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DECADAL CLIMATE VARIABILITY: ECONOMIC IMPLICATIONS IN AGRICULTURE AND WATER IN THE MISSOURI RIVER BASIN

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Abstract

Economic research on decadal climate variability (DCV) is scarce. DCV refers to ocean-related climate influences of duration from seven to twenty years. The DCV phenomena and their phases are associated with variations in crop and water yields. This paper examines the value of DCV information in the Missouri river basin using a mathematical programming model. The analysis shows the value of a perfect forecast is about 5.2 billion dollars, though 86% of this value can be obtained by a less perfect forecast based on already available data. Results show differential responses in major crops acreage and water usage.

Key words: Decadal climate variability, value of information, adaptation, crop insurance

1. INTRODUCTION

Ocean-related climate variations and their implications for human activities have been a subject of research for years. Numerous studies have addressed the identification and prediction of the influences of seasonal and interannual climate phenomena, such as the El Niño Southern Oscillation (ENSO) (Latif and Keenlyside 2009; Weng et al. 2007; Chen and Chang 2005; Chen et al. 2005; Solow et al. 1998; Hill and Mjelde 2002; Hill and Mjelde 2002b). Still, a climate force that has not received much attention is the decadal climate variability (DCV). DCV refers to regional and seasonal variations in weather patterns and climate on the time scale of seven to twenty years (Hurrell et al. 2010). Some important DCV phenomena, which are analyzed in this dissertation, are the Pacific Decadal Oscillation (PDO), the Tropical Atlantic Gradient (TAG) and the West Pacific Warm Pool (WPWP). They all may take positive or negative phases (for a total of 8 DCV phase combinations) and may remain on it for several years, introducing the issue of persistence. The impacts are spatially differing over crop and water yields, and the intensity may be attributed to a particular phenomenon or phase, introducing as well the issue of phase dominance. Then, when considering a study of the value of the DCV, the policy focus switches from addressing short-term conditions towards medium-term and persistent effects, with differing implications for the selection of adaptive production technology (Podestá et al. 2009).

The objective of this paper is to investigate the economic implications of DCV, through the value of information framework, in the Missouri River Basin (MRB) and in interaction with crop insurance. For this we build an economic model that depicts the MRB hydrologic water flows, water diversions, and agricultural cropping. That model, labeled as RIVERSIM, is used to assess the impacts on welfare given the information on the likelihood of DCV-phase combinations. The model is an extension of the models by Cai (2010) and Han (2008). This paper is structured as follows: Section 2 is a brief background on decadal climate variability and the DCV impacts on agriculture and water. Section 3 presents the conceptual framework of RIVERSIM. Section 4 reports select results. Section 5 concludes.

2. BACKGROUND

Decadal Climate Variability

DCV phenomena have not been extensively studied from an economic viewpoint. One of the few economic approaches to DCV is Kim and McCarl (2004) where they estimate the welfare gains through early phase announcements of the North Atlantic Oscillation. The crop mix and consumption adjustments range from 600 million to 1.2 billion dollars a year (Kim and McCarl 2004). The DCV phenomena analyzed in this paper are: (a) the Pacific Decadal Oscillation (PDO), (b) the West Pacific Warm Pool (WPWP), and (c) the Tropical Atlantic Gradient (TAG). They may take either a positive or negative phase and occur in combination with the other DCV phenomena.

