Effectiveness of Weather Derivatives as Cross-Hedging Instrument against Climate Change: The Cases of Reservoir Water Allocation Management in Guanajuato, Mexico

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1. Introduction

In many Latin-American countries, on-going climate change has already caused important struggles in agricultural production triggering crop losses and affecting the functioning of markets. Furthermore, in these countries, water allocation is a big issue and water supply could be affected by changes in temperature and shifts in precipitation patterns. Still, there is no certainty in how climate change could alter precipitation.

No doubt agriculture and primarily the irrigation sector, the main destiny of fresh water, will be affected. Although markets and pricing for water can improve a more efficient water use, their implementation is unfeasible because of the institutional, social and political connotations of a price system for water. In contrast, water is typically managed as a natural monopoly because of network externalities and under-priced by regulatory authorities rather by market equilibrium.

Mitigation and adaptation have been identified as main strategies in dealing with climatic change. However, while in developed countries mitigation and adaptation are parallel strategies; for developing countries, the dominant strategy is adaptation. Thus, the adaptation strategy to climate change in the agriculture sector that this research proposes relies on the potential improvements of water management in irrigation districts with two cycles –wet and dry seasons – by instrumenting weather derivatives as an insurance mechanism. Weather derivatives are able to incentive the adoption of new allocation patterns that consider more generous allocations for dry seasons while provide reduced allocations for wet seasons, where the farmer is able to cope with the risk of shortages in water by using weather derivatives.

In these circumstances, insurance scheme may compensate distortions in the intertemporal allocation of water by the regulation authority. At the same time, insurance supports the adoption of changes in allocation policy as adaptation strategy to face climate change, and not only as a smoothing mechanism for farmers' income. In addition, weather derivatives are able to incorporate additional information to reflect climate change that historic data does not reflect and strengthening the ability of management entities (irrigation districts) to deal with water availability and demand. Weather derivatives, could not only smooth farmer's income, but also might induce an intertemporal reallocation of water in irrigation districts attaining a higher efficiency of their use in the long term. For demonstrating such affirmation, the proposed instrument is applied for the Alto Rio Lerma Irrigation District (ARLID), located in the state of Guanajuato, Central Mexico, where the effectiveness of such instrument, in the terms previously described, is verified.

The irrigation district has experimented increasing variability in precipitation patterns and extreme weather events attributable to climate change. Analysis is circumscribed in to the regulatory framework based on water rights and a regulatory authority. However, ARLID is able to effectively cope with the risk of rain shortage because one of its two seasons (Spring-Summer) is partially rain fed, which allows introducing the weather derivatives to support the application of a more efficient allocate policy.

The analysis is conducted in three stages. The first stage, the baseline scenario characterizes the authorities' optimal water allocation strategy among farm-users using an intertemporal optimal equilibrium and historical data on production, profits and precipitation. The second stage incorporates into the baseline the IPCC climate change scenarios (on precipitation) to get the optimal water allocation strategies.[1] Finally, the third stage introduces the weather derivative into the optimal water allocation model to compensate Spring-Summer producers for a shortfall in precipitation realization measured over a certain time period. Once more, optimal water allocation strategy is calculated under different climate change scenarios and the weather derivative instrument. Weather derivatives contracts are structured as an option on a rainfall index.

2. Literature Review

The assessment report of the Intergovernmental Panel of Climatic Change (IPCC) forecasts an increase of local temperature between 1°C to 2°C by 2100 especially in lower-latitudes, seasonally-dry and tropical regions (IPCC, 2007). It is projected that by mid-century, crop yields and productivity could decrease across many regions and localities.

Such as Brown and Carriquiry (2007) mention, in irrigation districts, higher variability in precipitation and temperature patterns could exponentially increase the competition for water

[1] The model at this stage includes Global Climate Models' (GCM) predictions to reflect into the model climate change risks.

between users given the high and diversified demand and the inflexible design of infrastructure systems, increasing the challenges for water authorities and managers.[2]

Since early 2000's there are numerous documented cases that prove the benefits of weather insurance in transferring weather risk into global markets (Turvey, 2001, Mahul, 2001, Vedenov and Barnett, 2004, World-Bank, 2005, Osgood, et. al, 2007). Weather derivatives can quickly provide financial resources and technical support to people at natural disaster risk because loss assessment is not required. They can be a potential risk transfer mechanism with an inclusive strategy to manage the uncertainty associated with climate change in agricultural production for developing countries: Mexico (2001), Ethiopia (2007), Kenya (2007), Mali (2007), (Agrawala and Fankhauser, 2008).

In basins, where irrigation districts are typically located, drought is a phenomenon that builds slowly over time based on shortages of runoffs from daily rainfall. There, weather derivatives can map the costs associated to the provision of water during contingency situations from the hydrological space to the financial space through option contracts on a rainfall index. In addition, these instruments could incentive farmers more easily to switch between comprehensive strategies for adaptation. Thus, the combination of insurance, forecasting and adaptive operations strategies might improve the efficiency of reservoir operation (Block, et. al., 2007). More details on weather derivatives are in Appendix F.

The main advantage of weather derivatives over other insurance schemes is that they could effectively reduce future uncertainty through the incorporation of a better understanding of the climate system behavior for the coming decades. Then, in presence of climate change the main challenge is to overcome the problem of the increasing costs from higher expected losses and higher payouts. Agrawala and Frankhouser (2008) showed that these issues might create market imperfections such as insurance overpricing or insurance companies' reticence to cover these risks that require the government intervention to subsidize insurance premium and to improve access to insurance. More details on design and pricing of weather derivatives considering climate change are in Section 5.

Some useful findings in applied research of this topic are summarized. Zeuli and Skees (2005) designed a rainfall index contract for correcting the inefficiencies produced by the water

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[2] Irrigation districts are local farmer organizations that plan and decide on the allocation of water resources for agriculture; manage and maintain the irrigation infrastructure systems. In Mexico, irrigation districts contribute about 50% of the total value of agricultural production and accounts for about 70% of agricultural exports.

management systems in drought situation. According to these authors, this instrument might reduce uncertainty in supply and demand, associated with the extremely conservative authority's estimations of available water creating inefficiencies in the allocation. In this paper, it is proved the efficiency of index insurance to create incentives for the authority to estimate more accurately the availability of water supply and demand and farmers trade water rights because insurance replaces their need to self-insurance. However, Zeuli and Skees research does not show a clear insight of the effect of this instrument into the water demand, saying anything about their contribution to water management policy.

Leyva and Skees (2005) designed an index based on river flows to address the risk associated with water management for irrigation in the Rio Mayo Valle district in Northwest, Mexico. Also, these authors model the intertemporal operation of the reservoir through water released rules and planting response functions and the effectiveness of this instrument is evaluated. However, such as Block (2008) mentions, although the use of river inflows as rainfall indices are a direct measure of the available water in single-reservoir systems, it could be a poor option for hydrological systems with multiple reservoir systems and important diversion of upstream flows, which is the dominant case in Mexico and other Latin America countries, where irrigation districts are located within hydrological basins.

Brown and Chaquirry (2007) proposed an index insurance based in reservoir inflows for mitigating water supply cost incurred through an option contract purchase of water in drought years.[3] They considered that inflows have advantages over the storage levels, because inflows to reservoir represent integration over space and time of the rainfall in a basin, while the reservoir storage levels can be manipulated by the water authority.

Although the studies previously mentioned contain relevant findings for this research, their significance as an adaptation strategy to climate change could be limited. They do not incorporate in the analysis the dynamic of the variability in climate variables and in consequence, they do not offer a policy respond. Instead, this study incorporates new dimensions and challenges to the problem initially formulated by Leyva and Skees (2005). This research proposes the use of weather derivatives as a helpful tool for the implementation of strategies that lead to higher efficiency in the management of the resources in the irrigation districts, which in the long term could represent an effective adaptation strategy. In addition, the operational

[3] These authors centered their study in the Angat reservoir in Manila, Philippines.

configuration of the analyzed irrigation district entails a more complex problem because the model includes (in the case of Mexico) a wet season or temporal, which implies an extra source of uncertainty.[4]

3. Alto Rio Lerma Irrigation District (ARLID)

By 2050, the Mexican Institute of Water Technology expects a decline between 7-12% in precipitation in the Southern basins, 3% in the Mexican Golf basin, and 11% in the central basins, while diminished river flows could contribute into higher evapotranspiration. (Martinez, 2008). In the early 1970s the average return period of extreme events was 12 years, by the early 2000s it was about 5 years (Groisman, et al., 2005). The recurrence of heavy precipitations during the wet season has increased followed by more severe droughts in the dry season (Aguilar, 2005). In addition, it is expected that demographic growth (12.3 million of people for 2030) will settle in Central Mexico creating additional pressure on the hydrological regions of Lerma-Santiago-Pacifico and Valle de Mexico (CONAGUA, 2010).

This situation could imply in the near future an adjustment in water allocation for irrigation districts affecting agricultural production, where 70% of the fresh water is allocated, disturbing the irrigation districts operation (CONAGUA, 2010).[5]

ARLID is the third irrigation district in the country, located in the South of the state of Guanajuato in Central Mexico. Its average precipitation is 630 mm per year with rain season mainly between May and July, and an average temperature between 18 and 20°C. With favorable soils, the ARLID produce competitively a broad variety of crops including cereal, grains, perennials and vegetables for exportation. [6]

The ARLID obtains its water from the Lerma-Chapala Basin System, which is composed by 17 drainage basins with a multiple reservoir system along four states (Estado de Mexico, Guanajuato, Jalisco and Michoacán) and a significant upstream diversion where Lerma River is the main collector of the system. Although important runoffs (in average 1,000 millions of cubic meters, Mm^3) are annually generated upstream reservoir Solis, the reservoir Solis is the main

[4] Skees and Leyva (2005) includes two productive cycles completely dependent on irrigation water, while this research in the case of Mexico includes two seasons: Fall-Winter season totally dependent of irrigation and Spring-Summer depending mainly on rain with a minimum requirement for irrigation.

[5] CONAGUA stands for Comision Nacional del Agua, the government authority in water management.

[6] In the period 2008-09, ARLID produced 1.6 million tons of agricultural products (CONAGUA, 2010).

body water where the ARLID's water supply is concentrated. Downstream Solis dam, the Lerma River watercourse is modified to the adaptation of the ARLID's irrigation needs.

By law, the whole operation of the ARLID is based in a water-rights concession system which awards to water users clear property rights over water, and provide to users associations roles, functions and responsibilities.[7] CONAGUA, which is the water regulatory authority who determines fees based on the volume that each module is buying and receives part of those fees as a recuperation payment (Kloezen and Garcés-Restrepo, 1997).

For the sake of the operation and management, ARLID is organized in 11 modules and each module is entitled to a proportional share of the water available for the irrigation district (see Figure 1).[8] Every module is in charge to carry out the final allocation of water and to collect fees from its users. Since 1996 the ARLID's limited liability company (LLC) was awarded with the irrigation infrastructure concession. So LLC operates, manages, conserves and maintain the irrigation network that includes primary canals, secondary canals, drainage and coordinates and monitors modules. Also, LLC schedules deliveries of water resources to the modules and checks weekly the ditch tender reports at each module.

Figure 1 Alto Rio Lerma Irrigation District, ARLID

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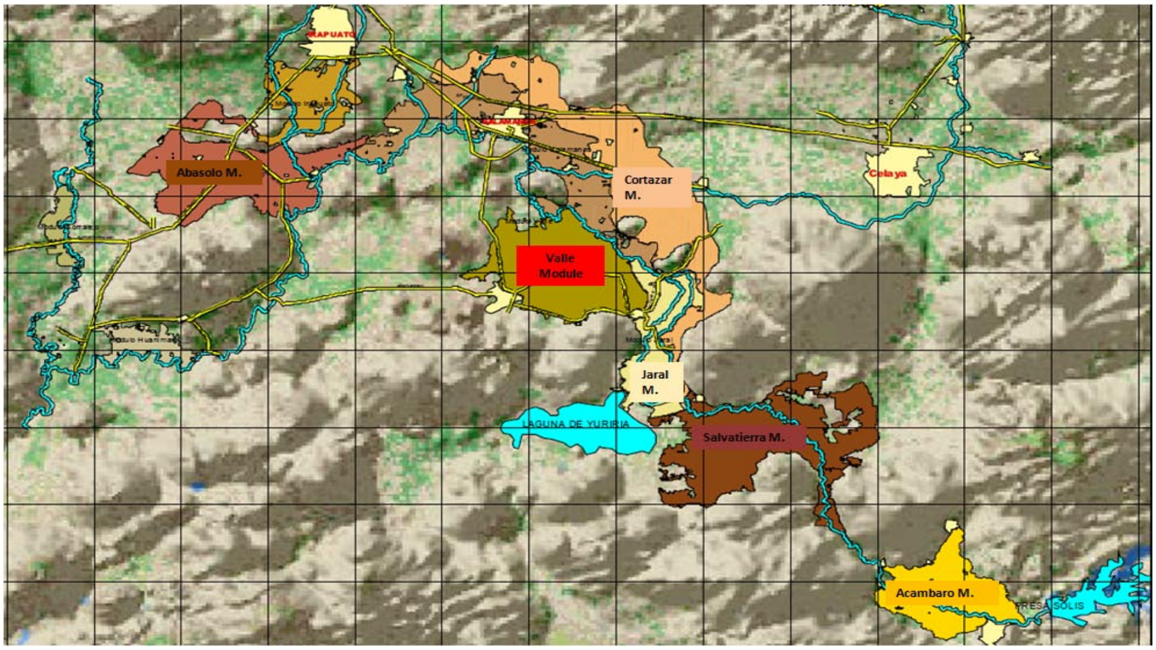
[7] Water-rights system requires the concessionaire pays for the volume of extracted water, the payment is theoretically set in relation to their shortness in every region of the country and with different rates for every use. Industry and services pay more than urban users, while for agriculture and farm related activities is free. Thus, the fees that water users pay are related to the cost operation fee for the irrigation district infrastructure and for the use of the main infrastructure (dams, channels, etc.) that CONAGUA operates.

[8] These eleven modules are: Acambaro, Salvatierra, Jaral del Progreso, Valle de Santiago, Cortazar, Salamanca, La Purisima, Irapuato, Abasolo, Corralejo, Huanimaro, and Pastor Ortiz module was added in 2004.



Source: CONAGUA, 2011

The ARLID's irrigation cycle starts in early November, when the hydrological cycle of the basin begins and CONAGUA, according to official rules of distribution, carries out the hydrological balance and allocates the water volumes for every one of the nine irrigation districts in the basin. CONAGUA quantifies the total supply of water based on the "restitution runoffs" methodology for every basin; see Appendix E for more details.[9]

The water volume that every module receives is the result of negotiations on irrigation plans between the CONAGUA, the LLC and every module. Within modules, water is allocated between users according their water rights and the schedule of irrigations since early November (Kloezen, et al., 1997).

ARLID produces in two different cycles. Fall-Winter (FW) is the dry season, completely dependent on irrigation. Spring-Summer (SS) is the wet season which depends mainly on rainfall for satisfy the crop's water requirements. Due to the increasing water shortness and the low average efficiency in transmission (65%), the ARLID provides irrigation water only for 70% of the registered physical surface, where the property rights on the water are concentrated. Since the beginning, the priority is the dry season (FW) crop, entirely grown by irrigation.

