Optimal Decision Making, Adaptation to Climate Change in the Agricultural Sector.

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Abstract
The aim of this paper is to develop a framework applying Bayesian updating of beliefs for modelling the decision of adaptive behaviour of farmers to climate change. Subjective beliefs of the likelihood of each possible climate scenario are taken as a starting point, and then we show how these beliefs can be updated based on observed changes. These observed changes are simulated climate developments. The framework allows modelling of the complexity of climate changes. The main focus of this paper is on the development of the framework and aims to show the advantage of proactive, rather than reactive adaptation to climate change. The inspiration for using the Bayesian theorem as updating of beliefs comes from the work of Yousefpour et al. (2013). The Bayesian framework developed applies a hypothetical decision making approach toward the choice between three agricultural systems (dryland crop, irrigated crop and livestock) under a trajectory of three climate scenarios.

In this study we specifically analyse the difference between updating based on temperature and precipitation fluctuations. Implicitly, the variance for temperature is 0.2161 and variance for precipitation is 0.0662.

In conclusion, the framework works as intended, that even when the decision-maker has beliefs contrary to the direction of the realised climate development, the Bayesian updating of beliefs allows an adjustment of such beliefs, guiding the choice of agricultural system in the direction of the preferred agricultural system under the influence of climate changes.

Introduction
There is scientific consensus that our climate is changing (Christensen et al. 2013; Christensen et al. 2007; IPCC 2007), and that climate change presents very serious global risks and demands an urgent global response (Stern 2006). Research confirms that it is the poorest and most vulnerable developing countries and population groups that will be hit the hardest by the climate change (IPCC 2007). It is equally recognised that a comprehensive response to climate change requires both mitigation and adaptation actions (Matocha et al. 2012; Ayers and Huq 2009; Adger et al. 2007; Klein et al. 2007).

One characteristic of the changing climate is that it is associated with a high degree of uncertainty. This uncertainty is not easily identified by past observations, providing time series or the like on which the best response to such an uncertainty might be analysed. Rather, it is a development which we will learn about as time passes. This is true not only with respect to the actual changes, but also with respect to the nature of the changes and the characteristics of the uncertainty, etc. Traditional approaches toward characterising the uncertainty based on past experience - as taken e.g. from the real option literature - are therefore not suitable. Instead, we apply a Bayesian updating of beliefs to the climate change. Basically, the idea is that a decision-maker holds a set of initial beliefs in various climate scenarios. In this paper the decision-maker equals a farmer's decision. As time passes, the farmer will observe how the climate develops, and that presents an opportunity to adapt his choices, in this paper his or her choice of agricultural system, in relation to the observed climate development. This makes it possible to simulate behaviour in a forward looking fashion.

The aim of this paper is to develop a framework applying a Bayesian updating of beliefs. Subjective beliefs of the likelihood are taken as a starting point, and then we proceed to show how these beliefs can be updated based on observed changes. The observed changes are here simulated climate developments. The framework allows modelling of the complexity of climate changes. The paper aims to show the advantage of a proactive rather than a reactive adaptation to climate change. Research has shown that proactive adaptation activities can provide significant welfare gains and resilience to climate change at household level (Boko et al. 2006).

The case analysed is a case of West African farmers facing changes in their agricultural production. While there may be an adjustment from season to season for some crops, some changes require changes in the agricultural production system as such, which may not be easily reversible. This may lead to a changed pressure on common land for grassing and on water for irrigation. Therefore, we address the question of *when* to switch the effort from one production system to another. We base it on a single farmer's decision. In this paper only Ghana is included, representing West Africa.

Risk and uncertainty are crucial aspects of both mitigation and adaptation. There is considerable uncertainty associated with climate change, the magnitude of the impact of climate change and the resilience or vulnerability of human and natural systems to climate change. The fundamental distinction between risk and uncertainty is that risk refers to cases where the probability of outcomes can be ascertained through well-established theories with reliable and complete data, while uncertainty refers to situations where the appropriate data might be fragmentary or unavailable (Halsnæs et al. 2007). Predicted climate change scenarios by e.g. IPPC (2007) do not have a probability attached to them and due to the nature of the change, no empirical historical data can be used to estimate the uncertainty. Yet methodologically we may still use the methods of handling risk to analyse decision making in connection with climate change – if adjustments are made. This is the reason we refer to beliefs and not probabilities.

