soviet countries includes issues such as weak property rights (Ledeneva, 2005), existence of networks in the government and poor markets (Van Assche et al., 2010). In the settings of Uzbekistan, farmers cannot freely adjust their farm sizes to improve production efficiency due to ban on land markets (Djanibekov et al., 2012). The state owns the land and farmers have the usufruct rights for land, which leads that the state may expropriate the land from farmers during the land consolidation process for the purpose of having more efficient agricultural production, especially to fulfil cotton production target. The possible reasoning of land consolidation process is that infrastructure and institutions are inherited from the Soviet Union and designed for *kolkhozes* and *sovkhozes* and thus considered to be suitable for large-scale farms to mainly produce cotton.

The performance of farm production can be influenced by agricultural risks and uncertainties (Hardaker et al., 2004). In our analysis, we consider production, market and institutional risks and illustrate how the land consolidation process occurs under such risks and influence risk-averse farmers. Our results show that the low performance events are due to the high variability of cotton yields, which leads to land transfer from one farmer to another. The yield variability causes that in average terms, farmers cannot meet the state cotton production target and their land area is reduced in the BAU scenario. Hence, none of the considered farm types might be efficient in meeting the state cotton procurement and other policy measures need to be developed that consider the risk aversion of farmers. In addition, such farm size change is due to the low state cotton procurement prices that bring to farmers losses or low benefits from cotton cultivation. The price for which farmers sell cotton can be even lower, because farmers have to sell the entire cotton output to the state and the state is a monopsonist. In addition, the land consolidation process is found to increase income inequalities across farmers. Similar to our study, Djanibekov et al. (2012) argues that the farmland consolidation in Uzbekistan can trigger unfavorable side-effects and reduce rural livelihoods.

At the same time, the state cotton procurement policy may reduce the efficiency of farm operations. Several studies showed that the cotton procurement policy may not be beneficial for farmers. For example, Guadagni et al. (2005) identified that the low state cotton purchase price creates disincentives for farmers to grow cotton. In support of that argument, Pomfret (2000) concluded that the cotton procurement policy prevents the output growth and land use diversification. Several studies also proposed options to improve cotton production. For instance, abolishing the cotton procurement policy and liberalization of marketing cotton may increase cotton output and farm incomes (e.g., Guadagni et al., 2005; Chertovitsky et al., 2007). Rudenko et al. (2009) showed that the liberalized marketing channels for raw cotton can motivate farmers to grow cotton and improve their revenues. Similarly, our study shows that farmers increase cotton production when cotton price increases due to possibility to generate higher cotton gross margins. In turn, increase in cotton prices under the land consolidation and cotton procurement state policies might improve the cotton production levels. In contrast, when the cotton price does not improve and farmers have the land use flexibility, then farmers most likely fail to deliver the required level of cotton output as they do not have sufficient economic incentives for cotton production and cannot manage risks. Hence, the government of Uzbekistan needs to be cautious when implementing the land consolidation process for farmers with the cotton procurement policy as none of the farmers might be able to meet the cotton production targets under conditions of agricultural risks. In such case, the land of cotton-grain farms might need to be distributed to other farm types or new cotton-grain farms need to be formed.

We find that providing land tenure security for farmers is another possibility to produce cotton, even though with lower cotton production levels than in the BAU scenario, improve incomes and reduce the income disparity among farmers. Furthermore, in absence of land expropriation, tenure security might encourage farmers to make long-term planning and investments that over time can bring high profits, improve agricultural production and sustain ecology (Abdulai and Goetz, 2014). In contrast, insecure land tenancy rights often lead to intensified land management practices to obtain profits in short-term that reduce the land productivity and state of other natural resources (Goldstein and Udry, 2008). Trevisiani (2009) concluded that unstable and unpredictable land tenure arrangements, discouraged farmers in Khorezm to make agricultural investments. Secure land possession option can also motivate farmers to obtain loans and finance agricultural activities (Feder and Feeny, 1991). Hence, prior to long-term investments and introduction of sustainable land use practices the land tenure rights of farmers should be secure.