[9] Runoffs restitution is the institutional indicator provided by CONAGUA for the allocation of the volumes of water. This measure was not used to estimate the index because it is not a transparent; its methodology is complex, unverifiable, unobservable and unable to be reported in a timely manner.

In contrast, although average rainfall is enough to grow the SS crop, because of the higher rainfall variability, usually one “initial irrigation” is scheduled to guarantee that the crop seed attain germination. Hence, this “initial irrigation” that can be considered as a purely hedge against the risk of low precipitation, could have deep repercussions in water allocation efficiency. This “initial irrigation” by definition creates inefficiency in allocations, even getting worst when irrigation districts face extreme weather conditions from climate change.

Thus, it could be the case that authorities are allocating water to an “initial irrigation” in the SS crop to ensure its germination even when there is not enough rain to make that happen. Hence, the cost of this hedging strategy is less water for the dry season crop (FW) and, therefore, lowers barley profits.

This research effort relies on the premise that the spreading of the risks attained by a weather-based insurance can support the adoption of changes in water allocation strategies, improving the efficiency in the operations of irrigation districts. Thus, weather derivatives based in a rainfall index essentially could substitute the SS “initial irrigation” thereby spurring higher FW profits. Furthermore, weather derivatives are privately profitable because actuarially fair premiums are low relative to the opportunity cost of the “initial irrigation”.[10]

This study will focus on the module Valle de Santiago (Valle). The module was selected because of four reasons —productive efficiency, proximity to weather stations, cultivation of similar products in the same productive cycles (useful for calibration), and well organized ownership structure, extremely useful for the functioning of insurance schemes –.

Valle is the third largest module in terms of irrigated area and also the most efficient module (with a rate of 92%). Valle is located in the center of ARLID, mainly irrigated by gravity. The main products of Valle are barley for the FW cycle and sorghum and corn for the SS or second round of crops. Sorghum grain represents 38% of Valle production and barley grain represents 35%.

Based in historical data, baseline model will get the optimal water allocation path between both cycles. For hedging water supply risk, the contract’s weather index is measured in the area of the isohyets with the highest rain intensity for the reservoir Solis (167 mm/hour),

[10]This is a consequence of that rain shortage during the initial SS has low probability of occurrence based on historical data, even with climate change.

where an important proportion of the rain occurs.[11] This scheme insurance will cover SS farmers against negative precipitation shocks in Solis reservoir. This insurance provides incentives for SS farmers to accept a reduced allocation of water. In addition, the introduction of climate change will allow evaluating the effectiveness of this instrument.

4. The Model

This research effort is carried out in three stages. The first stage considers a baseline scenario, which estimates a dynamic water allocation model under uncertainty, originally developed by Miranda and Fackler (2002). Based on stochastic prediction of rainfall, the model characterizes authorities' optimal water allocation between two crop seasons for a single farmer. Then, water consumption is simulated for a planning horizon, and farmer's welfare can be calculated.

The second stage incorporates IPCC climate change scenarios (on rainfall) in the optimal water allocation model described above. Based on the stochastic rainfall predictions a new optimal water allocation strategy is developed for the farmer.

The third stage introduces the weather insurance contract in to the optimal water allocation model to compensate producers for a shortfall in realization of a particular weather variable measured over a certain time period. The model combines an analytical understanding of climate change risk through the inclusion of Global Climate Models predictions in to the model and the use of simulation to estimate likely loss profiles to attain more accurate pricing of weather derivatives. Once more, optimal water allocation strategy is calculated under different climate change scenarios and a designed weather derivative instrument. Finally, the water consumption paths are simulated and the corresponding farmer's welfare.

4.1 The Baseline

The baseline scenario models the interaction between a farmer and a central planner in the context of a functioning water rights system with a well defined regulatory framework. The following assumptions are taken to simplify the analysis.

Assumption 1: The central planner (water authority) allocates reservoir water among farmers, who are "water takers".

[11] Isohyet is a line that denotes an area of equal precipitation intensity.

Basically, the central planner knows how many hectares will be planted, so that he allocates specific amount of water per hectare, based on how much water is available. Under this consideration, the farmer is water taker in the sense that he uses what he receives. On the other hand, the central planner knows the amount of water needed for farmer to maximize his profits. For that reason, there will be no situation where farmer gets more water than the optimal.

Assumption 2: Under the baseline model there is no climate change and no insurance.

Assumption 3: The representative farmer approach is used to model the farmer's behavior.

The representative farmer approach conceptualizes all producers located in the irrigation district as a unique farmer who takes productive decisions. Thus, the representative farmer is composed by the aggregation of all farmers in the irrigation district, who have similar local features (farm structure, size, production practices, and production costs). Also, they are ruled under the same regulatory framework.

Assumption 4: The farmer has divisible technology.[12]

Valle de Santiago has two main crop activities and each one is carried out during different seasons. The farmer grows barley during the FW season and cultivates sorghum in SS season. Thus, production decisions per hectare are analyzed, under different water allocation strategies. For the sake of the analysis, it is assumed that the same farmer cultivates barley and sorghum. This assumption has powerful implications because the irrigation districts are water rights systems that provide to the water users in the module with the dotation determined by their non-transferable water rights, established by law and linked to the land property. So, this supposition simplifies the problem to an intertemporal reallocation of the same volume of water that could represent an improvement on management water efficiency.[13]

Assumption 5: Farmer's technology is characterized by quadratic production functions.

Farmer's technology is characterized by quadratic production functions. Barley and sorghum crops are represented as a function of water used in a quadratic specification.

Because barley is cultivated in the dry season (fall-winter), it is totally dependable on water allocated by the central planner. However, sorghum which is raised during the rainy season

[12] Henceforth, farmer and representative farmer will be used indistinctly.
[13] Since water rights are non-transferable, automatically the introduction of the insurance does not affect the trade of water rates. However, this assumption can be relaxed for a more deep analysis in this matter.

(spring-summer) has two sources of water: rainfall and reservoir. The production functions for each crop are shown next,[14]

$$barley_t = a_0 + a_1(irrigated\ water)_t + a_2(irrigated\ water)_t^{\ 2} \quad (1)$$

$$sorghum_t = b_0 + b_1(irrigated\ water + rainfall)_t + b_2(irrigated\ water + rainfall)_t^{\ 2} \quad (2)$$

Note that sorghum production function, grown-up during the wet season, depends on the precipitation received into the farmer's field. In consequence, sorghum production process is more uncertain, as well as famer's profit[15].

Assumption 6: Each farmer is small enough so that input and output prices are not affected by farmer's decisions.

Farmers' profits for each crop are expressed separately. The farmer's profit functions in the Fall-Winter (FW) and in the Spring-Summer (SS) are defined as,

$$Profit_{\mathrm{FW}} = Price_{barley} \times barley \ - Price_{water} \times (Irrigated\ Water) \ - \ other\ cost \quad (3)$$

$$Profit_{SS} = Price_{Sorghum} \times Sorghum \ - Price_{water} \times (Irrigated\ Water) \ - \ other\ cost \quad (4)$$

The barley and sorghum prices are assumed stochastic. In both equations (3) and (4), the water price represents the cost of water allocation that must be paid by the farmers. This fee might represent the marginal cost of water provision which is constant over time.[16] On the other hand, the planning authority may decide to vary the fee depending on the allocation level so as to regulate the potential demand.

Assumption 7: Inputs for the production are classified in two groups: water and other inputs. It is assumed that the farmer has already decided the amount of other inputs used.

The current model evaluates the marginal effects of irrigation water and rainfall on crop output, holding other conventional inputs constant. However, the input usage depends on the weather because of pest intensity. Thus, it could be the case that input costs would increase over time, especially under extreme weather events. In such case, simulations might not reflect this input issue on the farmer's profit and welfare.

[14] The constant terms in equations (1) and (2) represents that conventional input such as labor, capital are constant.

[15] Appendix A shows estimation results for these equations. Estimated coefficients for both regressions are statistically significant at 5% level. R-squared for barley regression is 30.3%, while it is 21.6% for sorghum regression. In addition, all coefficients exhibit the expected sign. Water has a positive effect on yields in both cases, and exhibits diminishing marginal productivity, which denotes the concavity of the production function.

[16] If it were not constant, it would be a decision variable for the planner. In that case the profit maximization problem for each farmer would give us a water demand as a function of water price. Thus, the dynamic optimal allocation would depend on the optimal path of water price established by the planner.

Assumption 8: It is assumed that representative farmer is risk averse and derives utility from profits.

Financial and economics literature suggest the use of Constant Relative Risk Aversion utility (CRRA) to represent agent's preferences (Boulier, et al., 2001, Cairns, et al., 2006). Bradt et. al (2009) points out that CRRA utility owns desirable properties such as twice differentiability and continuity that increases the efficiency of numerical optimization algorithms, while incorporates preferences toward higher-order moments in a simpler way. Thus, the representative farmer's utility function at any year is equal to:

$$utility = \frac{profit_t^{1-\gamma}}{1-\gamma} \quad (5)$$

The risk aversion parameter γ in (5) reflects producers' willingness to forgo a certain amount of risk-premium in exchange for elimination of uncertainty.

Assumption 9: The amount of available water per hectare at the beginning of t+1 for the irrigation module must be at least equal to the volume of available water per hectare at the beginning of t minus the released water during the seasons FW and SS per hectare plus the random inflow (runoff) to the reservoir attributable to that module, also per hectare.

The amount of water needed to carry out planting activities is provided by CONAGUA, who manages the water in Lerma-Chapala Basin and reservoir Solis. CONAGUA make the balance between the supply and demand for water in the period t. The supply of water for the period t is obtained by the accountability of the available water in the body waters of the basin at the final of the period t-1. In the other hand, the demand for water is obtained for the planting intentions that ARLID submit to CONAGUA. Then CONAGUA, once known the balance, allocates a specific amount of water to Valle de Santiago module,[17] according to its water rights at the beginning of the agricultural year t (prior to the start of fall-winter season).[18] Finally, the LLC and Valle de Santiago module must distribute the water volumes among their users in the module. For more details on procedures and institutional framework about the water management in ARLID (see Appendix E).

[17] The module Valle de Santiago is located in the Municipality of Valle de Santiago.
[18] Kloezen and Garces-Restrepo (1998), Kloezen, et al. (1997).

Let S_t be the amount of available water for irrigation in module per hectare in the dam. During the rainy season the reservoir levels are replenished by random inflows to the reservoir with the volume of ε_t units of water per hectare from reservoirs attributable to module. The local water authority releases $X_{FW,t}$ units per hectare for irrigation during the FW season (the driest season) and $X_{SS,t}$ units per hectare for irrigation during the SS season (the rainy season). The reservoir level at the beginning of each year is then represented by a controlled Markov process[19]. This dynamic is represented by the transition equation.

$$S_{t+1} \geq S_t - X_{FW,t} - X_{SS,t} + \varepsilon_t \quad (6)$$

Equation (6) summarizes the assumption 9.

Assumption 10: The objective of the central planner (LLC authority) is to find the optimal water allocation strategy for both seasons, maximizing the total discounted expected utilities over the planning horizon.

This means, the sum of means for farmers' expected utilities from farming profit over a certain number of periods expressed in present-day monetary units. This approach assumes that productive decisions are centrally taken. Thus, the optimal allocation strategy satisfies Bellman equation

$$V(s_t) = \max_{x_{fw,t}, x_{ss,t}} \{u(Profit_{FW} + E(Profit_{SS})) + \delta EV(s_{t+1})\} \quad (7)$$

The Bellman equation (7) is maximized subject to equation (6). Given that SS-profit depends on x_{SS} and random rainfall in Valle, equation (7) considers the expected utility for SS-farmer. The parameter δ represents the discount factor. It can be rewritten as the Euler equilibrium condition on shadow price of used water $\lambda(s)$ so that

$$\frac{\partial u(\cdot)}{\partial x_{FW}}\left[p_{barl}\frac{\partial Barley}{\partial x_{FW}} - q\right] - \frac{\partial u(\cdot)}{\partial x_{SS}} E\left[p_{sorg}\frac{\partial Sorg}{\partial x_{SS}} - q\right] - \delta E\lambda(s_{t+1}) = 0 \quad (8)$$

[19] Markov process is a random process in which the probability of any outcome in a given period depends only on the events in the previous period (no long-term memory). A controlled Markov process is a Markov process in which the outcome is also affected by a deterministic decision made each period.

$$\lambda(s_t) = E\left\{\frac{\partial u(\cdot)}{\partial x_{SS}}\, E\left[p_{sorg}\frac{\partial Sorg}{\partial x_{SS}} - q\right]\right\} + \delta E\lambda(s_{t+1}) \quad (9)$$

It follows that the condition that must be satisfied along the optimal path is

$$\frac{\partial u(\cdot)}{\partial x_{SS}} E\left[p_{sorg}\frac{\partial Sorg}{\partial x_{SS}} - q\right] = \frac{\partial u(\cdot)}{\partial x_{FW}}\left[p_{barl}\frac{\partial Barley}{\partial x_{FW}} - q\right] + \delta E\lambda(s_{t+1}) \quad (10)$$

Equation (10) specifies the central planner objective. On the margin, the benefit received by the SS farmer from releasing one unit of water must be equal to the FW farmer's marginal benefit from retaining the unit of water plus the discounted expected benefits of having that unit of water available for either SS farmer or FW farmer in the following year.

Hence, equation (10) along with constraint (6) make possible to calculate the reservoir's optimal allocations for both seasons -SS and FW- for all possible reservoir storage levels s_t. Under this scheme, optimal water allocation are made at the beginning of the period t, so that the farmer uses x_{FW}, and $x_{SS} + \eta_t$. It could be the case that the farmer is using more water than he needs in SS. In such case, the model assumes he uses that excess water in different activities that report a residual utility.

Once, these allocation strategies are known, the allocated water volumes for each farmer can be projected over the planning horizon. Numerical analysis is used to get the optimal allocation strategies.

4.2 Incorporating the climate change

In the previous section, an optimal water allocation model was presented. It was required to get historical time series data for η and ε to estimate their probability distribution functions. Now, we focus on how to introduce climate change in that model.

The precipitation projections for different regions around the world can be obtained for some climate change scenarios. Thus, once the geographic zones for both the field and the dam are identified, rainfall projections for η and ε can be obtained for some scenarios. Based on those projections, the probability distribution functions h_η and h_ε can be re-estimated and incorporated into the model and new irrigation policy can be derived.

4.3 Incorporating the weather insurance

The general idea of a weather-based insurance (or weather derivatives) is to compensate producers for a shortfall in the realization of a particular weather variable (e.g. precipitation) measured over a certain time period. If weather variable is sufficiently correlated with producers' profit, the payoff of the weather derivate would then offset the producers' loss.

During the FW season, crop activities depends exclusively on irrigation water x_{FW}, but in the SS the farmer has two sources of water- the rainfall η and irrigation water x_{SS}. In this context, when there is not enough water flowing into the reservoir to meet all of the water demand ($x_{FW} + x_{SS}$), barley production can be compromised because the FW season is the driest one. However, if it were the case, sorghum production could depend more on water from rainfall. In this context, the central planner would like to prioritize water requirements in the driest season (the first one).