Earlier Work

Over the years a significant body of research has been established within the field of adaptation and mitigation in the agricultural sector (Adger et al. 2007; Klein et al. 2007; Locatelli et al. 2011; Reyer et al. 2009; Smith et al. 2007). In this paper we address how to proactively adapt to future climate change and variability in the agricultural sector, given the uncertainty of climate change. The Bayesian updating of beliefs makes it possible to simulate how a management decision can change when new and more accurate information becomes available as time passes and climate change develops. The inspiration for using the Bayesian theorem as updating of beliefs comes from the work of Yousefpour et al. (2013). Yousefpour et al. (2013) use the Bayesian updating of beliefs in relation to management of forest resources under climate change. The Bayesian updating of beliefs makes it possible to simulate how the true climate trajectory is revealed over time, even though initially it is unknown to the decision-maker.

With inspiration found in Yousefpour et al. (2013) we will in this paper develop a framework for handling the complex decision regarding *when* farmers should make a switch to another agricultural system - dryland crop, irrigated crop or livestock - when faced with climate change. The developed Bayesian framework applies a hypothetical decision making problem regarding the choice between three agricultural systems under a trajectory of three climate scenarios.

Yousefpour et al. (2013) discuss how belief updating can be done based on observation of climate change as well as on forest characteristics ('forest' is the case they work on), but they do not specify on which basis their model updates the beliefs – climate change is simply described by a variable which could be either temperature, precipitation or another natural hazard that could influence the growth and revenue of an agricultural system. In this study we analyse updating based on climate variables, more specifically the difference between updating based on temperature and on precipitation. Implicitly, the variance for temperature is 0.2161 and the variance for precipitation 0.0662. Whereas we keep the variance for the Bayesian framework constant by 0.3.

Benhin (2006) shows that the crop net revenues concentrated in South Africa will likely fall as much as 90% by year 2100. The study also shows that small-scale farmers will be the most severely affected by the impact of climate change. Even though the study is done on South Africa, it is likely to have relevance to the rest of Africa as well. Boko et al. (2007) also confirm that in Africa, especially agriculture-dependent households are vulnerable to climate change. Research shows that it is a possibility that adaptation will reduce these negative effects (Benhin 2006), and that proactive adaptation could result in welfare gains and resilience to climate changes on household level (Boko et al. 2006).

It is therefore important that farmers adapt by choosing an agricultural system that can give them high net revenues considering the uncertainty of climate change. This may be a balance between flexibility (e.g. how easy it is to change crops), vulnerability, and return. Crops have different optimal conditions for their highest return. Changes from one agricultural system to another may imply establishment cost and a time lag before the crop gives a return. Furthermore, some crops may vary more with climate change than others. The balance between these aspects is the focus of the current paper.

An earlier study on crop selection (Boko et al. 2007) shows that farmers in Africa select crops there are adapted to the current climate in their regions, and that farmers tend to shift toward more heat-tolerant crops as the weather becomes warmer. Increase or decrease in precipitation makes farmers shift toward more water-loving or drought-tolerant species (Boko et al. 2007).The research from Boko et al. (2007) emphasises that a proactive strategy enhances the adaptation to climate change, which proves the importance of a framework that can simulate the optimal choice of agricultural system and can change over time as more information of the climate trajectory is revealed.

Method and Data

To identify the relevant updating, we structure the following steps in the Bayesian framework: i) definition of climate scenarios, where precipitation and temperature are following a separate latter in the Bayesian framework, and ii) definition of net revenues per farm for each of the agricultural methods under the three climate scenarios, concluding with the Bayesian analysis of the decision making problem and an estimation of how the three different farming methods will do under the three climate scenarios. This is done by simulating the climate development in 10,000 random draws from a distribution of years ranging from 2015 to 2099, with the intervals of year; 2015, 2030, 2050, 2075 and 2099. In this paper we follow the same method as Yousefpour et al. (2013).

Updating of Beliefs Using Bayesian Analysis

We now set up a framework for how the decision-maker holds a set of beliefs regarding the likelihood of each possible climate scenario. This also shows how the decision-maker may change his beliefs using Bayesian updating given and depending on any new observations (Yousefpour et al. 2013). W_{it} is the decision-maker's belief that a particular climate scenario (*i)* will occur in the year *t*, such that beliefs are complete (see function (1)):

$$\sum_{i=1}^{W} W_{it} = 1\,, W_{it} \geq 0 \text{ for all } i, t. \qquad (1)$$

W_{it} is the decision-maker's belief that at time *t* a climate scenario *i* is the true representative of the climate state {W_{it}= $Pr(model_{i,}t$} given all available information (Yousefpour et al. 2013). If a decision-maker fully believes in a scenario, W_{it}=1, and if he does not believe in a scenario at all, the belief is W_{it}=0.

New knowledge about the climate will appear as time goes. This may be obtained through monitoring, observations, or other new insight. Let x_t^0 be an estimate of the climate state for each period. Then the belief in this, W_{it}, is what is being updated.