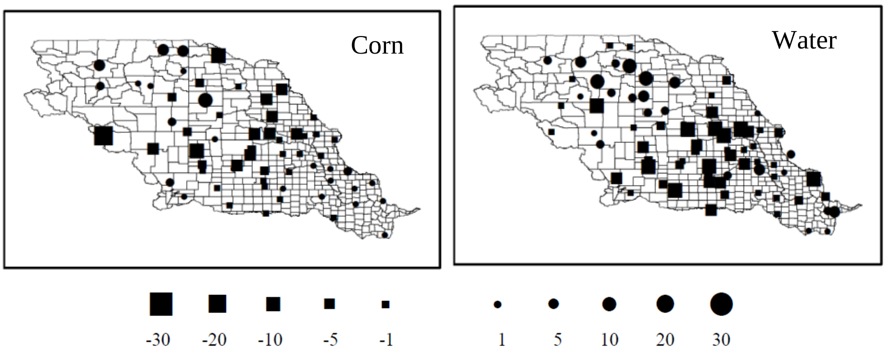
The PDO has been described as a long-lived El Niño-like pattern of Pacific climate variability with variations and periods between 15 and 21 years (Mantua and Hare 2002; Mantua et al. 1997). Biondi, Gershunov and Cayan (2001) argue that PDO phases affect sea surface temperatures along the west coast of the Americas. The WPWP produces anomalies in levels of temperature and precipitation where the positive phase is associated with precipitation being below its annual average and temperatures falling above average in Missouri, western Iowa, western North Dakota, western South Dakota, eastern Wyoming and Montana Wang and Mehta (2008). The TAG, on the other hand is associated with variability in winds and rainfall in the southern and central U.S. (Murphy et al. 2010).

The Missouri River Basin

The MRB is the largest river basin in the U.S., and is one of the most important crop and livestock-producing regions in the world. It encompasses areas of the states of Montana, North Dakota, South Dakota, Wyoming, Nebraska, Colorado, Kansas, Missouri, Minnesota, and Iowa. The MRB drains one-sixth of the conterminous United States and encompasses

529,350 square miles. The MRB region produces approximately 46% of U.S. wheat, 22% of its grain corn. About 117 million acres are in cropland and of that total 12 million acres are irrigated. Decadal climate variability in the MRB is an item of concern because it explains 60 to 70% of the total variance of annual-average precipitation in the region, exerting a large influence on temperature and water yields. The alternative forms of DCV and their phases, whether they occur singly or in combination, are correlated to the past occurrence of droughts and floods in the MRB region (Mehta, Rosenberg and Mendoza 2012). Figure 1 shows an example of the DCV phase combination PDO-TAG-WPWP- over corn and water yields in the MRB (Mehta et al. 2012). Impacts are interpreted as the deviations from the ten-year average yields. For corn, there are 65 counties which are affected where the impacts range from -33.33% to 36.04%. Impacts on water yields range from -58.76% in Douglas County, Nebraska, to 41.54% in Cheyenne County, Nebraska.

Figure 1: DCV Impacts on Corn and Water Yields (%) for PDO-TAG-WPWP-.



3. The RIVERSIM Model

RIVERSIM is an economic and hydrological model incorporating: (a) sectoral water demand; (b) spatial river flow relationship, and (c) uncertainty about crop yields and water availability under the DCV influence. The model projects water usage and agricultural land allocations and will be used to estimate the economic value of forecasting DCV-phase combinations. It is a two-stage stochastic programming model with recourse. In the first stage the crop mix is decided when the phase combination is unknown, then, in the second stage harvest and irrigation use can be adjusted once DCV impacts become known. RIVERSIM maximizes the consumers' and producers’ surpluses, subject to a set of supply and demand balances, water flow, and resource restrictions. The model estimations are carried at county-level.

Value of Information of DCV-Phase Combinations Forecast

DCV forecasts may help inform the decision maker by providing a better expectation of the (conditional) probability associated with DCV events. The value of information (VoI) is the difference between the expected value when an imperfect forecast (i.e. using a historical frequency distribution) is available, and when forecast information exists (i.e. under a transition probabilities distribution or a perfect information case) (Cerdá and Quiroga 2011; Adams et al. 1995). For the VoI estimation we require simulations of the adjustments of the decision makers conditional on the alternative forecasts. In the case when historical information is available, the decisions are made facing the full yield distribution without considering the influence of DCV phases. In turn, when DCV forecasts become available the decisions are conditional on the altered probabilities of phase combinations. The crop mixes are tailored to the probabilities inherent in the forecast. Additionally, we investigate the role of crop insurance as a risk-spreading mechanism through which the costs of climate-related events are distributed among other sectors and throughout society. Following Chen and Chang (2005), a public yield-based crop insurance program is assumed where farmers can purchase a 50%-coverage fixed-indemnity contract for a given premium.