In this work, an index insurance scheme is proposed based on rainfall level (ε) at Solis Dam. It is assumed that farmer is willing to use β% of the original x_{SS} during the rainy season. Moreover, the total amount of irrigated water available during the first season should be $x_{FW} + (1 - \beta\%)x_{SS}$. However, given that rainfall η is a random variable, the farmer could be better off if he would be compensated when he gets rainfall shortages. Based on this new water allocation, the representative farmer's profit can be derived.

Farmer should choose the parameter β such that it maximizes his expected utility assuming that he would buy weather insurance contract.

Designing the weather insurance contract

As was stated above, the farmer is willing to give up $(1 - \beta\%)x_{SS}$ unit of water unless he would be compensated when he gets rainfall shortages. In this section, it is established how parameter β is chosen together with the insurance contract. Following (Vedenov and Barnett, 2004), a weather derivative is modeled as an "elementary contract" with the payoff according to the schedule:

$$I(\varepsilon|x, \varepsilon^*, \mu) = x \times \begin{cases} 0 & if\ \varepsilon > \varepsilon^* \\ \frac{\varepsilon^* - \varepsilon}{\varepsilon^* - \mu\varepsilon^*} & if\ \mu\varepsilon^* < \varepsilon \leq \varepsilon^* \\ 1 & if\ \varepsilon \leq \mu\varepsilon^* \end{cases} \quad (8)$$

where ε is a realization of the rainfall at Solis Dam. The contract starts to pay when ε falls below the specified "strike" ε^*. Once rainfall falls below the limit $\mu\varepsilon^*$, the insured receives the maximum indemnity x. When rainfall falls between the strike and the limit, the contract pays a proportion of the maximum indemnity. The parameter μ varies between 0 and 1, with the limiting case of 0 corresponding to the conventional proportional payoff with deductible, and 1 corresponding to a "lump-sum" payment once the contract is triggered regardless of the severity of the shortfall. The contract is completely designed once the values of strike, limit and maximum indemnity are specified.

In order to price the designed contract for a given set of parameter values, the probability distribution of ε is used. The actuarially-fair premium is set equal to the expected payoff of the contract, i.e.

$$P(x, \varepsilon^*, \mu) = \int I(\varepsilon | x, \varepsilon^*, \mu)\, h_\varepsilon(\varepsilon) d\varepsilon \quad (9)$$

The parameters in equation (8), together with the parameter β, are selected for so as to provide the maximum risk reduction for the farmer who is exposed to the risk area-wide yield loss. For the sake of simplicity, the strike is selected as the long-time averages of rainfall. In particular, the parameters are selected so as to maximize the expected utility

$$max_{\beta,\mu,x} \int_{-\infty}^{+\infty} \int_{-\infty}^{+\infty} u\big(Profit_{FW} + Profit_{SS} + I(\varepsilon | x, \varepsilon^*, \mu) - P(x, \varepsilon^*, \mu)\big)\, h(\eta, \varepsilon) d\eta\, d\varepsilon \quad (10)$$

where profits defined in (10) take into account water allocation defined in the previous section. $h(\eta, \varepsilon)$ is the joint probability distribution of η and ε. In this work, it is assumed that $h(\eta, \varepsilon) = h_\eta(\eta) h_\varepsilon(\varepsilon)$, basically it means that rainfall on field and on dam location are independent.

5. Data Selection Process

SIAP[20] provides historical data series on sorghum and barley yields at the module level. Those data are available since 1985 to date. CONAGUA provides historical water allocation for both

[20] SIAP stands for Sistema de Informacion Agropecuaria y Pesquera (Information System for Agricultural and Fisheries)

sorghum and barley crops. It is available since 1985 to date. SMN[21] provides us monthly rainfall data on Valle de Santiago and on Solis Dam, which are available since 1910 to date[22]. Reservoir's storage levels and volumes of water available in basin Lerma–Chapala were obtained from Organismo de Cuenca Lerma-Santiago-Pacífico, CONAGUA central headquarters in Mexico City and CONAGUA offices in Guanajuato. Climate changes scenarios data was obtained from the Instituto Nacional de Ecologia (INE).[23] INE developed an application of the climate prediction and predictability engine originally developed by the National Oceanic and Atmospheric Administration (NOAA).[24] This engine simulates data on climate change scenarios based in 24 General Circulation Models for all Mexican territory. Thus, the precipitation projections from the Geophysical Fluid Dynamics Laboratory Coupled Model, version 2.X (GFDL.CM2.X) were incorporated into the model.

Descriptive Statistics

Table 1 displays descriptive statistics for sorghum and barley yields and water allocated[25]. The average for barley and sorghum yields were 5.06 and 8.46 tons/ha, respectively, during the study period. The highest standard deviation was 0.99 tons/ha for sorghum yield. The average irrigated water for barley and sorghum were 5,778 and 5,438 m3/ha, respectively. The highest standard deviation was 1,072 m3/ha for sorghum. Figure 2 shows the averaged annual rainfall distribution by month during 1985-2010. It suggests rainfall is heavy in June through September, which is part of the Spring-Summer in Mexico.

Before estimating weather-yield and weather-water models, several unit root tests were performed to detect whether yields and weather variable have stochastic trends. We followed the unit root test strategies by (Elder and Kennedy, 2001, Harvey, et al., 2009). Results suggested most of the series do not exhibit unit root. The trend stationary variables were detrendend following the procedure describe in (Vedenov and Barnett, 2004); and for those stationary in difference, we applied procedures suggested by (Enders, 2004)[26].

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[21] SMN stands for Sistema Meteorologico Nacional (National Meteorological System)
[22] Rainfall data were collected from weather station 11079 for Valle de Santiago and from 11076 for Solis Dam.
[23] http://zimbra.ine.gob.mx/escenarios/
[24] http://www.gfdl.noaa.gov
[25] Sample statistics on rainfall level over Valle de Santiago and Dam Solis are available upon request.
[26] Unit root results are available upon request.

Estimating the production function

Estimation results for barley and sorghum production function (see equations 2 and 3) are presented in the table 2[27]. Estimated coefficients for both regressions are statistically significant at 5% level. R-squared for barley regression is 30.3%, while it is 15.6% for sorghum regression. In addition, all coefficients exhibit the expected sign. Water accessibility has a positive effect on yields in both cases, and exhibits diminishing marginal productivity.

Estimating Probability Distribution Functions

A gamma distribution was used to estimate the probability distribution for cumulative rainfall. Cumulative rainfall was modeled as a discrete variable by applying the following steps. First, 1000 random numbers were generated from the continuous gamma distribution and these random values were used to create 6 intervals.[28] Thus, the discrete probability distribution of cumulative rainfall suggests 6 possible levels, with their respective probabilities.

Precipitation projections were generated for two regions in the State of Guanajuato, Mexico: Municipality of Valle de Santiago, where module Valle is located and Acambaro Municipality, where the dam Solis is located. Those projections range from January-2012 to December 2050. Those were used to estimate the probability distribution under different climate change scenarios.

6. Results

In this section, the simulation results for the model presented above are displayed. It is solved by using the numerical solution for an stochastic infinite discrete-time dynamic model develop by (Miranda and Fackler, 2002). In that setup, the reservoir level (S_t) and the irrigated water (w_1, w_2) are defined to be the state and control variables, respectively. Those variables are defined to be discrete and finite.

The simulations were performed using the risk aversion parameter (γ) obtained from the application of the method suggested by (Babcock, et al., 1993). It is assumed a 5% discount rate[29]. Water price was set to 160 pesos per thousand of m^3. The Barley and sorghum prices were assumed to be stochastic. Thus, autoregressive models for those output prices were estimated

[27] Based on a box-plot analysis, outliers were not considered.
[28] Six intervals were used to avoid "out of memory" computer problems.
[29] The model was estimated using discount factor of 1% and 10%. In general, the results were consistent.

based on historical time-series data. Based on that, predictions were made and incorporated into the dynamic model.

First, results for the baseline scenario are shown, followed by simulation results under climate change and specific insurance scheme.

6.1 Baseline Model

Figure 3 and 4 show the optimal irrigation policy for both seasons. For example, when the water available is 6.8 thousand of cubic meters per hectare (TM3H), barley and sorghum farmers receive 4 and 2.6 TM3H, respectively. It means that FW-and-SS farmers receive 60.6% and 39.39% of the total amount of water allocated, respectively.

Figure 5 shows the optimal state path. Based on simulated results for 50 years, the steady state for reservoir level is 10.81 T3MH. It means that in the long run, the central planer would have 10.81 T3MH of water to allocate between FW-and-SS farmers.

Figure 6 shows the steady state distribution for the reservoir level. Figure 6 shows the proportion of water allocated between FW-and-SS farmers for different reservoir levels. For each reservoir level, FW-farmers receive more water than SS-farmers do.

This result is consistent with the model. When the central planner allocates water between both farmers, he knows that SS-farmers are able to use rainfall in his crop. For that reason, the central planner allocates more water for FW-farmers, holding this policy for different reservoir levels. This optimal policy is quite similar to that observed in the historical data (see figure 8). Since 1989, the allocated water for FW-farmers have accounted in average for 66.7% of the total water allocations.

6.2 With Climate Change

In its special report IPCC (2000) considers that future greenhouse emissions are the result of a very complex dynamic system, determined by driving forces such as demographic development, socio-economic development and technological change.[30] IPCC developed 40 different scenarios to evaluate the possible states of the world given different assumptions on global population, economic growth, and final energy use. These scenarios have been grouped in scenarios families which contains common themes within. For the sake of the analysis, this study focuses on A2

[30] Textual citation from IPCC (2000)

and B1, which are more consistent with the conditions of Mexico. However, only results for A2 scenario are displayed. A brief resume of the scenarios' features is cited.[31]

The A2 storyline and scenario family describes a very heterogeneous world. The underlying theme is self-reliance and preservation of local identities. Fertility patterns across regions converge very slowly, which results in continuously increasing global population. Economic development is primarily regionally oriented and per capita economic growth and technological changes are more fragmented and slower than in other storylines.

The B1 storyline and scenario family describes a convergent world with the same global population that peaks in midcentury and declines thereafter, as in the A1 storyline, but with rapid changes in economic structures toward a service and information economy, with reductions in material intensity, and the introduction of clean and resource-efficient technologies. The emphasis is on global solutions to economic, social, and environmental sustainability, including improved equity, but without additional climate initiatives.

In Appendix C, simulation results are shown when discount rate is 5%. Figure 9 shows the optimal irrigation policy for both seasons under A2 scenario[32]. For example, when the water available for irrigation in the reservoir is 6.8 thousand of cubic meters per hectare (TM3H), barley and sorghum farmers receive 3.8 and 2.8 TM3H, respectively. It means that FW-and-SS farmers receive 57.58% and 42.42% of the total amount of water allocated, respectively. Figure 10 shows the proportion of water allocated between FW-and-SS farmers for different reservoir levels. For each reservoir level, FW-farmers receive more water than SS-farmers do.

This result is consistent with the model. Given that the SS-farmers may also use rainfall for their crops, the central planner allocates more water for FW-farmers. This policy holds for different reservoir levels.

Figure 11 shows the optimal state path. Based on simulated results for 50 years, the steady state for reservoir level is 8.09 TM3H. This is long run volume of water available that the central planer would allocate between FW-and-SS farmers (see figure 12).

Figure 13 shows the optimal value function for different water level with and without climate changes. For all these cases, the more reservoir level per hectare is, the higher utility farmers get. The Steady-State for reservoir water is higher under historical data than under A2

[31] The description of each scenario is taken textually from IPCC (2000).
[32] Simulation for B-1 scenario was also carried out, however, their results did not show significant differences with respect to those presented under A-2 scenario. For that reason they are shown here, but are available upon request.

scenario. Extreme events -excessive rainfall or lack of rain- are more likely under A2 scenario than under the basic case. Optimal allocations made by the central planner produce higher utility under historical data than under scenario A2.

6.3 With a weather insurance scheme

The present section shows the simulation results for the dynamic water allocation model with IPCC scenarios predictions for precipitation. The simulation procedure was carried out in two steps. First, the equation (10) is modeled to estimate the optimal value for β and the contract parameters. Second, based on those estimations new water allocation patterns are calculated.

The simulation results suggest that the optimal value for β is 75%, while the contract parameters are: ε^* is equal to 562.77 mm, λ is equal to 0, and the maximum liability is 4600 pesos per hectare. The premium is equal to 243.8 pesos per hectare. Graphically, this standard contract is shown in figure 14.

In Appendix D, simulation results are shown when discount rate is 5%. Figure 15 and 16 show the optimal irrigation policy for both seasons under A2 scenario with insurance[33]. It is important to note that irrigated water during the fall-winter increase when reservoir level is less than 4.5 TM3H. However, when the level is greater than 5 TM3H, the farmer receives around 3 TM3H. On the other hand, the irrigated water has a different pattern. When the reservoir level is less than 8 TM3H, farmer receives around 1 TM3H, after that he receives 5.2 TM3H.

Figure 17 shows the optimal path for the reservoir level. After 10 years, that level is 8.60 TM3H. Figure 18 shows the steady state distribution, which is centered on the steady state as was expected.

Figure 19 shows the optimal value function under A2 scenario with and without insurance. As was expected, under different reservoir level farmers are better off when he is able to buy weather insurance.

7. Institutionalization and Implementation of Weather Derivatives

The market for weather derivatives started operations in 1997, and its dynamic only was interrupted by the crisis 2008-09. In Latin American countries, weather derivatives have not

[33] Simulation for B-1 scenario was also carried out, however, their results did not show significant differences with respect to those presented under A-2 scenario. For that reason they are shown here, but are available upon request.

generalized their use as an instrument to cope with climatic risks mainly because their institutional framework is immature to embrace such operations. Public policies, directed to develop the weather derivatives market in Latin America countries, have had some advances in institutional issues and technology adoption for reducing costs. However, they have shown poor results in reducing market failures, improving the access to information and credibility, and the creation of favorable environments for the operation of these instruments (Arias and Covarrubias, 2006).

The use of weather derivatives as insurance engine requires the intervention and support of bilateral and multilateral institutions: government, NGOs, private foundations, intermediaries, insurance companies, credit companies, agribusiness firms, saving and credit organizations, cooperatives, etc. In addition, their operation involve the development of multiple mechanisms and processes, such as delivery channels, marketing, promotion, training of retailers, investments in education for clients and end-users (Hellmuth et. al, 2009). The channel of implementation is a primary issue because it must be selected according to the available resources in the target population's location, minimizing the transaction and administrative costs (Arias and Covarrubias, 2006).

In developed countries, with a consolidated financial structure, the main channels are energy companies, insurance and reinsurance companies and hybrid companies (those which offer insurance, reinsurance and derivatives), Arias and Covarrubias (2006). In contrast, in developing countries the use of available channels for commercialization implies taking advantage of the existent social networks and social capital. For this reason, the best condition for weather derivatives as financial tool occurs when it is integrated into broader comprehensive risk management strategy, such as programs of rural development (Hellmuth et. al, 2009).