This information is used to update our beliefs in each of the alternative models, using Bayes' theorem (Bayes and Price 1763). Thus the belief in a given climate model is the probability that *model$_i$* is true, given the observation x_t^0:

$$w_{i,t+1}(x_t^o) = \Pr\left(\mathrm{model}_i \middle| x_t^o\right) = \frac{\Pr\left(x_t^o \middle| \mathrm{model}_i\right)\Pr(\mathrm{model}_i, t)}{\sum_{i=1}^{I}\Pr\left(x_t^o \middle| \mathrm{model}_i\right)\Pr(\mathrm{model}_i, t)} \quad (2)$$

For simplicity reasons we assume $\Pr(x_t^0|\mathrm{model}_i)$ to be normally distributed $N(x_{it},\sigma)$ (See function (2)). We simulate a climate development based on 10,000 random draws from this distribution of years from 2015 to 2099 and update the belief for each draw given an initial set of beliefs.

For this paper, we have carried out the Monte Carlo simulation in the MATLAB2012b environment.

Climate Scenarios

We used three climate scenarios to test the approach. In this paper we have used the A1B scenario from the 4th Assessment Report of the Intergovernmental Panel on Climate Change (IPCC) 2007 (Christensen et al. 2007). The A1B scenario is the regional average of temperature and precipitation projections from a set of 21 global models (Christensen et al. 2007). In Christensen et al. (2007), Africa is divided into 5 regions: the Mediterranean, the Sahara, West Africa (WAF), East Africa (EAF) and South Africa (SAF). In our Bayesian framework we have simplified the complex and multidimensional path of climate change by using a trajectory of three climate scenarios.

Climate scenario 1 (C1) represents the baseline scenario where it is assumed that nothing will change from today and until year 2099.

Climate scenario 2 (C2) is the 50% fractile of the A1B scenario (Christensen et al. 2007) of the different regions of Africa represented in the Bayesian framework. The A1B scenario predicts that the warming effect of the climate change scenario will most likely be more pronounced for the African continent than the global annual mean warming. This is applicable throughout the African continent and in all seasons (Christensen et al. 2007). Therefore, we have found it relevant to consider the last climate scenario as a worst case scenario.

Climate scenario 3 (C3) is the worst case scenario of the A1B scenario (Christensen et al. 2007). Regarding the development of the temperature in the C3 scenario the maximum temperature response is estimated based on the A1B scenario in the year 2099 for the given region. Regarding the development of precipitation in the C3 scenario, the minimum precipitation response is estimated based on the A1B scenario in the year 2099 for the given region.

In the A1B scenario (Christensen et al. 2007) the temperature response is shown as estimated percentage changes in degrees Celsius in the year 2099, while precipitation response is the estimated percentage changes in precipitation in the year 2099.

To simulate climate scenarios C2 and C3 we have made a linear regression from today's temperature to the 2099 temperature. In this way we calculated the changes in temperature for the different decision points in time: 2015, 2030, 2050, 2075 and 2099. To simulate the changes in precipitation in West Africa, changes in millimetre precipitation have been calculated based on data from Ghana (Kurukulasuriya et al. 2006). Regarding precipitation we are also using linear regression to calculate the changes in precipitation for each of the decision points in time. Figure 1 and Figure 2 illustrate the development of temperature and precipitation in West Africa for the three climate scenarios over time (year 2015 to 2099).