RIVERSIM Structure

The MRB contains areas or all of a total of 411 counties. The sectors considered as water users are agriculture, industry, residential, mining, reservoirs, aquaculture and golf courts irrigation. For agriculture, the crops analyzed are barley, corn, alfalfa hay, oats, sorghum, wheat (durum, winter and spring), soybeans, sugarbeets, canola and potatoes. The irrigation practices are categorized as irrigated or dryland. Crop production budgets are adapted from Beach et al. (2010) and Adams (1996). We follow Adams (1996) and Fajardo, McCarl and Thompson (1981) for calibration and, in order, to avoid overspecialization the model solution, crop acreage is restricted to a convex combination of the historically observed crop mixes (Onal and McCarl 1991, McCarl 1982). We use 2010 as base year. Prices are at state-level whereas yields are at district-level. Data on own-price elasticities are adapted from Beach et al. (2010) and Adams (1996).

County-level water usage data comes from the U.S. Geological Survey. Data on residential water usage are transformed to a monthly basis using the monthly fractional shares in Cai (2010). Water rates come from the information on the municipalities web sites in each county and from phone calls when online information was not available. RIVERSIM contains 13,154 nodes, for an equivalent number of rivers or reaches. RIVERSIM relies on simulations of the SWAT model where output provides simulated monthly inflows, outflows and evaporation loss. Since SWAT output does not provide the location of water diversion points, then we rely on 10 mile-influence zones around human settlements and locations where water-usage activities take place. Every river/reach within each zone is attributed an equal probability, according to the number of rivers, of being a water diversion point.

Climate data, from 1950 to 2010, were drawn from the National Oceanic and Atmospheric Administration. They include temperature (in Celsius degrees) and number of days when precipitation was less than 0.1 inches, which represent the number of days in a month without rainfall. County-level impacts of each DCV-phase combination are 10-year average percentage deviations from long-run average yields of corn for grain, sorghum for grain, soybeans, spring wheat, and winter wheat (Mehta, Rosenberg and Mendoza 2012). Each scenario corresponds to the 8 possible DCV-phase combinations. Considering the 61 years of data, the relative frequency with which each scenario occurred are in

Table **1**. It shows, for example, that the phase combination PDO- TAG- WPWP- occurred 16.1% of the time.

Table 1: Historical Distribution of DCV-Phase Combinations

Phase Combinations	Probability	Phase Combinations	Probability
PDO- TAG- WPWP-	0.161	PDO+ TAG- WPWP-	0.080
PDO- TAG+ WPWP-	0.064	PDO- TAG- WPWP+	0.112
PDO+ TAG+ WPWP-	0.161	PDO- TAG+ WPWP+	0.225
PDO+ TAG+ WPWP+	0.112	PDO+ TAG- WPWP+	0.080

There are some caveats relative to the use of a frequency-based probability distribution. First, it may not carry enough information on the differential impacts of DCV phenomena, and the persistence and dominance of particular phases over the regional climate variability (Gan and Wu 2012); and, second, it may not incorporate the information on the literature on the correspondence between persistent anomalous events and the historical occurrence of a particular DCV-phase. Then we estimate the transition probabilities between DCV phase combinations, and rather than relying on the origin of each phase, we focus on the differential impacts (Mehta el al 2012). Under this framework of persistent and dominant phases,

Table 2 contains the transition probabilities which reflect the long-run likelihood of each scenario and accounts for the year to year persistence of particular phases.

Table 2: Transition Probabilities (Decimals)

		Next year's DCV Phase Combination							
		PDO- TAG- WPWP-	PDO- TAG+ WPWP-	PDO- TAG+ WPWP+	PDO+ TAG+ WPWP+	PDO- TAG- WPWP+	PDO+ TAG+ WPWP-	PDO+ TAG- WPWP-	PDO+ TAG- WPWP+
This year's DCV Phase Combination	PDO- TAG- WPWP-	0.200	0.100	0.200	0.000	0.200	0.200	0.000	0.100
	PDO- TAG+ WPWP-	0.000	0.250	0.250	0.000	0.250	0.000	0.000	0.250
	PDO- TAG+ WPWP+	0.308	0.077	0.462	0.077	0.077	0.000	0.000	0.000
	PDO+ TAG+ WPWP+	0.000	0.000	0.143	0.286	0.286	0.286	0.000	0.000
	PDO- TAG- WPWP+	0.143	0.143	0.429	0.143	0.143	0.000	0.000	0.000
	PDO+ TAG+ WPWP-	0.000	0.000	0.100	0.200	0.000	0.300	0.300	0.100
	PDO+ TAG- WPWP-	0.200	0.000	0.000	0.000	0.000	0.400	0.400	0.000
	PDO+ TAG- WPWP+	0.200	0.000	0.000	0.200	0.000	0.200	0.000	0.400