Furthermore, the dependency on one crop increases the profit risks for farmers (Hardaker et al., 2004). We show that consideration of agricultural variability may lead that none of the modelled farms are able to produce the state target amount of cotton and hence experience the reduction in area and incomes. Diversification of the agricultural production can be a desirable option that provides more stable income by including land uses that have non-perfect (i.e., smaller than +1) correlation in terms of revenue fluctuations (Chavas and Di Falco, 2012).

It should be noted that in addition to aleatory uncertainty the model outputs can be affected by epistemic uncertainty as a result of fuzziness and gaps in model parameters and of complexity in model structure and methodological choices (Zehetmeier et al., 2014; Troost and Berger, 2015). Thus, to better represent agricultural uncertainty in transitional country settings, both aleatory and epistemic uncertainties need to be modelled. Moreover, our study considers three farms that might represent the group of farms in the region but not the entire population of farms. Hence, due to insufficient data, our model misses to capture fully the interactions of farms in the region that can be performed using the agent-based model (Schreinemachers and Berger, 2006). As in most scenarios of our study, government expropriates land from all simulated farmers (in average terms), by using the agent-based model it might be possible to address the land distribution among all farms and identify farmers that have farm size increase from the land consolidation process. Also, by using the agent-based model it is possible to capture various interactions of farmers (Villamor et al., 2014) that also could include risk-sharing arrangements to better manage agricultural risks (Otsuka et al., 1992). Considering interactions of different agents, impacts of policies targeted towards farmers can affect not only these farmers but also have indirect effects on other groups of population, e.g., through the rural interdependencies such as contractual arrangements between farmers and rural households (Roumasset, 1995). Changes implied in cotton production, especially increase in the procurement price of cotton, may also have impacts beyond the agricultural sector, since such reforms may reduce government revenues (Müller, 2006). Accordingly, in future research, it is important to increase the number of analyzed farms to the number of farms in the entire study area and to consider the spillover effects on other groups of population and economy from land consolidation process and cotton procurement policy change under both aleatory and epistemic uncertainties.

5. Conclusions

The farm land consolidation process in Uzbekistan aims to improve agricultural production and specifically cotton output. We illustrate how the farm land consolidation policy for enhancing the production of cotton –under the consideration of different sources of agricultural risks contributes to high farm size change and re-allocation of land resources that in turn reduce farm incomes. This is as a result of low cotton purchase price, transfer of low productive lands and insufficient resources to manage larger farms. We find that the modification of cotton procurement policy by giving flexibility in land use decision-making for farmers under agricultural variability can result in farm size reduction and is ineffective option to achieve the cotton procurement target. Offering higher cotton procurement price is found to motivate farmers to increase cotton production levels, and implies fewer farm size changes and higher profits. However, state-level profits might be reduced, because substantial amount of the produced cotton is exported and Uzbek government might not be able to influence the international cotton prices to maintain or earn higher profits. Secured land tenure and liberalized policy scenarios are found to result in lower cotton production levels, but allow farmers to generate higher incomes that can potentially generate also revenues for the state. In addition, among the modelled scenarios, Liberalized scenario leads to the highest land use diversification and the lowest income inequality among farmers. Accordingly, there is no single policy measure that can simultaneously address cotton production, farm incomes, farm size changes, agricultural risks and land use diversification, and hence different policy measures need to be implemented jointly to improve these aspects.

Appendix A

Table A.1. Average and standard deviation (SD) of simulated over 10 years the net present value of crops under 14% discount rate on different soil productivity levels, in USD.

Crops	Soil productivity							
	Low		Average		Good		High	
	Mean	SD	Mean	SD	Mean	SD	Mean	SD
Farm A								
Cotton	-494	249	616	383	1651	508	2557	617
Cotton with modified prices	3937	869	7418	1334	10668	1768	13508	2148
Wheat	656	864	2269	1296	3868	1725	5401	2135
Rice	4639	4621	4639	4621	4639	4621	4639	4621
Maize	2672	1484	5167	2231	7607	2961	9807	3619
Vegetables	8328	2834	12304	3724	17827	4960	23806	6298
Farm B								
Cotton	-319	195	884	300	2006	397	2988	483
Cotton with modified prices	4485	736	8259	1130	11782	1498	14862	1820
Wheat	736	874	2389	1311	4028	1745	5599	2160
Rice	4057	4035	4057	4035	4057	4035	4057	4035
Maize	2880	1533	5479	2304	8020	3059	10312	3739
Vegetables	7933	2533	11785	3328	17135	4433	22929	5629
Farm C								

Cotton	-261	136	972	210	2124	278	3131	337
Cotton with modified prices	4666	598	8537	918	12151	1217	15311	1478
Wheat	771	860	2442	1290	4098	1716	5686	2125
Rice	4412	3977	4412	3977	4412	3977	4412	3977
Maize	2684	1444	5186	2170	7631	2881	9836	3521
Vegetables	8129	2524	12043	3317	17479	4418	23365	5610

Appendix B

Table B.1. Model parameters.