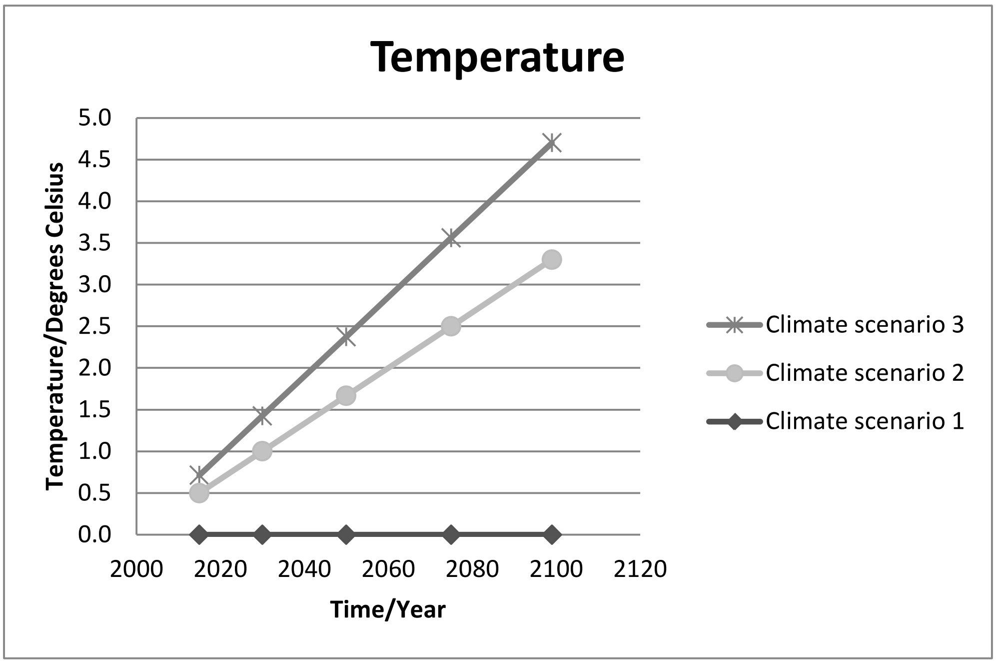

Figure 1: The development of temperature in West Africa in the three climate scenarios over time.

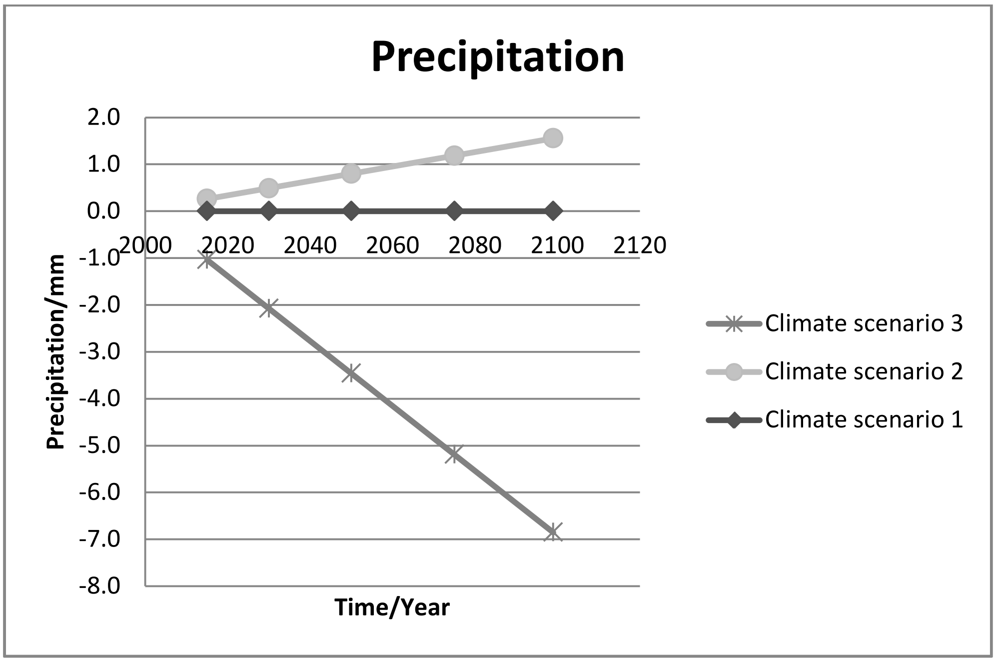

Figure 2: The development of precipitation in Ghana based on the present change in West Africa in the three climate scenarios over time.

Agricultural Systems

The decision-maker's objective in this paper is an economic interest, i.e. to maximise the net revenue of the agricultural activities. The decision-maker's objective could follow any economic, social, ecological goal or a mixture of these. The decision alternative is evaluated by the decision-maker to achieve these objectives (Yousefpour et al. 2013). We take a point of origin in Kurukulasuriya et al. (2006) to identify the African farmers' net revenues from their income sources. Kurukulasuriya et al. (2006) base their results on more than 9000 surveys from 11 countries. We have chosen to only look at Ghana as representing West Africa.

The main advantage of the data from Kurukulasuriya et al. (2006) is that the net revenues from their analysis reflect the benefit and costs of autonomous adaptation strategies. This includes a variety of contributions and the introduction of substitute actions which farmers have incorporated to adapt to the current climate viabilities (Kurukulasuriya et al. 2006). However, the labour cost of the household has not been included, because the shadow price of wages that farmers apply to their own time cannot easily be measured (Kurukulasuriya et al. 2006). Kurukulasuriya et al. (2006) use a cross sectional approach to estimate to which degree the net revenue at farm level is affected by climate change compared with the current mean temperature. The result is presented as median net revenue per farm from dryland crop, irrigated crop and livestock. This leads to a function for the marginal climate impacts on net revenue per farm, where temperature and precipitation from the three climate scenarios are used as variables. These three agricultural systems have been chosen as the variety of agricultural systems that the decision-maker can choose between. It is based on research by Kurukulasuriya et al. (2006), showing that farmers across Africa use a combination of dryland crop, irrigated crop and livestock.