Demand and Factor Supply Curves

The required parameters for the construction of the residential water demand curve are the quantity used, water rates, the municipal fractional monthly water usage by county, monthly residential own-price elasticities (from Bell and Griffin 2011), climate elasticities (from Bell and Griffin 2005), and the variable cost of water. A climate-driven shifting factor is introduced to reflect the effect of climate on water demand (Bell and Griffin 2011). For industrial usage, the demand structure is similar but since no data is available, we assume the demand is constant with respect to climate variations. The crops and the water demand functions for the residential, commercial and industrial sectors take a CES form. For computing efficiency, we implement a separable programming approach with 50 steps defined. In turn, for self-supplied industries, mining, golf course irrigation and aquaculture we also assume constant marginal benefit for water usage.

Table 3 summarizes the mathematical structure of RIVERSIM. The structure of the demand and factor supply equations is incorporated in the objective function (equation 1) so that it represents the weighted net benefit from water use, where $prob(s)$ is the probability of each DCV phase combination (s); t is the type of water use; P_{sctm} and Q_{sctm} are the monthly water price and quantity, which differ across counties (c) and months (m); MC_{sctmd}

are the marginal cost functions of water supply; and DQ_{sctmd} are the amounts of water withdrawn from a river place. Crop insurance (equation 2) is embedded in the objective function where the per unit indemnity, $I_{c,crops}$, is assumed to be the market price in the base year; $\bar{Y}_{crops}$ is the insured yield which is assumed as the average level of yield in each county during the sample period 1960-2010. The premium per acre ($\overline{premium}_{crops}$) is based on the average loss per acre from DCV impacts in each affected county.