Parameters	
Period of analysis, years	10
Time interval	Annual
Discount rate, %	14
Average of simulated irrigation water availability, m^3 ha^{-1}	11395
Coefficient of variation of simulated irrigation water availability	0.29

Table B.2. Crop specific model parameters.

	Cotton	Wheat	Rice	Maize	Vegetables
Land occupation by crops	March-November	October-June	July-September	July-September	April-September
Average value of maximum attainable crop yields on different land productivity types, t ha^{-1}					
Poor	1.6	2.4	4.1	3.2	5.7

Average	2.5	3.6	4.1	4.8	7.5
Good	3.3	4.8	4.1	6.4	10.0
High	4.0	5.9	4.1	7.8	12.7
Ratio of crop by-product to crop main product	1	1.1	1.1	1.5	n.a.
Crop main product prices					
Initial price, USD t^{-1}	227	166	682	227	260
Drift	n.a.	0.081	0.075	0.106	0.003
Volatility	n.a.	0.40	0.40	0.35	0.20
Crop by-product prices, USD t^{-1}	36	33	33	30	n.a.
Input use for crops					
Diesel, m^{3}	0.25	0.21	1.30	0.20	0.18
Fertilizer, t	0.34	0.30	0.36	0.33	0.18
Labor, hours	755	525	635	405	1309
Input costs for crops, USD ha^{-122}					
Diesel	122	105	650	100	90
Fertilizer	152	135	166	150	80
Labor	152	105	127	81	401
Other costs	66	147	274	107	355

Irrigation use for crops to achieve maximum yield, m^3 ha^{-1}	5612	5497	28216	5311	8572

Note: n.a. = not applicable.

Appendix C

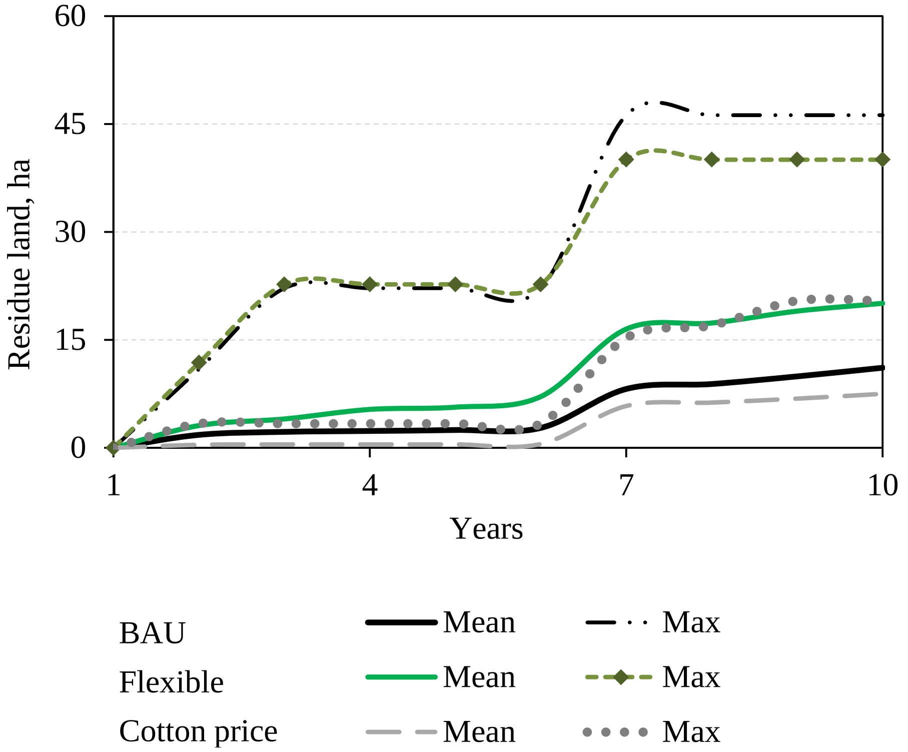

Fig. C.1. Land area that is expropriated from the modelled farms, when none of them meet the cotton procurement target in the business-as-usual (BAU), Flexible and Cotton price scenarios. Note: Residue land is the land expropriated from modelled farms when none of them is able to meet the cotton procurement target; Minimum residue land area is 0 ha; in the Tenure and Liberalized scenarios no change in farm size takes place.