The revenue itself does not fully reflect the cost associated with switching between the agricultural systems, so we have made some adjustments. Furthermore, because in this paper we are mainly interested in the development of the framework, we have made some adjustment to ensure that the agricultural systems become relevant from a decision making point of view. The adjustments are -150, -600 and +350 for the net revenue of dryland, irrigation and livestock, respectively. This reflects that the estimated irrigation revenue is too high compared to what is likely in terms of available water, and that some establishment cost must be expected. Figure 3 illustrates the three climate scenarios and the graphs for the original functions for the net revenues (U.S. dollars) per farm for dryland crop, irrigated crop and livestock over time (year 2015 to 2099) as well as the adjusted functions for the three agricultural systems. Figure 3 shows how the adjustments have brought the functions for dryland crop and livestock closer together, and irrigated crop has been moved further down in scale. However, the function for irrigated crop has a very steep upward slope under C2 and C3 where dryland crop and livestock over time will develop negative net revenues under C2 and C3.

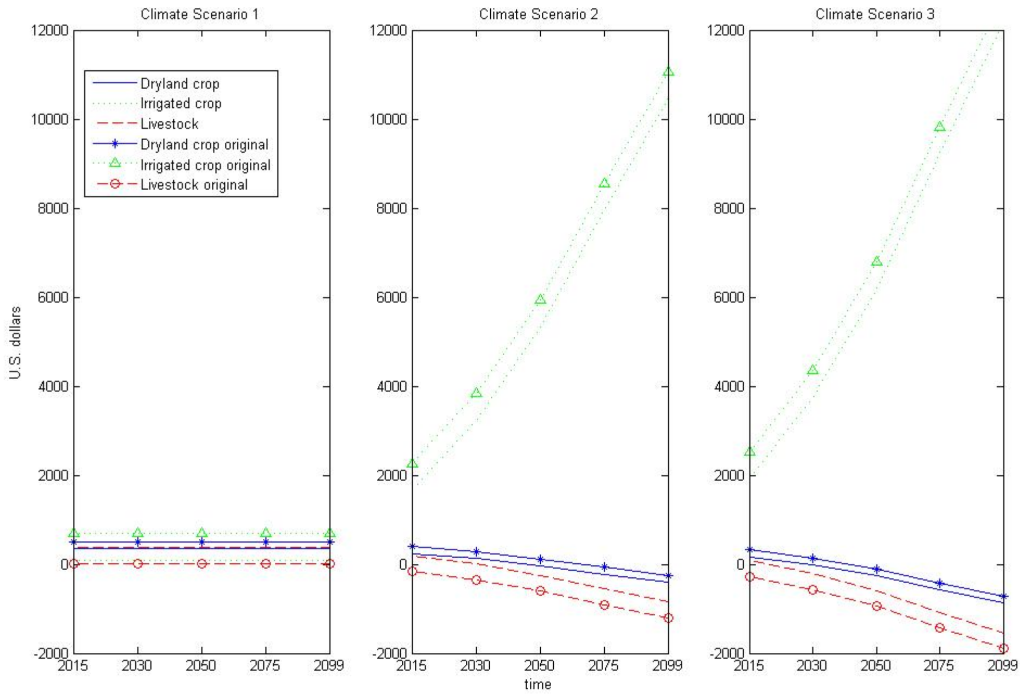

Figure 3: The three figures show the three climate scenarios, with each figure showing the development of dryland crop, irrigated crop and livestock in net revenue per farm (U.S. dollars). The figures also show the original values for the three agricultural systems before adjustments.

Results

This section presents the results of the Bayesian updating framework.

Table 1 shows the preferred choice of agricultural system based on the highest net revenue (in U.S. dollars), in order for the decision-maker to make the best possible decision considering the realised temperature development in the three climate scenarios over time (year 2015 to 2099). Table 1 shows that livestock is the preferred agricultural system after year 2030, when C1 is the realised climate development. If the decision-maker is very sure that C1 is going to be realised, he will choose livestock already from the beginning, i.e. from year 2015. Otherwise, he will choose irrigated crop in the beginning which performs much better under C2 and C3. However, he will soon realise that scenarios C2 and C3 are unlikely to occur since the realised climate development is scenario C1. Therefore, the decision-maker will be making the change from irrigated crop to livestock between year 2015 and 2030, when the realised climate development is equal to C1.

Table 1: Choice of agricultural systems (1 = dryland crop, 2 = irrigated crop and 3 = livestock), based on highest net revenue (U.S. dollars), in order for the decision-maker to make the best possible decision considering the realised temperature development in the three climate scenarios over time (year 2015-2099).