Table 3: RIVERSIM Mathematical Structure

$\sum_s prob(s) \left(\sum_c \sum_t \sum_m \left(\int_0^{Q_{sctm}} P_{sctm}(Q_{sctm}) dQ_{sctm} - \sum_c \int_0^{DQ_{sctm}} MC_{sctm}(DQ_{sctm}) dDQ_{sctm} - \sum_j \int_0^{DQ_{sctm}} MC_{sctmj}(GQ_{sctmj}) dGQ_{sctmj} \right) \right)$	(1)
$\left(\sum_c \sum_{crops} \sum_{ip} I_{c,crops} * max\left(0, \bar{Y}_{crops} - Y_{sc,crops}\right) * coverage - \overline{premium}_{crops} \right)$	(2)
$\sum_{crops} CROPACRES_{cs,Irrigated,crops} \leq IrrigatedLand_c - IRRTODRY_{cs}$	(3)
$\sum_{crops} CROPACRES_{cs,Dryland,crops} \leq DryLand_c + IRRTODRY_{cs}$	(4)
$IRRTODRY_{cs} \leq IrrigatedLand_c$	(5)
$CROPACRES_{cs,ip,crops} \leq \sum_l \lambda_{cl,ip} * mixdata_{scl,ip,crops}$	(6)
$\sum_r qinc_r * \hat{q}_{crops} * AGDEMANDs_{sr,crop,} = \sum_r CROPACRES_{cs,ip,crops} * Y_{sc,crops}$	(7)
$\sum_r qinc_r * \hat{q}_{crops} * AGDEMANDs_{sr,crops} = AGDEMAND_{s,crops}$	(8)
$\sum_r AGDEMANDs_{sr,crops} = 1$	(9)
$\sum_r qinc_r * \hat{q}_c^{dom} * DOMDIVERTERUSEs_{crsm} = \sum_c COLLECTCOUNTY_{csm}$	(10)
$DIVERTERUSEDOM_{sm,reaches} = \sum_c \sum_{reaches} COLLECTCOUNTY_{csm}$	(11)
$\sum_r qinc_r * \hat{q}_c^{ind} * INDDIVERTERUSEs_{crs} = \sum_c \sum_s COLLECTINDUSTRY_{cs},$	(12)
$INDDIVERTERUSE_{s,reaches} = \sum_c COLLECTINDUSTRY_{cs,reaches}.$	(13)
$\sum_{crops} CROPACRES_{cs,ip,crops} * cropdata_{cs,crops} = \sum_c \sum_{reaches} AGWATERUSE_{cs}.$	(14)
$DIVERSION_{cs,sector} \leq \sum_{reaches} \sum_c \sum_{sector} UpperDiversion_{c,reaches,sector.}$	(15)
$\sum_{months} DIVERTERUSEDOM_{s,m,reaches} \leq \sum_c DIVERSIONQDOM_{cs,reaches}$	(16)
$DIVERTERUSE_{s,reaches} = \sum_c \sum_{sector} DIVERSIONQ_{cs,reaches},$	(17)
$MINDIVERTERUSE_{s,reaches} = \sum_c \sum_{reaches} COLLECTMINING_{c,reaches}$	(18)
$AQUADIVERTERUSE_{s,reaches} = \sum_c \sum_{reaches} COLLECTAQUA_{c,reaches},$	(19)
$GOLFDIVERTERUSE_{s,reaches} = \sum_c \sum_{reaches} COLLECTGOLF_{c,reaches},$	(20)
$AGDIVERTERUSE_{s,reaches} = \sum_c \sum_{reaches} AGWATERUSE_{cs},$	(21)
$INDSELFCOLLECT_{cs} \leq selfIndDemand_c, \forall s$	(22)
$\sum_{sector} \sum_c \sum_s DIVERSION_{cs,sector} + FlowOut_{sm} + STOREafter_{sm} + OUTMRB_{sm} \leq RETURN_{sm} + FlowIn_{sm} + STOREbefore_{sm}$	(23)
$STOREafter_{sm} \leq storage_s,$	(24)
$STOREbefore_{sm} \leq storage_s.$	(25)
$\sum_s prob(s) * (\sum_m (STOREafter_{sm} - STOREbefore_{sm})) = 0$	(26)

Equations (3) and (4) are land constraints for agriculture, where $IrrigatedLand_c$ and $DryLand_c$ are, respectively, the amounts of irrigated and dry land available at each county; $IRRTODRY_{cs}$ is the amount of converted irrigated land to dryland. Land conversion cannot exceed the amount of irrigated land available at each county (equation 5).

Crop mix balance is on equation 6, where $\lambda_{cl,ip}$ denotes the contribution from historical harvests to the formation of the optimal acreage solution. For the price-endogenous nature of RIVERSIM, equation 7 represents the agricultural markets clearing conditions, and equation 8 the contribution of each step of the approximation such that the summation must equal the aggregate agricultural demand. The crop demand value is approximated by a convex combination of the function evaluated at the grid points so that $AGDEMANDs_{s,crops,steps}$, in equation 9, gives the contribution of each grid point in the approximation (Adams 1996).

Equation 10 indicates that the total water diversion for residential usage equals the demand. Equations 11 to 13 represent the stepwise water usage function and the balancing constraint between all diversions for commercial or industrial purposes ($INDDIVERTERUSE_{s,reaches}$) and usage ($COLLECTINDUSTRY_{cs,reaches}$). We assume that the water for irrigation usage ($AGWATERUSE_{cs}$) is linearly proportionate to the $CROPACRES_{cs,ip,crops}$ variable, and is determined once the DCV phase combination becomes known. Equation 15 represents the maximum water diversions ($DIVERSION_{cs,sector}$) allowed from all rivers. The upper diversion limits ($UpperDiversion_{c,reaches,sector}$) correspond to the 2005 water consumption increased by

10% in order to get an approximate figure for 2010 consumption (Kenny 2009). Equations 16 and 17 link river diversions to the estimated usage for all sectors, whereas equations 18 to 22 are the balancing constraints between all diversions for mining, aquaculture, golf courses irrigation use, agriculture and self-supplied industries and the estimated usage.