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Supplementary material

Agricultural risks and farm land consolidation process in transition countries: The case of cotton production in Uzbekistan

Utkur Djanibekov, Robert Finger

Contents:

Tables S.1-S.4

Fig. S.1

Table S.1. Land use pattern of three types of cotton-grain farms based on surveys and BAU scenario.

Farms	Crops	Observed (%)	BAU (%)
Farm A	Cotton	47	52
	Wheat	30	8
	Rice	8	7
	Maize	7	6
	Vegetables	7	26
Farm B	Cotton	49	52
	Wheat	30	7
	Rice	6	5
	Maize	7	6
	Vegetables	7	30
Farm C	Cotton	48	51
	Wheat	31	8
	Rice	8	6
	Maize	6	5
	Vegetables	6	30

Table S.2. Average land transfer from farms A, B and C in the business-as-usual (BAU), Flexible and Cotton price scenarios, in ha.

Farm type	Soil productivity level	Years								
		2	3	4	5	6	7	8	9	10
BAU scenario										
Farm A	Low	1.62	1.03	0.19	0.33	0.23	0.24	0.23	0.16	0.11
	Average	0.31	0.08	0.09	0.09	0.15	0.45	0.40	0.62	0.49
	Good	0	0	0	0	0	0.02	0.02	0.05	0.13
	High	0	0	0	0	0	0	0	0	0
Farm B	Low	0.43	0.05	0.20	0.11	0.10	2.46	0.22	0.41	0.38
	Average	0	0.01	0	0	0	1.65	0.18	1.00	1.55
	Good	0	0	0	0	0	0.01	0	0.02	0.06
	High	0	0	0	0	0	0.01	0	0	0
Farm C	Low	0	0.01	0	0.08	0.14	2.19	015	0.52	0.72
	Average	0	0.03	0.04	0	0.03	1.32	1.56	2.31	2.09
	Good	0	0	0	0	0	0	0	0	0
	High	0	0	0	0	0	0	0	0	0.02
Flexible scenario										
Farm A	Low	1.14	0.79	0	0.23	0.29	1.02	0.29	0.73	0.16
	Average	0.32	0	0.03	0.03	0.02	0.81	0.43	1.40	0.26
	Good	0	0	0	0	0	0	0.01	0.12	0.10
	High	0	0	0	0	0	0	0	0	0
Farm B	Low	3.40	0.64	0.54	0.14	0.39	1.65	0.28	0.47	0.07
	Average	0	0.01	0.02	0	0.07	0.58	0.06	2.90	1.96

	Good	0	0	0	0	0	0	0	0	0.08
	High	0	0	0	0	0	0	0	0	0
Farm C	Low	0.08	1.31	0.24	0.76	0.78	3.54	0.60	0.24	0.62
	Average	0	0.05	0.04	0	0.24	3.14	1.06	4.08	7.31
	Good	0	0	0	0	0	0.05	0	0.05	0
	High	0	0	0	0	0	0	0	0	0
Cotton price scenario										
Farm A	Low	0.46	0.09	0.09	0.07	0.09	0.75	0.33	0.43	0.42
	Average	0	0	0.01	0	0	0.07	0.01	0.19	0.13
	Good	0	0	0	0	0	0	0	0	0.01
	High	0	0	0	0	0	0	0	0	0
Farm B	Low	0.05	0.02	0.05	0	0.16	3.09	0.36	0.23	0.47
	Average	0	0	0	0	0	0.05	0.04	0.04	0.12
	Good	0	0	0	0	0	0	0	0	0
	High	0	0	0	0	0	0	0	0	0
Farm C	Low	0	0	0	0	0	1.79	0.19	0.10	0.26
	Average	0	0	0	0	0	0.47	0	0	0.33
	Good	0	0	0	0	0	0	0	0	0
	High	0	0	0	0	0	0.02	0	0	0