		Decision Makers Belief			Time				
		C1	**C2**	**C3**	**2015**	**2030**	**2050**	**2075**	**2099**
Realised Climate Development	**C1**	0.8	0.1	0.1	3 (385)	3 (372)	3 (370)	3 (370)	3 (370)
	C1	0.1	0.8	0.1	2 (1106)	3 (488)	3 (370)	3 (370)	3 (370)
	C1	0.1	0.1	0.8	2 (895)	3 (391)	3 (370)	3 (370)	3 (370)
	C2	0.8	0.1	0.1	2 (922)	2 (3176)	2 (5396)	2 (7961)	2 (10472)
	C2	0.1	0.8	0.1	2 (1613)	2 (3259)	2 (5348)	2 (7957)	2 (10472)
	C2	0.1	0.1	0.8	2 (1740)	2 (3530)	2 (5533)	2 (7973)	2 (10472)
	C3	0.8	0.1	0.1	2 (1339)	2 (3608)	2 (6123)	2 (9222)	2 (12149)
	C3	0.1	0.8	0.1	2 (1678)	2 (3413)	2 (5984)	2 (9207)	2 (12149)
	C3	0.1	0.1	0.8	2 (1856)	2 (3716)	2 (6169)	2 (9225)	2 (12149)
	C1	0.33	0.33	0.34	2 (617)	3 (391)	3 (370)	3 (370)	3 (370)
	C2	0.33	0.33	0.34	2 (1478)	2 (3331)	2 (5396)	2 (7961)	2 (10472)
	C3	0.33	0.33	0.34	2 (1696)	2 (3613)	2 (6123)	2 (9221)	2 (12149)

When C2 and C3 are the realised climate developments, irrigation is economically so dominant that irrigation will be chosen irrespectively of the decision-maker's initial beliefs. The reason is that the decision-maker chooses the agricultural system based on the highest expected net return, so if the return is high this system will be chosen.

Table 2 Choice of agricultural systems (1 = dryland crop, 2 = irrigated crop and 3 = livestock), based on highest net revenue (U.S. dollars), in order for the decision-maker to make the best possible decision considering the realised precipitation development in the three climate scenarios over time (year 2015-2099).

Realised Climate Development	Decision Makers Belief C1	C2	C3	Time 2015	2030	2050	2075	2099
C1	0.8	0.1	0.1	3 (355)	2.9994 (361)	3 (369)	3 (370)	3 (370)
C1	0.1	0.8	0.1	2 (1422)	2 (1929)	2.6141 (417)	3 (370)	3 (370)
C1	0.1	0.1	0.8	2 (752)	2.0373 (593)	2.9992 (366)	3 (370)	3 (370)
C2	0.8	0.1	0.1	2.5699 (356)	2 (1398)	2 (5083)	2 (7956)	2 (10472)
C2	0.1	0.8	0.1	2 (1542)	2 (3166)	2 (5332)	2 (7956)	2 (10472)
C2	0.1	0.1	0.8	2 (1025)	2 (2745)	2 (5302)	2 (7956)	2 (10472)
C3	0.8	0.1	0.1	2 (1870)	2 (3745)	2 (6181)	2 (9226)	2 (12149)
C3	0.1	0.8	0.1	2 (1911)	2 (3745)	2 (6181)	2 (9226)	2 (12149)
C3	0.1	0.1	0.8	2 (1917)	2 (3745)	2 (6181)	2 (9226)	2 (12149)
C1	0.33	0.33	0.34	2 (734)	2 (588)	3 (366)	3 (370)	3 (370)
C2	0.33	0.33	0.34	2 (1026)	2 (2741)	2 (5302)	2 (7956)	2 (10472)
C3	0.33	0.33	0.34	2 (1911)	2 (3745)	2 (6181)	2 (9226)	2 (12149)

When the updates are based on observed precipitation we get the results shown in Table 2. Again, it shows that livestock is the preferred agricultural system when C1 is realised, but this is acknowledged later than when the decision was based on observations of temperature. Consequently, unless the decision-maker strongly believes in C1 from the beginning, he will not change his management to livestock until year 2050. The reason is that the correlation coefficient for precipitation is larger. Livestock is the preferred agricultural system in the year 2015, when C2 is the realised climate development and C1 is the decision-maker's belief, but as precipitation observations are being made, the decision changes to irrigated crop. For all other initial beliefs irrigated crop is being implemented immediately. When the decision-makers is indifferent of his belief, and C1 is the realised climate development, livestock is also chosen from year 2050. Otherwise, irrigated crop is the preferred agricultural system.

The overall picture of Table 1 and Table 2 shows that the Bayesian framework is sensitive to the realised climate development of temperature as well as precipitation; however, there seems to be more variation when the realised climate development is based on precipitation rather than temperature. There is a strong tendency that irrigated crops will be the preferred agricultural system under the influence of climate changes. This is not surprising, given its high return (see figure 3).