In the case of Mexico, irrigation districts are a potential target population for the action of these instruments.[34] Mexican government has a net of weather stations along the country with

[34] Agroasemex, the Mexican government-owned reinsurance company, launched the Programa de Atención a Contingencias Climatológicas (PACC) during the 2001-2002 fall-winter cycle to cover three Mexican states (Sinaloa, Tamaulipas and Sonora) from catastrophic exposure related to agriculture. The objective was to increase the efficiency, timeliness and distribution of federal funds to farmers after a weather disaster. The index insurance package covered drought and flood and their transactions in the international weather derivatives market had an approximate value of US$15 million (World Bank, 2005).Although no studies for evaluating the performance of this insurance were carried out and the collocation was successful, in 2005 triggers caused payouts when farmers had not actually experienced crop damage; while the opposite occurred in 2006, when some farmers experienced crop losses but no payments were triggered (Hellmuth et. al, 2009).

available information in some cases since 1900. The modules as an entity are able to purchase weather derivatives because they operate as productive organizations with similar production conditions, under the same regulatory framework, the same operative structure and they already works as productive organization to access credits.

Mexican government, in particular Agroasemex the governmental reinsurance company, could use their experience in the emission of weather derivatives and also serve as a reinsurer company. Numerous channels of commercialization can be used; even weather derivatives could be introduced by rural financial agents. Financial government institutions such as FIRA or Financiera Rural could tie their credits to the purchase of an insurance schemes with this characteristics. Also, Mexican government could support the development of agreements between microfinances organizations and insurance companies to incentive the introduction of these instruments in the market.[35]

[35] Two successful experiences in life insurance tied to personal loans awarding have been already implemented in Mexico, see Alpizar and Gonzalez (2006).

8. Policy Conclusions, Challenges and Final Considerations

In most of the developing countries, efficient pricing mechanisms to optimize water use are impossible in institutional, political and social terms. Furthermore, in the coming decades higher variability in precipitation, associated to climate change, will make evident the need for reinforcing mechanisms that address efficient allocation of water in agriculture as an effective adaptation strategy.

This study proposes the adoption of more efficient allocative water policies in irrigation districts supported by weather derivatives to cope the precipitation shortage as an effective strategy against climate change, such as in ARLID. Weather derivatives are able to incorporate the analytical understanding of future climate change risks that historic data does not reflect.

Weather derivatives, as insurance schemes, are more effective to compensate distortions in the intertemporal allocation of water by the regulation authority when irrigation districts have at least one of its seasons depending on precipitation in situ.

Institutionally talking, the success in the adoption of weather derivatives as adaptation strategies to climate change requires initial conditions in irrigation districts. A good level of organization in irrigation districts is required to be able to purchase weather derivatives. Also, clear rights of water, an acceptable rate of efficiency of the conduction of the irrigation are requirements for guaranteeing an appropriate performance of the irrigation functioning, previous to the acquisition of the weather derivatives.

The dynamic allocation model characterizes the historical allocation pattern that awards higher water volumes for those farmers who are not able to diversify their risk. While provide reduced water allocation for those farmers who are able to diversify their risk. The inclusion of the climate change scenarios in the model introduces more dispersion in the steady-state distributions because of having more frequent extreme weather situations.

Higher variability in precipitation patterns, due climate change, are turned into higher premiums that reflect the high level of risk that insurance company would have to absorb in the future, such as it is shown in scenario A2 and B2. Thus, higher insurance prices from higher expected losses and higher payouts might create market imperfections that only the government could help to reduce by the creation and development of healthy public private partnerships

(PPP), avoiding the creation of perverse incentives and supporting the adaptation decisions.[36] Thus, PPP's could overcome the operational and financial constrains from higher premiums due to climate change and facilitate the risk sharing between private insurance companies and the state. Public policy could do important contributions to the functioning of weather derivatives by adapting the laws and regulations, and amending legal and regulatory gaps to potentiate the sphere of action for insurance companies.

Modules of irrigation districts are a potential target population for the action of these instruments. Governments could support the operation of this scheme as an integral strategy against disaster emergency and also procuring the development of institutional characteristics to embrace these operations. Once the weather insurance is working, it has good probabilities to be an effective tool to improve the actual management of the water in irrigation districts and print some dynamics into weak water markets.

Strong assumptions were adopted into the model to simplify the initial analysis. However, numerous dimensions can be incorporated into the analysis by relaxing every assumption in the model. In particular, interesting results can be derived when water rights are allowed to be traded.

The main limitations of the study come from the inaccurate of climate change scenarios to anticipate the future performance of precipitation patterns. Also, as in any index based insurance scheme, basis risk imposes some level of vulnerability into the model. In both cases the basis risk is reduced. In the case of ARLID the basis risk is minimize using data that comes from a weather station located in the isohyets with the highest intensity precipitation, in reservoir Solis.

Finally, some enrichment experiences of the application of the weather derivatives as a potential risk transfer mechanism in developing countries has been applied. An inclusive strategy to manage the uncertainty associated with climate change in agricultural production has been implemented in developing countries such as: Mexico (2001), Ethiopia (2007), Kenya (2007), Mali (2007), (Agrawala and Fankhauser, 2008).

[36] An inappropriate public policy to develop the insurance market might worsen the negative effects of natural disasters in the target population and facilitating the capture of public resources by the private agents (Arias and Covarrubias, 2006).

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Appendix A

Table 1 Descriptive Statistics for Valle de Santiago, 1985-2010

Variables	Mean	Std. Dev.	Min	Max
Yield Barley (tons/hectare)	5.06	0.77	3.42	6.35
Yield Sorghum (tons per hectare)	8.46	0.99	6.02	10.92
Irrigated Water Barley (thousands of m3/hectare)	5.778	0.358	4.663	6.201
Irrigated Water Sorghum (thousands of m3/hectare)	5.438	1.072	2.399	7.545

Note: Std. Dev. stands for standard deviation.

Figure 2 Valle de Santiago, Average Annual Rainfall (mm), 1985 – 2010

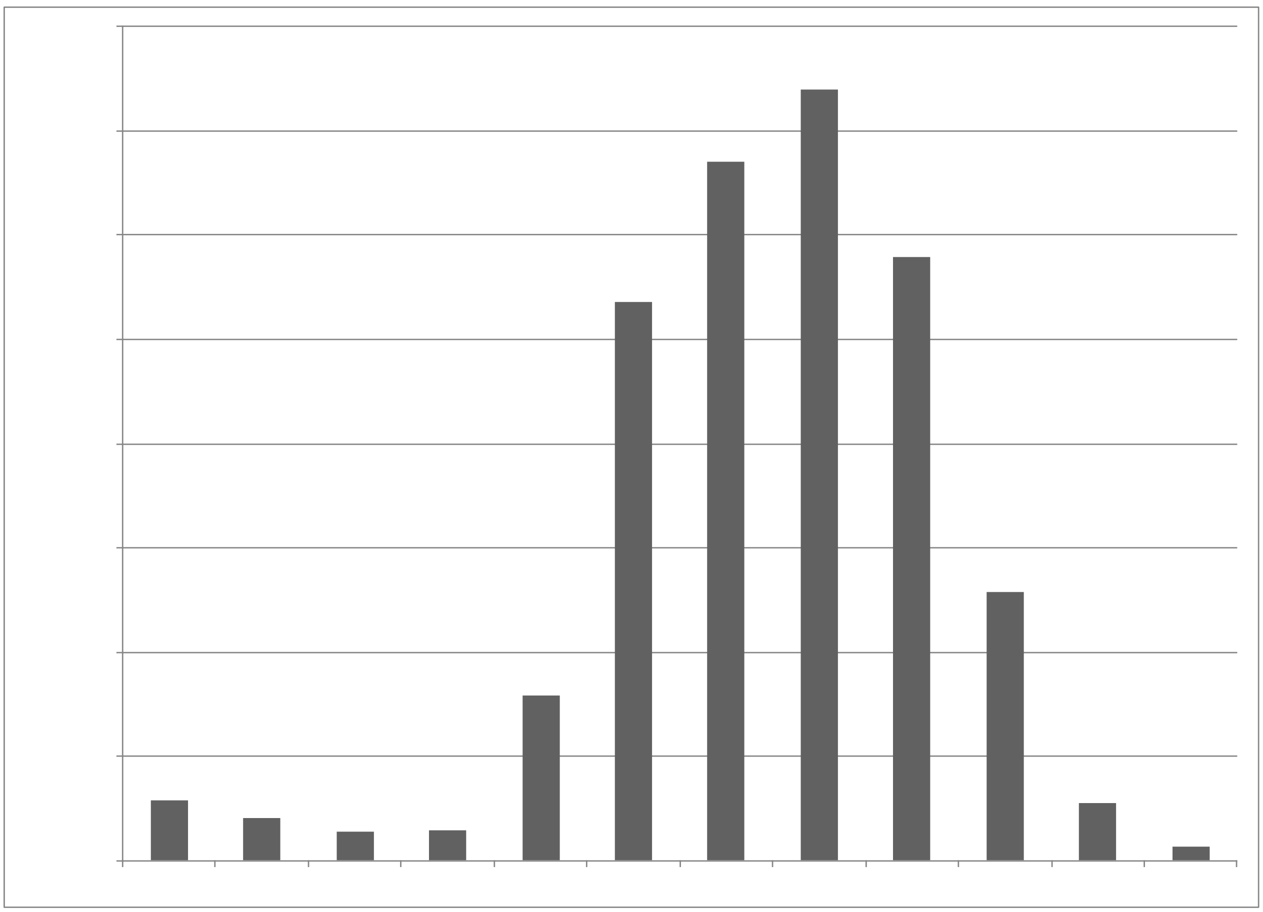


Table 2 Estimation Results for Production Functions

	Barley	Sorghum
Water Accessibility	50.47*	4.042*
	(2.46)	(2.57)
Water Accessibility square	-4.389*	-0.237*
	(-2.45)	(-2.64)
Constant	-144.6*	-16.97*
	(-2.46)	(-2.55)
Number of Observations	17	17
R-square	0.303	0.216

Note: t statistics in parentheses. Coefficient is significant at the 10 percent level; * at the 5 percent level; ** at the 1 percent level.