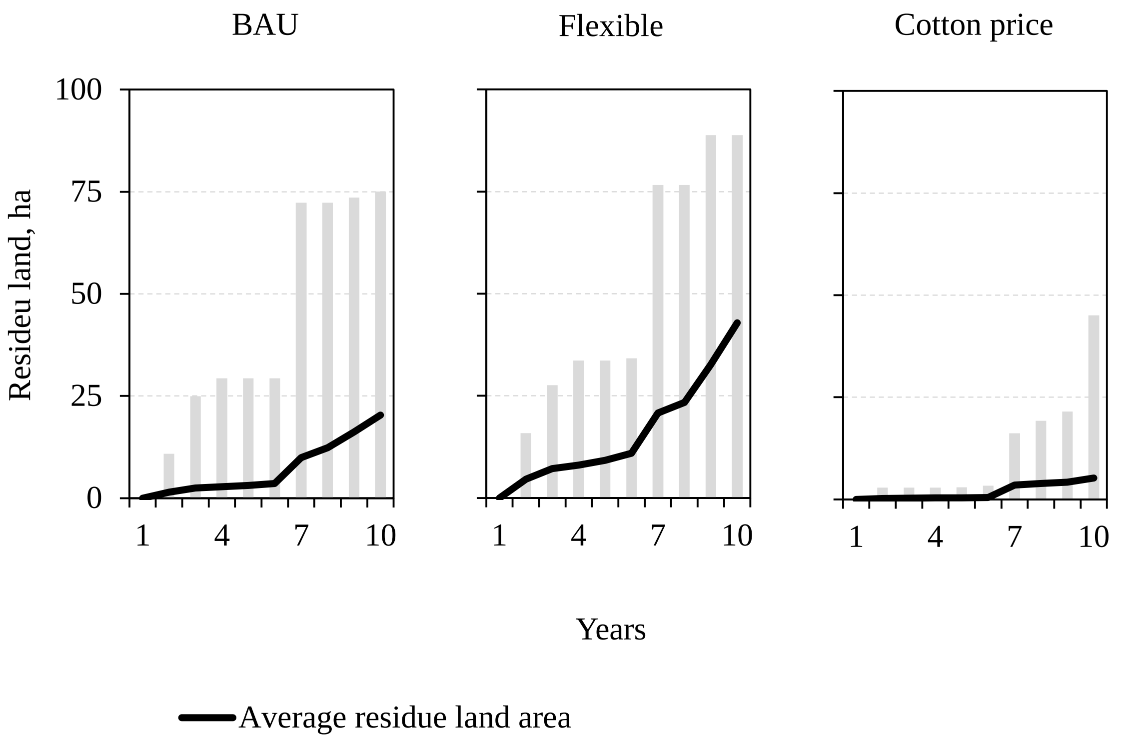

Fig. S.1. Land area that is expropriated from modelled farms when none of them meets the cotton procurement target in the business-as-usual (BAU), Flexible and Cotton price scenarios. Note: Residue land is the land expropriated from modelled farms when none of them is able to meet the cotton procurement target; Shaded bars show the range of land area expropriated from farms; Minimum residue land area is 0 ha; in the Tenure and Liberal scenarios no change in farm size takes place.

Table S.3. Average cumulative over 10 years the transaction costs of farms A, B and C from receiving additional land in the business-as-usual (BAU), Flexible and Cotton price scenarios, in USD.

Farm types	Scenarios		
	BAU	Flexible	Cotton price
Farm A	0	291	545
Farm B	1259	501	343
Farm C	2381	892	1521

Table S.4. Averaged over 10 years shadow prices of irrigation water of farms A, B and C in the business-as-usual (BAU), Flexible, Cotton price, Tenure and Liberalized scenarios, in USD m^{-3}.

	Scenarios				
	BAU	Flexible	Cotton price	Tenure	Liberalized
Farm A	0.002	0	0.007	0.010	0.001
Farm B	0.094	0	0.103	0.048	0.071
Farm C	0.121	0	0.146	0.106	0.073