Table 3 Choice of agricultural systems (1 = dryland crop and 3 = livestock), based on highest net revenue (U.S. dollars), in order for the decision-maker to make the best possible decision considering the realised temperature development oin the three climate scenarios over time (year 2015-2099).

		Decision Makers Belief			Time				
		C1	C2	C3	2015	2030	2050	2075	2099
Realised Climate Development	C1	0.8	0.1	0.1	3 (356)	3 (369)	3 (370)	3 (370)	3 (370)
	C1	0.1	0.8	0.1	1 (282)	3 (350)	3 (370)	3 (370)	3 (370)
	C1	0.1	0.1	0.8	1 (284)	3 (364)	3 (370)	3 (370)	3 (370)
	C2	0.8	0.1	0.1	1 (284)	1 (102)	1 (-46)	1 (-224)	1 (-408)
	C2	0.1	0.8	0.1	1 (241)	1 (118)	1 (-32)	1 (-223)	1 (-408)
	C2	0.1	0.1	0.8	1 (195)	1 (36)	1 (-83)	1 (-227)	1 (-408)
	C3	0.8	0.1	0.1	1 (242)	1 (23)	1 (-246)	1 (-571)	1 (-869)
	C3	0.1	0.8	0.1	1 (233)	1 (77)	1 (-208)	1 (-567)	1 (-869)
	C3	0.1	0.1	0.8	1 (182)	1 (-7)	1 (-260)	1 (-572)	1 (-869)
	C1	0.33	0.33	0.34	1 (319)	3 (365)	3 (370)	3 (370)	3 (370)
	C2	0.33	0.33	0.34	1 (235)	1 (90)	1 (-46)	1 (-224)	1 (-408)
	C3	0.33	0.33	0.34	1 (212)	1 (22)	1 (-247)	1 (-571)	1 (-869)

That irrigated crop is so dominating may be unrealistic for many farmers, as it implies a more intensive management and is not necessarily available to the majority. Therefore, we also analysed the decision making process where the choice of agricultural systems in the three climate scenarios is made solely between dryland crop and livestock.

Comparing table 3 with Table 1 it is clear that when irrigated crop is excluded, dryland crop takes over the vacant place of the irrigated crop, while livestock maintains its position from Table 1 to Table 3. Further, the net revenue of the agriculture system will be negative after year 2050, if C2 and C3 are the realised climate developments.

Comparing Table 2 and Table 4 where the realised climate development is based on precipitation, we see again that dryland crop has taken over the vacant place of irrigated crop, and that the realised climate scenarios C2 and C3 have a negative influence on the net revenue for the selected agriculture system, for C2 as the realised climate development after year 2050 and for the C3 scenario already after year 2030.

Table 4 Choice of agricultural systems (1 = dryland crop and 3 = livestock), based on highest net revenue (U.S. dollars), in order for the decision-maker to make the best possible decision considering the realised precipitation development in the three climate scenarios over time (year 2015-2099).

		Decision Makers Belief			Time				
		C1	C2	C3	2015	2030	2050	2075	2099
Realised Climate Development	C1	0.8	0.1	0.1	3 (355)	3 (361)	3 (369)	3 (370)	3 (370)
	C1	0.1	0.8	0.1	1 (259)	1 (222)	3 (342)	3 (370)	3 (370)
	C1	0.1	0.1	0.8	1 (308)	1 (320)	3 (366)	3 (370)	3 (370)
	C2	0.8	0.1	0.1	1.916 (341)	1 (261)	1 -(11)	1 -(223)	1 -(408)
	C2	0.1	0.8	0.1	1 (251)	1 (131)	1 -(29)	1 -(223)	1 -(408)
	C2	0.1	0.1	0.8	1 (288)	1 (162)	1 -(27)	1 -(223)	1 -(408)
	C3	0.8	0.1	0.1	1 (176)	1 -(15)	1 -(263)	1 -(572)	1 -(869)
	C3	0.1	0.8	0.1	1 (172)	1 -(15)	1 -(263)	1 -(572)	1 -(869)
	C3	0.1	0.1	0.8	1 (171)	1 -(15)	1 -(263)	1 -(572)	1 -(869)
	C1	0.33	0.33	0.34	1 (309)	1 (320)	3 (366)	3 (370)	3 (370)
	C2	0.33	0.33	0.34	1 (288)	1 (162)	1 -(27)	1 -(223)	1 -(408)
	C3	0.33	0.33	0.34	1 (172)	1 -(15)	1 -(263)	1 -(572)	1 -(869)

Table 4 can also be useful in the discussion of the potential of updating beliefs, compared to not doing it. When irrigated crop is not an option as described above, both dryland crop and livestock will give negative values during later periods under the influence of climate scenarios C2 and C3.