Appendix B: Simulation Results under No Climate Change and No Insurance

Figure 3 Optimal Irrigation Policy Fall-Winter

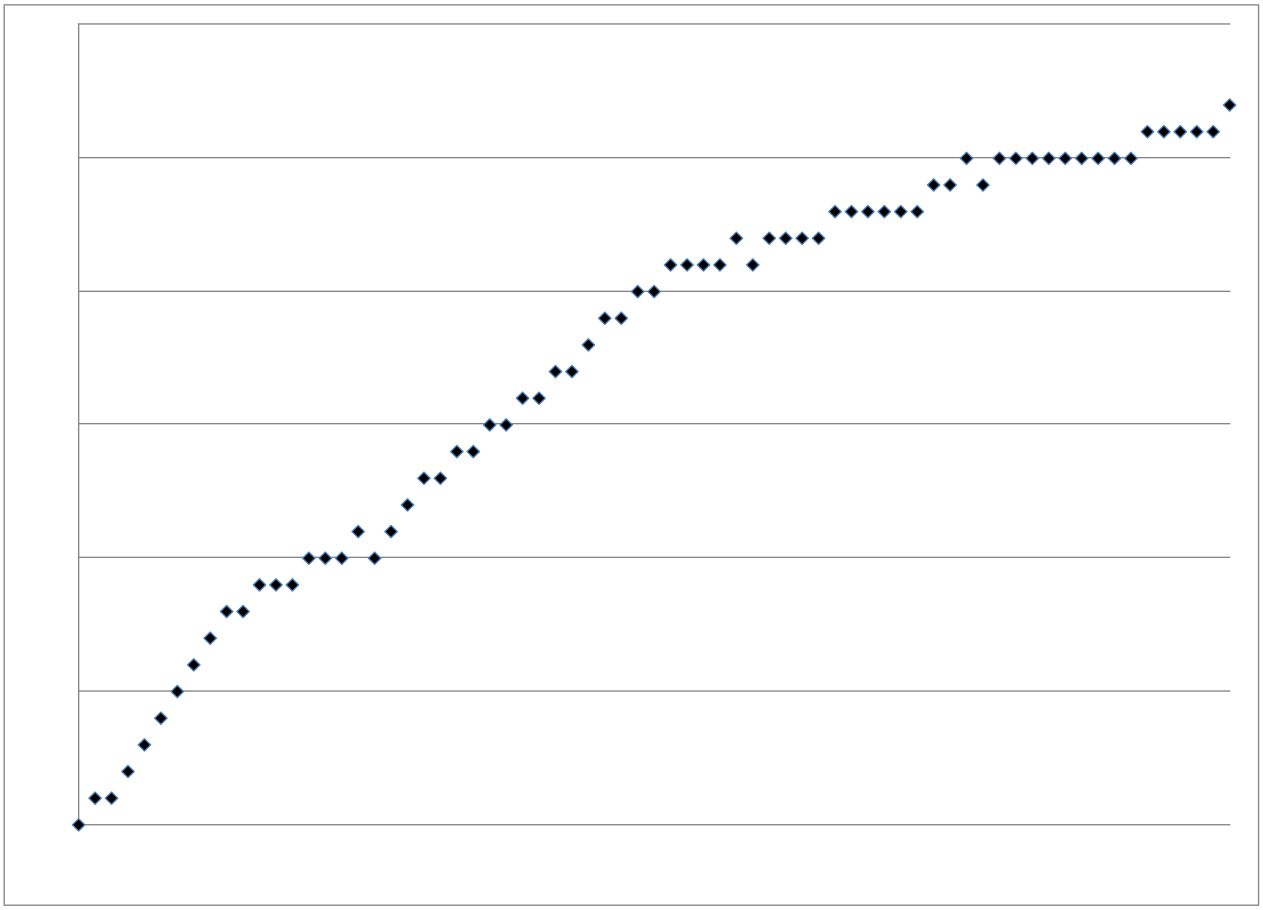


Figure 4 Optimal Irrigation Policy Spring-Summer

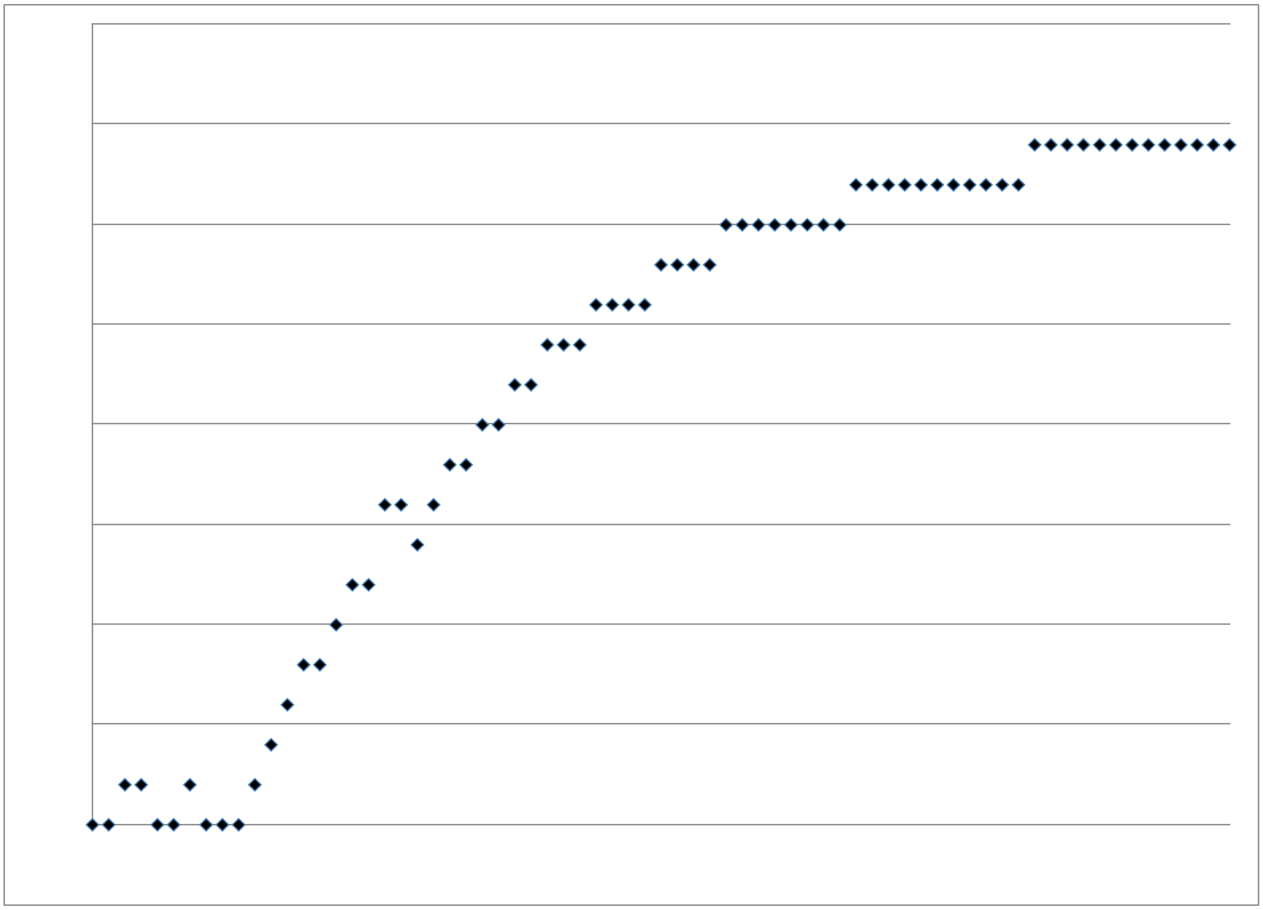


Figure 5 Optimal State Path

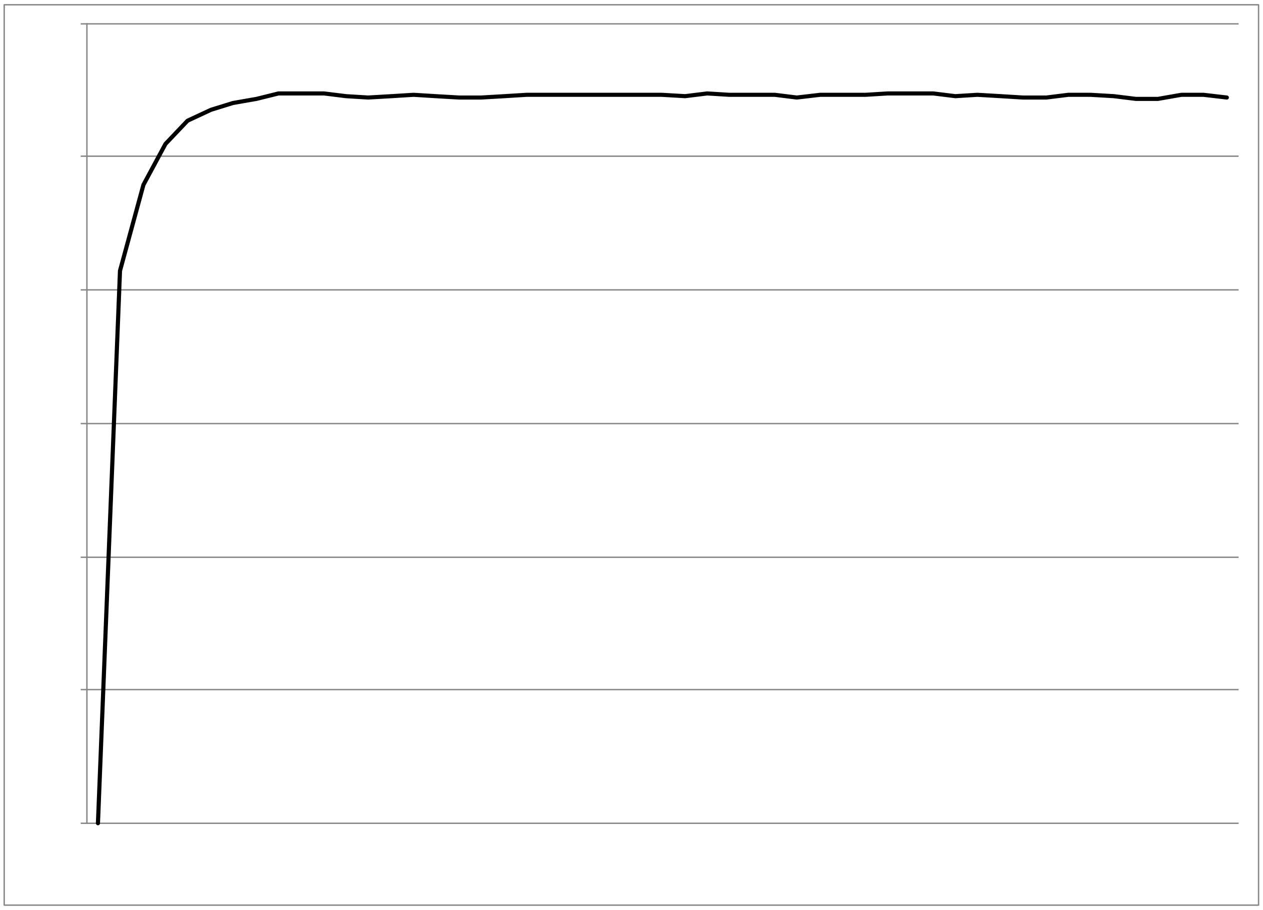


Figure 6 Steady State Distribution

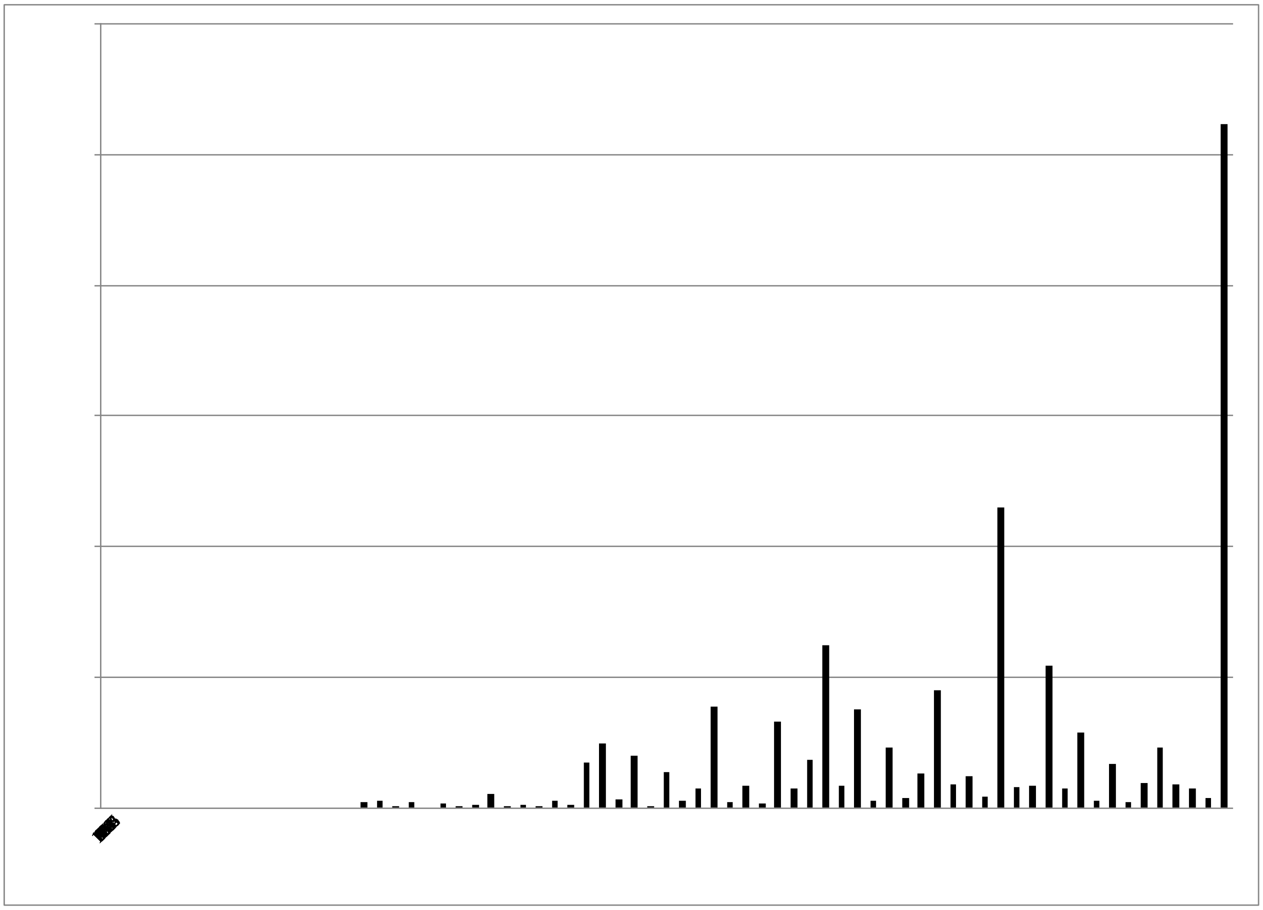


Figure 7 Proportion of Water Allocated between FW and SS farmers

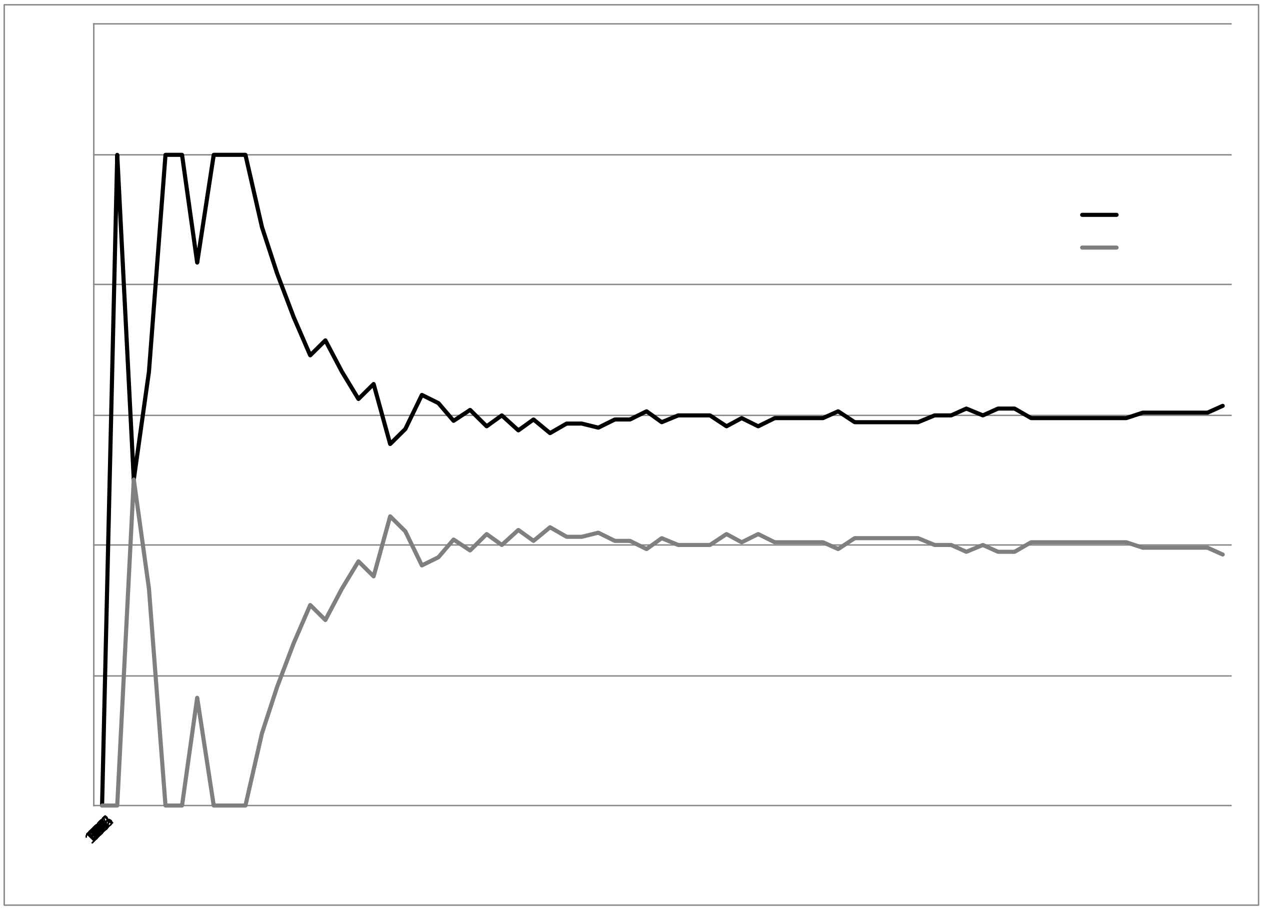
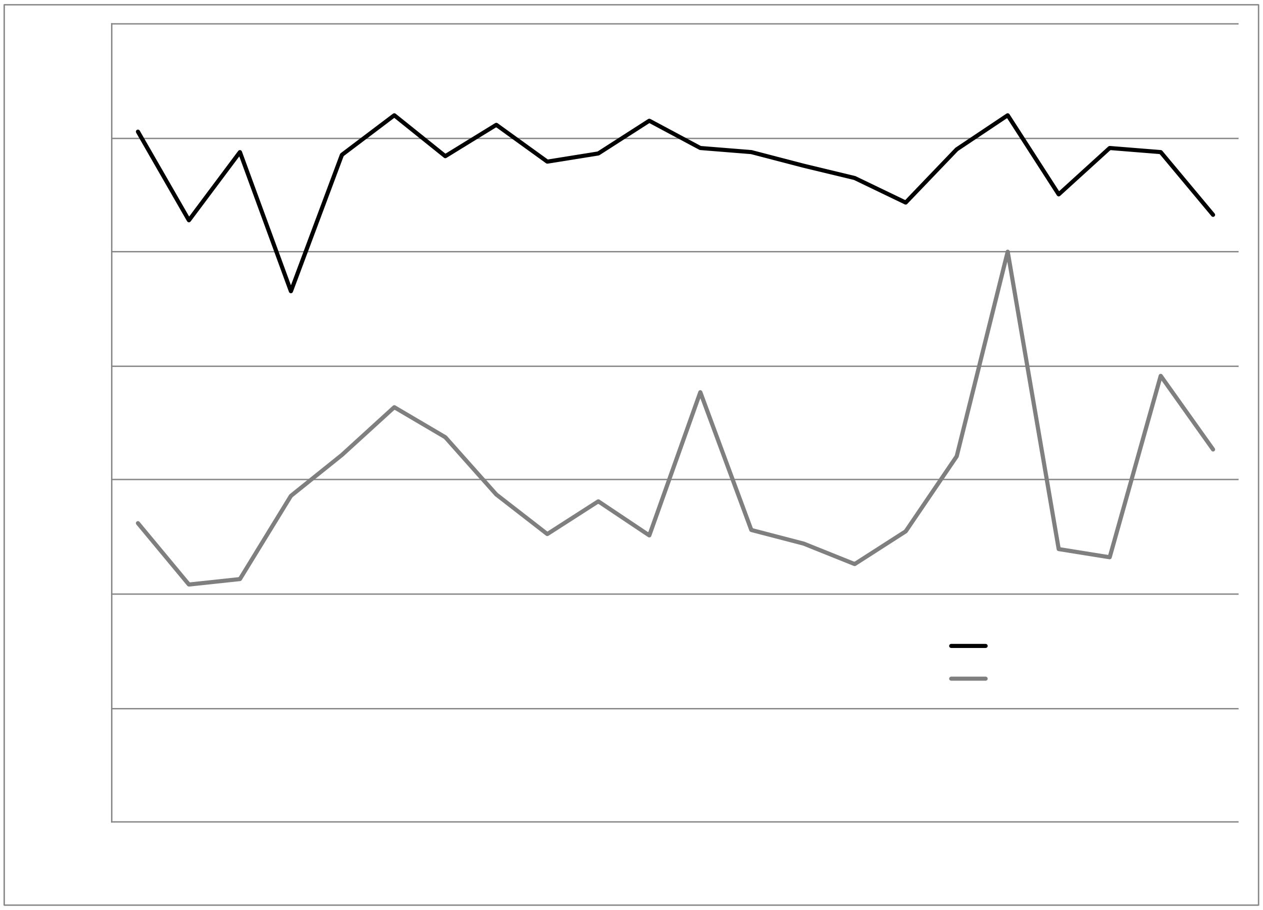


Figure 8 Evolution of Water allocated in Valle de Santiago



Appendix C: Simulation Results with Climate Change

Figure 9 Optimal Irrigation Policy Fall-Winter

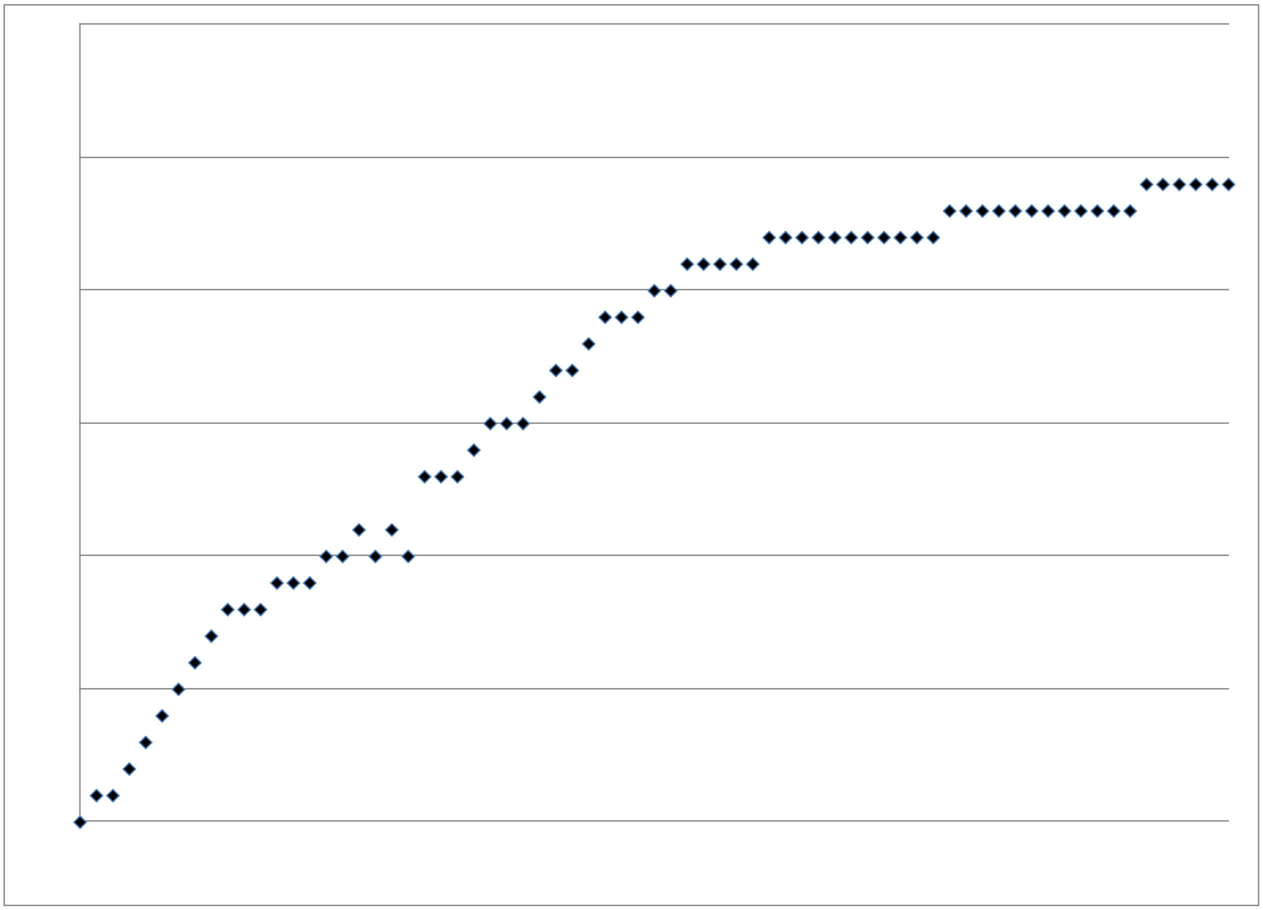


Figure 10 Optimal Irrigation Policy Spring-Summer

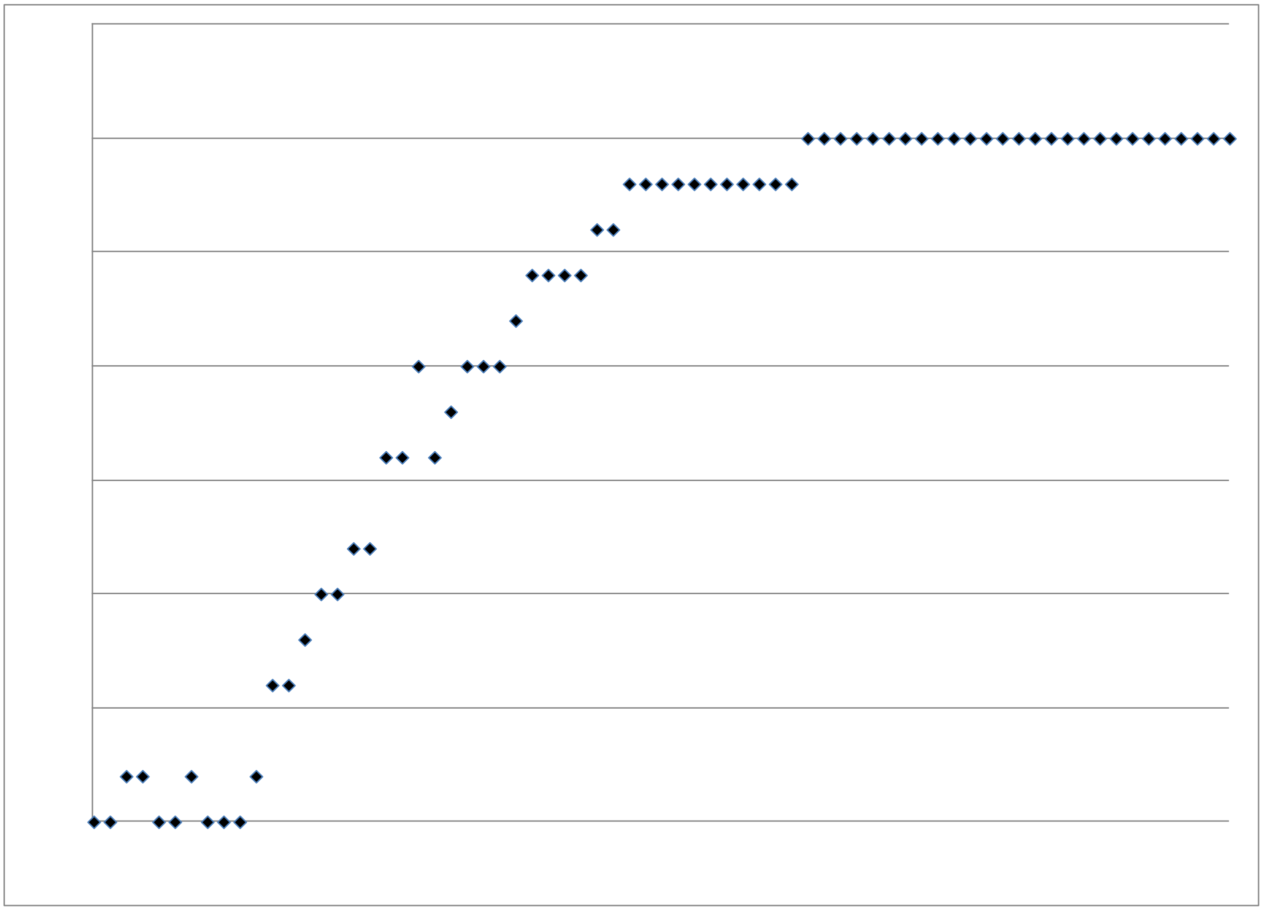


Figure 11 Optimal State Path

Figure 12 Steady State Distribution

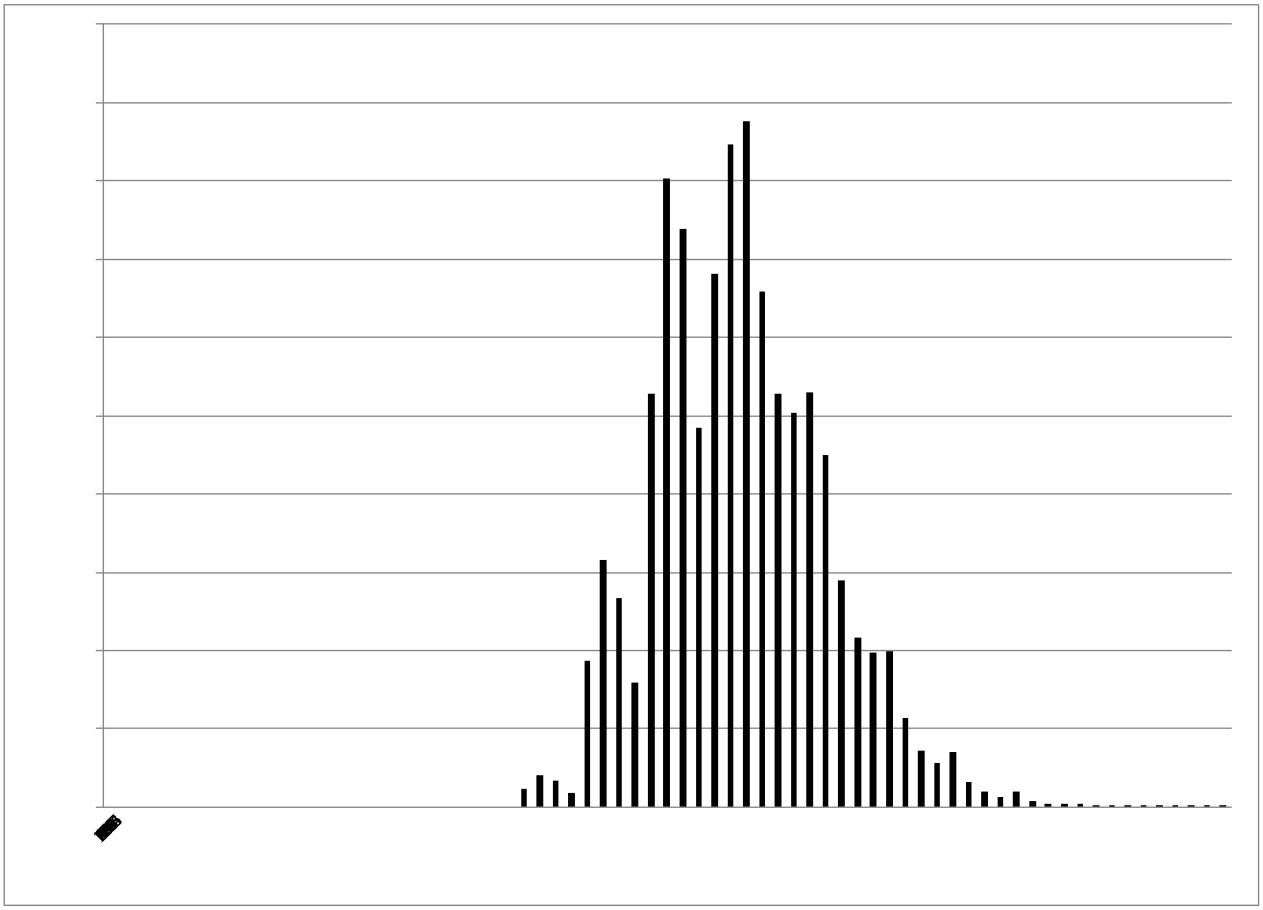
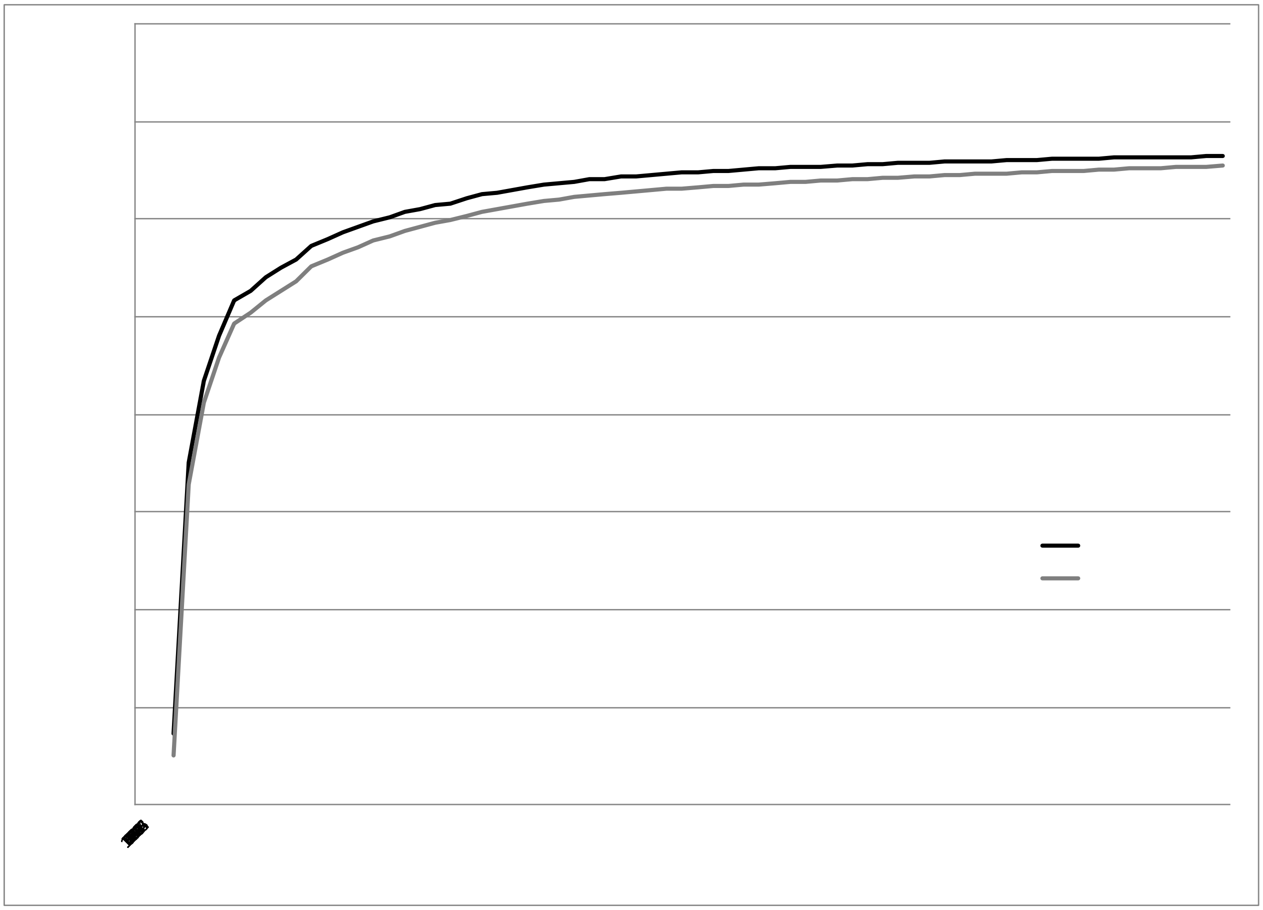