Discussion

This study contributes to the discussion on how the Bayesian approach can contribute to the development of adaptation to climate changes, and how the decision-maker can handle the uncertainty of climate change. Therefore, the discussion will focus on the Bayesian framework developed in this paper, its relevance and the options for improvement. The exact results regarding *which* agricultural system to choose *when* will only be briefly touched upon, as the data has not been evaluated sufficiently, cf. the above section regarding 'Agricultural Systems'.

The main finding of this paper is that independently of whether temperature or precipitation is the basis for the realised climate development, irrigated crop is the preferred choice of agricultural system, due to the very steep and rising curve for the net revenues (U.S. dollars per farm/ year) in scenarios C2 and C3 (see figure 3). The choice of irrigated crop may, however, be too optimistic as the implementation of irrigated crop will require a high investment for the farmer (naturally depending on the way the irrigation is carried out). This is the main reason why the functions for net revenues per farm over time have been adjusted. Another relevant main finding in the results is that when the choice of the decision-maker was solely made between dryland crop and livestock, dryland crop becomes the preferred agricultural system. In this context it should be mentioned that dryland crop is cultivated on the farmer's privately owned land, whereas it is the tradition to use common or public land for livestock grazing (Kurukulasuriya et al. 2006). Consequently, there is no linear relationship between a farmer's income from livestock and the amount of land he owns or has the right to cultivate. The choice between livestock and dryland crop is thus more a matter of *where* to make the effort in terms of required investment (e.g. seeds, animals) and labour. Also, livestock covers a huge range of animals, and it should be considered that small livestock like goats is more heat tolerant then cattle. This is incorporated to some extent in the net revenues for livestock, as the data from Kurukulasuriya et al. (2006) includes a variety of contributions, and the introduction of substitute actions which farmers have incorporated to adapt to the current climate viabilities (Kurukulasuriya et al. 2006). The discussion of *where* to make the effort also leads to a discussion of cost of labour, as the cost of the household labour is not included in the functions for the net revenues of the agricultural systems. The results from Kurukulasuriya et al. (2006) indicate that growing a crop is more management intensive then keeping livestock. Kurukulasuriya et al. (2006) base this assumption on the fact that a household with many people earns higher revenue from crops, and lower from livestock.

Further, it might be relevant to discuss that some farmers will do a combination of the three suggested agricultural systems. Kurukulasuriya et al. (2006) also mentioned this in their description of data, assuming that the farmer chooses inputs and outputs that optimise the net revenue of these three main agricultural systems. We have therefore evaluated that it is relevant to compare them within this framework, when it comes to being proactive and adaptive to climate changes.

We assume that the decision-maker bases his beliefs on either temperature or precipitation. A decision-maker could be more willing to update his beliefs, if changes occur in precipitation rather than in temperature because the former have a bigger influence on growth. The decision-maker could update his beliefs on precipitation, even though it would be wrong, as there can be huge fluctuations in precipitation. This indicates that a solid foundation of knowledge is needed before the decision-maker updates his beliefs, in order for him to determine a realistic updating of beliefs. This also implies that it could be interesting to take a more stochastic approach to the development of the precipitation over time and see how this will influence the preferable agriculture system, compared to the purely linear approach currently used in this framework.

The Bayesian framework is a first step in developing an approach to updating of beliefs regarding climate change, making proactive adaptation possible. Most importantly, we see the need to move from the current level of advancement at farm level to working in a village or country setting, when there is a scarcity of resources, e.g. water, as it will not be possible for all farmers to irrigate their crop under the influence of climate changes, even though the results of the Bayesian framework suggest that it is preferable to choose this agricultural system. Therefore, the next step will be to develop a model merging individual decision making with available resources. Linear or non-linear optimisation will be considered as the method for the next step of this paper.

Another expansion possibility is that we model the Bayesian framework as a function of both temperature and precipitation, as a combined variable, where the current update is done either on temperature or precipitation. A third possibility would be to model the changes in return only as a function of only either temperature or precipitation. The influence of fluctuations in precipitation on the net revenue could be different from the influence of temperature fluctuations, but this could be handled in a two-dimensional Bayesian updating taking both precipitation and temperature into account as realised climate developments.

Conclusion

This paper aims at developing a framework using Bayesian updating of beliefs as a contribution to proactive adaptation to climate change in the agricultural sector. The framework works as intended, that even when the decision-maker has beliefs contrary to the direction of the realised climate development, the Bayesian updating of beliefs allows an adjustment of such beliefs, guiding the choice of agricultural system in the direction of the preferred agricultural system under the influence of climate changes.

In a wider perspective, it would be of huge interest to see how a Bayesian framework could contribute to revealing and identifying the interrelationship between adaptation and mitigation and - if possible - how it could contribute to optimisation of the resilience to climate change.

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