Figure 13 Optimal Value Function



Appendix D: Simulation Results under A2 scenario and Insurance

Figure 14 Payoff structure of an elementary contract

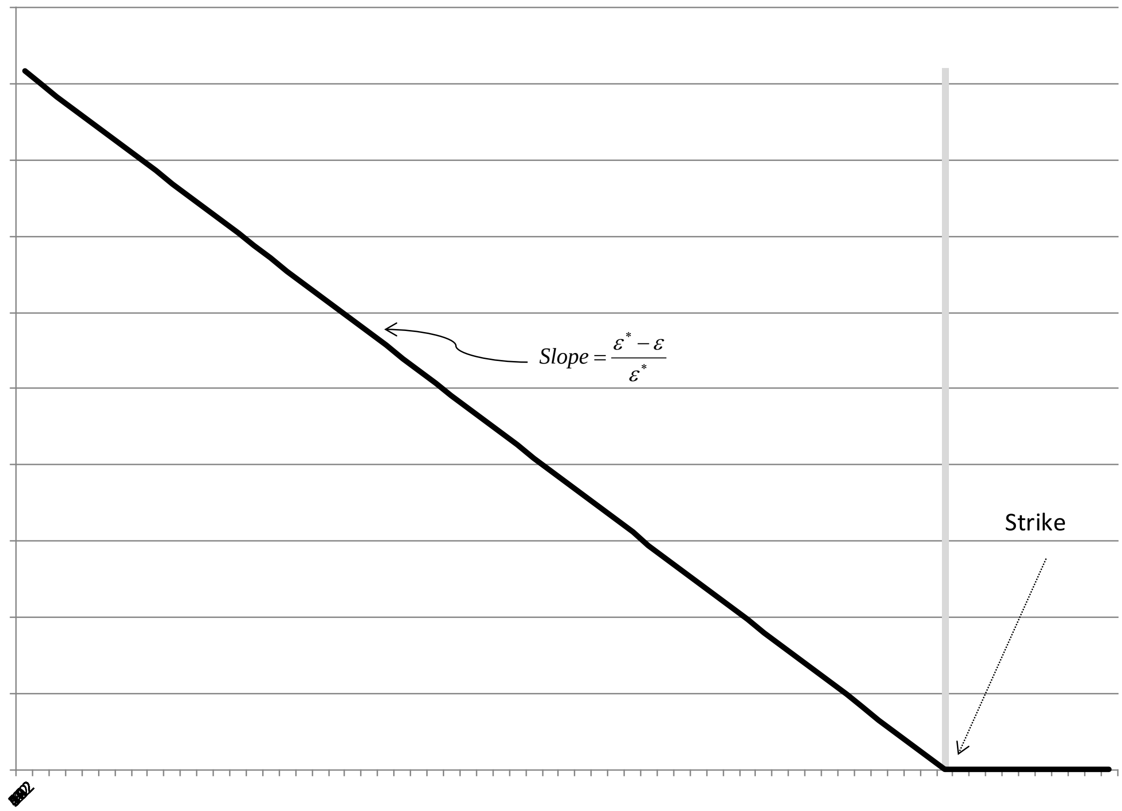


Figure 15 Optimal Irrigation Policy Fall-Winter

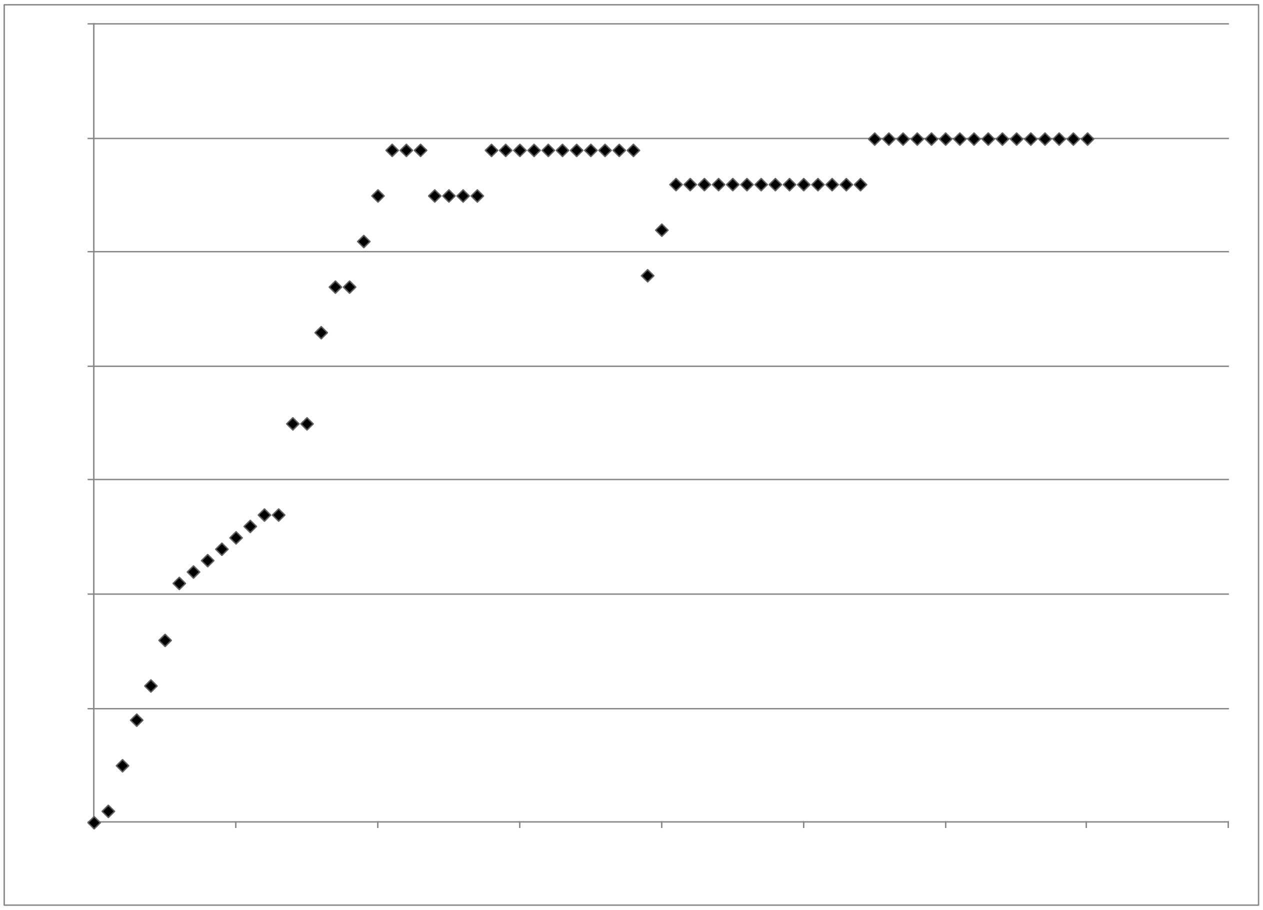


Figure 16 Optimal Irrigation Policy Spring-Summer

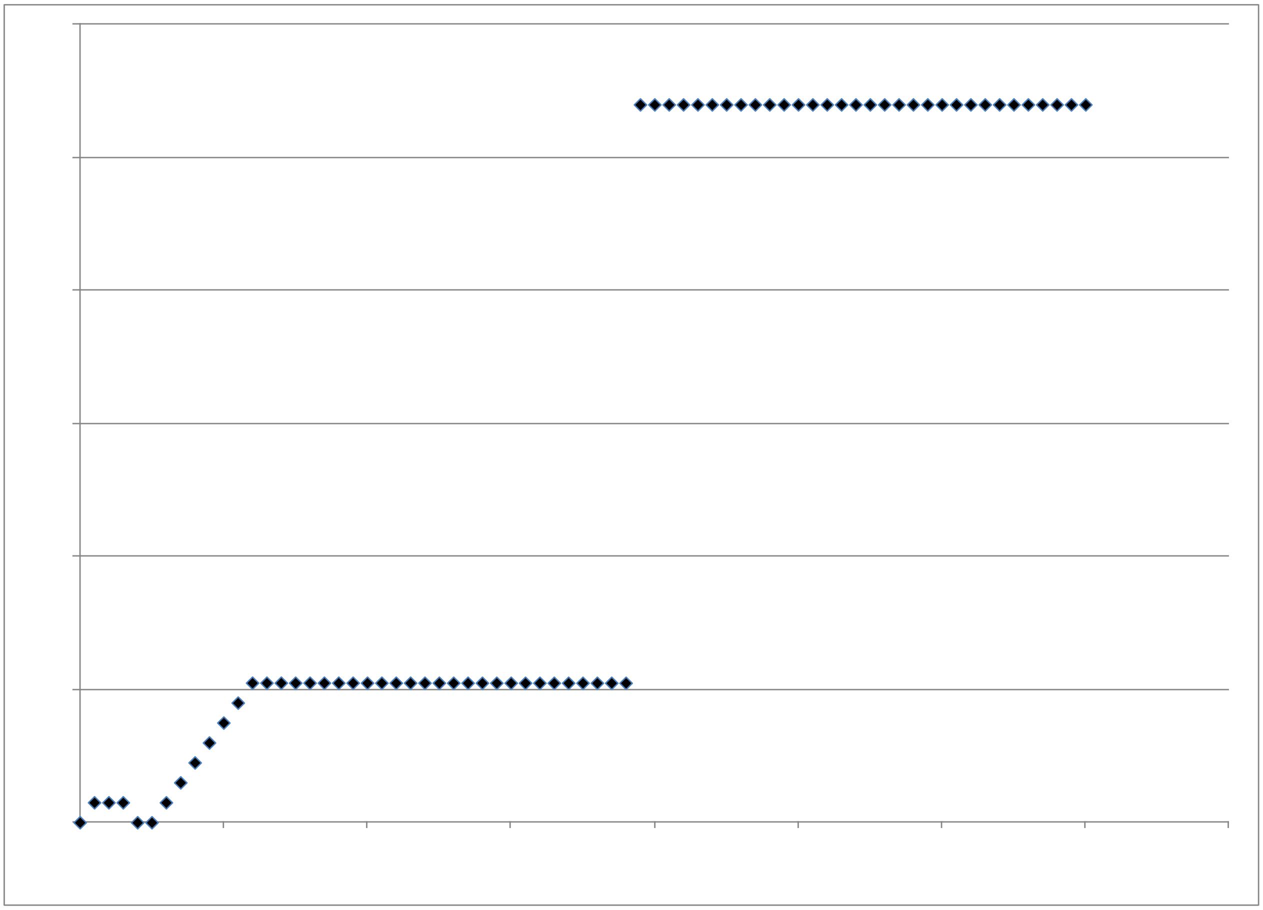


Figure 17 Optimal State Path

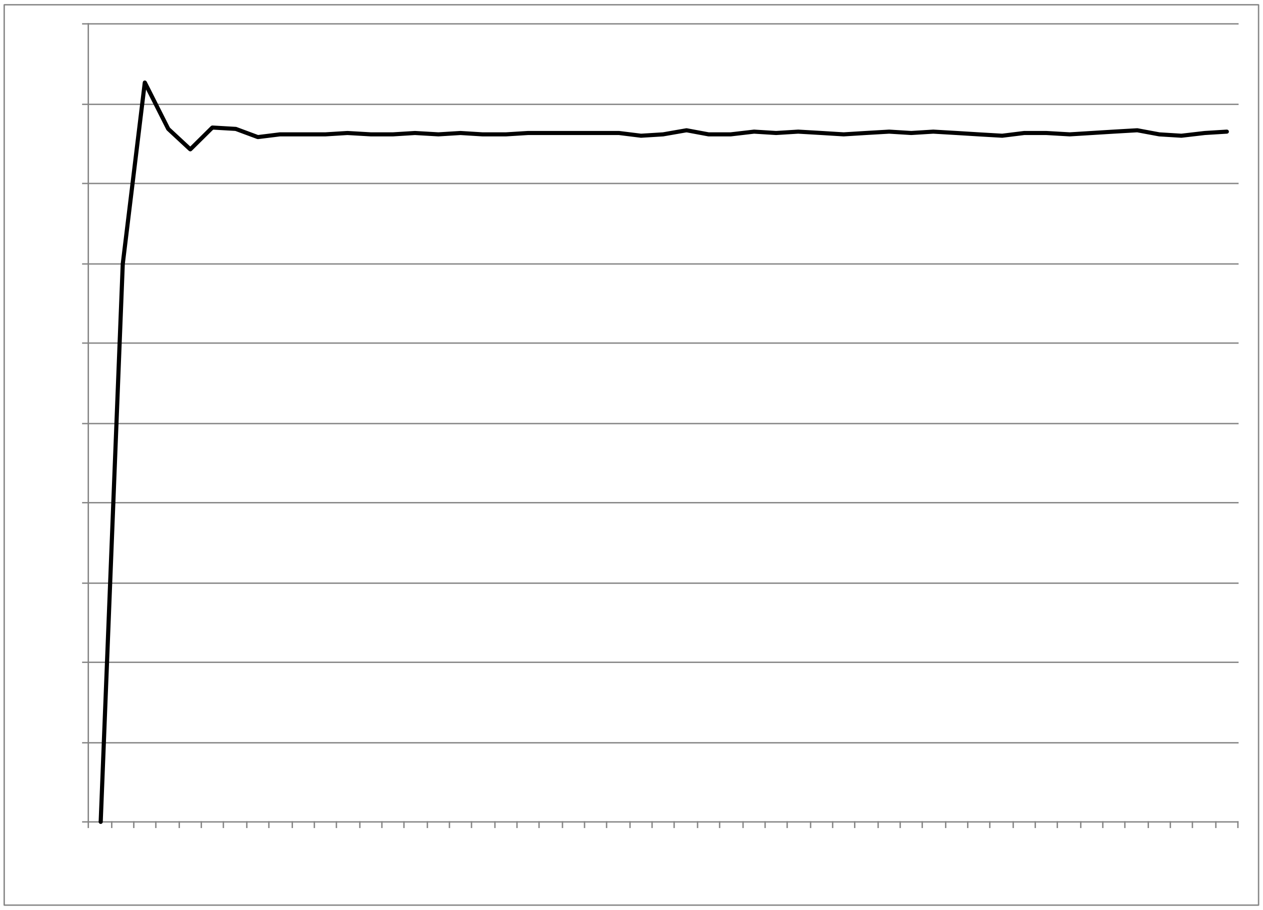


Figure 18 Steady State Distribution

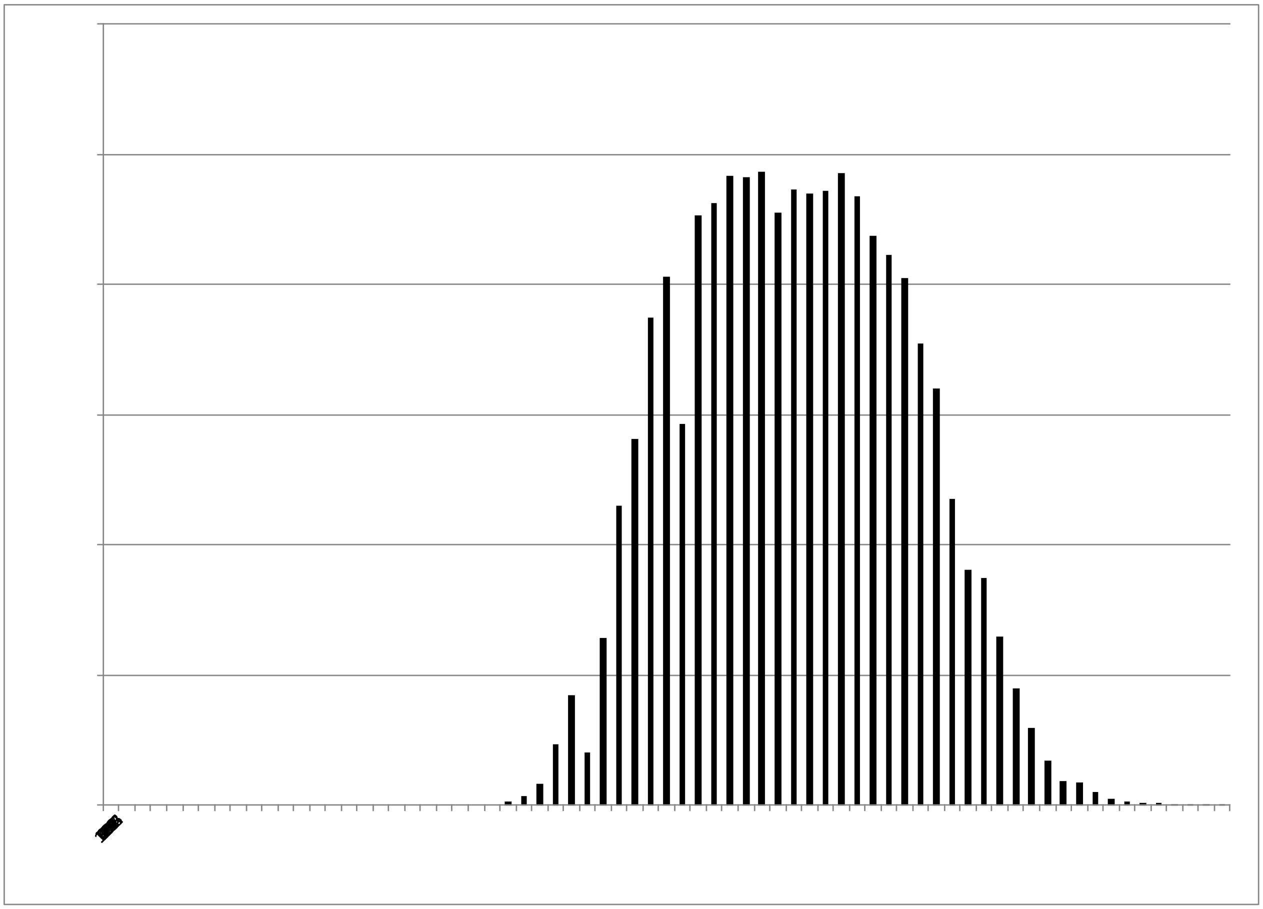
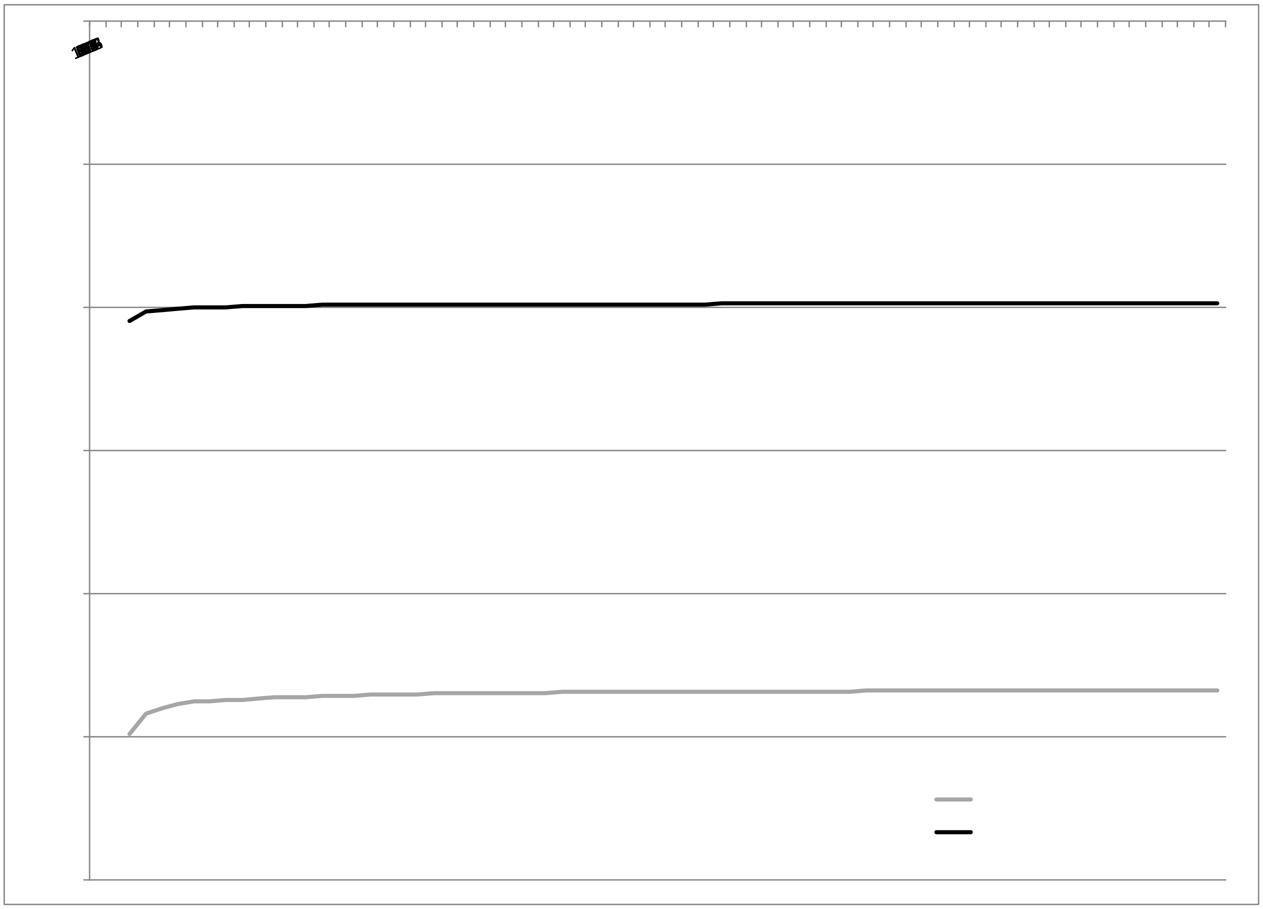


Figure 19 Optimal Value Function State Distribution



Appendix E: Institutional Framework for the Management of Superficial Water in ARLID, Guanajuato-Mexico.

The Alto Rio Lerma irrigation district (ARLID) obtains its water for irrigation from the Lerma-Chapala Basin System which is divided in 17 drainage basins.[37] This system is located in the central region of the country with a surface of 47,116 km². The main collector in the system is the Lerma River, which along its 700-km is fed by the tributaries Gavia, Jaltepec, Laja, Silao-Guanajuato, Turbio, Angulo y Duero.

Since 1991, the water supply for irrigation in the ARLID was determined under the Federal Agreement for the Distribution of the Superficial Water in the Lerma-Chapala Basin. Under this Agreement the supply water for ARLID was determined as a percentage of the storage levels from dams Solis and Tepuxtepec. The water for irrigation within the ARLID was distributed according to the licenses and rights.

In 2004, a new agreement with a global basin management was incorporated. The water supply for the ARLID was determined by the calculation of the total runoffs restitution for five of the seventeen basins located in the Upper Lerma region: River Lerma (Alzate), River La Gavia (Ramirez), River Jaltepec (Tepetitlan), River Lerma 2 (Tepuxtepec) and River Lerma 3 (Solis).[38] Once the annual volume of restitution run-offs is calculated, the following allocation rule for the ARLID is applied.

"When the maximum volume of the total surface runoffs generated by the five basins (Alzate, Ramirez, Tepetitlan, Tepuxtepec and Solis) of the previous period is between 0 and 999.00 hm^3, then the maximum extraction volume will be 477.06 hm^3. When the runoffs are higher than 999.00 hm3 and less than 1,644.06 hm^3, the maximum volume of extraction will be 74.08% of the sum of the set of the basins minus 263.12 hm^3. Finally when the total maximum leakages generated in the basins would be higher than 1,644.06 hm^3, the maximum volume of extraction will be 955 hm^3." (CONAGUA, 2006)

Thus, by the second week of September of every year, the Commission calculates the basin's runoffs generated during the 10 months (from November to August), along with a

[37] River Lerma 1 (Alzate); Río La Gavia (Ramírez); Río Jaltepec (Tepetitlán); Lerma 2 (Tepuxtepec); River Lerma 3 (Solis); River La Laja (Begoña); River Querétaro (Ameche); River La Laja 2 (Pericos); Laguna de Yuriria; Lerma 4 (Salamanca); River Turbio (Adjuntas); River Ángulo; River Lerma 5 (Corrales); River Lerma 6 (Yurécuaro); River Duero; River Zula; River Lerma 7 (Chapala)

[38] Total runoffs volume = downstream runoffs – upstream runoff – importations – returns + uses (irrigation districts+ small scale irrigation + potable water) + evaporation from bodies of water inside the basin + variation of the storage in bodies of water inside the basin + exportations.

forecast for September and October (based on historical records for the same periods). In particular, more weight is given those years with similar runoffs volumes during September and October. Averages are also calculated, as well as minimum and maximum values to compute their variations.

Although the allocation rule considers five basins previous to Solis dams, in the practice ARLID extracts water mainly from Solis reservoir and from other watersheds no considered in the initial accountability for allocation (Yuriria Lagoon and Purisima reservoir).

For the sake of the operation and management, the ARLID is organized in 11 modules. The main ARLID's task is to distribute the allocated water to those modules. Each module is entitled to a proportional share of the water available in those four reservoirs. Those entitles are determined by the rights of water that the users of the module own and provided that the volume is available at the start of the season in November (Kloezen, et al., 1997). Water Users Associations operate individual modules. Every module must collect fees from its users. The CONAGUA receives part of those fees collected. The irrigation fees are determined by the CONAGUA based on the volume that each module is buying. A single limited liability company (LLC) created in 1996 operates, manages, conserves and maintain the irrigation network that includes primary canals, secondary canals and drainage.

The CONAGUA schedules deliveries of water resources to the modules, performs monitoring at the field, module, and district levels, and checks the weekly reports of the ditch tenders at each module (Kloezen and Garcés-Restrepo, 1997).

Appendix F: Weather Derivatives

This section has the objective of explaining the some differences between weather-based derivatives. In the context of the present research, the purpose of weather derivatives will be to compensate farmers for the loss due to insufficient water allocation or precipitation. Weather derivatives are defined by three main criteria: the insured event, the duration of the contract, and the location at which the event is insured. There exist different methods for calculate the indemnities paid by the contract and to calculate the actuarially-fair price of the contract (see Turvey, 2001, Mahul, 2001; Vedenov and Barnett, 2004; Zeuli and Skees, 2005).

According to Turvey (2001), weather derivatives can be brokered as an insurance contract or as an over-the-counter traded option. Weather derivatives can be structured as swaps, futures, option contracts. In general terms, any derivative is indexed to a weather variable such as temperature or cumulative rainfall measured in a specific location over a specified period. All derivatives contracts specify a level keyed to the index (strike level) and the payments are calculated at the contractual rate "tick rate". All payments accumulate over the contract period and are payable after the contract period. The contract duration varies and contracts could include specific instructions to measure index, make payments and an upper bound on payments called "cap" (Dischel and Barrieu, 2002).

There are important differences between derivatives and their characteristics define their utility as instruments to cope with agricultural risks. Swaps and collars usually operate with no initial exchange of money, which make attractive to speculators, because they can assume risk positions, an even build a portafolio of risk, with no initial outlay of capital. Swaps can be more risky than options as downside risk can be better controlled with options. In swaps and collars the buyer is the one who benefits from the rising index; the swap buyer receives a payment form the seller only when the index is greater than the swap level, up to the cap. Conversely the swap seller benefits from a declining index, and would receive a payment only when the index is less the swap level (Dischel and Barrieu, 2002).

In the case of options, the buyer pays to enter into a contract that may requires the seller to pay at the end of the option period, an amount calculated from a specified measure of the weather, the weather index (Dischel et. al., 2002). The insured can buy a put option that would provide an indemnity if the weather index is lower that the attachment strike at the end of a specified period. Also, the insured can buy a call option and, if weather index exceeds a specified level (the attachment strike) he will receive a payment at the end of the specified period. Also the insured could select both (collar). Payments are keyed to the difference between the index and the strike level, for each millimeter of rainfall that the option is in the money, a payment per unit is made. Detailed exemplifications of the derivatives scape from the objectives of the present study, for more details consult Dischel and Barrieu (2002).