Equation 23 depicts that for each influence zone, water outflows cannot exceed inflows, where $FLOWout_{sm}$ denotes water outflows downstream; $STOREafter_{sm}$ is the amount of water stored at the end of a month in a reservoir; $OUTMRB_{sm}$ represents the outflows out of the MRB; $FLOWin_{sm}$is the inflows from upstream; $STOREbefore_{sm}$ denotes the amount of water stored at the beginning of a month in a reservoir; and $RETURN_{sm}$ is the amount of water returned to the stream flows after serving a particular economic purpose. Equations 24 and 25 represent that water stored, either at the beginning or end of any month, cannot exceed the storage capacity of a reservoir ($storage_s$). Finally, equation 26 is a storage balance constraint for any reservoir. That is, the probability-weighted sum of water stored at the end of the month must be in balance with the probability-weighted sum of water stored at the beginning of the month in a reservoir.

4. RESULTS

Consumers' and Producers' Surplus

Table 4 reports the producers' and consumers' surplus for the historical case,

whereas

Table **5** reports the percentage deviations of consumers' and producers' surplus between the transition probabilities case and the historical case. Results concur with Chen et al. (2002) and Mjelde and Hill (1999) in the sense that information may not necessarily benefit producers. The forecast improves production and causes a rightward shift in the supply curve, which coupled with an inelastic demand curve, can result in producer losses. We find that when insurance is not available producers' surplus decreases across DCV phase combinations, but these declines are less pronounced when insurance is introduced. Moreover, there are potential gains under the PDO- TAG+ WPWP+, PDO+ TAG+ WPWP+ and PDO- TAG- WPWP+ scenarios. In turn, consumers' surplus increases occur under all phases but shows small gains with insurance under PDO- TAG- WPWP+ and PDO+ TAG+ WPWP–.

Table 4: Average Consumers' and Producers' Surplus under the Historical Distribution (U.S. dollars)

Producers' surplus	3.05E+10
Consumers' surplus	1.45E+23

Table 5: Consumers' and Producers' Surplus under Transition Probabilities - Percentage Deviation from Model runs based on Historical Frequencies

	No Insurance		Insurance	
	Producers' surplus	Consumers' surplus	Producers' surplus	Consumers' surplus
PDO- TAG- WPWP-	-8.60	38.30	-0.04	38.30
PDO- TAG+ WPWP-	-8.93	24.36	-0.03	24.36
PDO- TAG+ WPWP+	-15.43	47.22	0.00	47.22
PDO+ TAG+ WPWP+	-10.98	54.49	0.38	13.98
PDO- TAG- WPWP+	-14.49	18.29	3.04	18.29
PDO+ TAG+ WPWP-	-9.57	27.46	-2.85	6.52
PDO+ TAG- WPWP-	-9.64	26.90	-0.06	26.90
PDO+ TAG- WPWP+	-8.97	21.82	-0.04	21.82

Table 6 reports percentage changes in consumers’ and producers’ surplus under the perfect information case relative to the historical frequencies and the transition probabilities. For the case when no insurance is available and relative to the transition probabilities, producers’ surplus increases for all scenarios except for PDO- TAG+ WPWP+, PDO+ TAG- WPWP – and PDO+ TAG- WPWP+. For the PDO+ TAG- WPWP+, the consumers’ surplus decreases. When insurance is introduced, producers’ surplus changes are negative for PDO- TAG+ WPWP+, PDO+ TAG- WPWP- and PDO+ TAG- WPWP+, whereas for the rest of combinations changes are positive and slightly different relative to non-insurance. For the consumers’ surplus, there is a similar pattern except for PDO+ TAG+ WPWP+ where there is a sign reversal. With respect to the historical distribution case, producers’ surplus consistently decreases across DCV phase combinations, whereas for consumers’ surplus the DCV phase combinations where no decreases occur are PDO+ TAG- WPWP– and PDO+ TAG- WPWP+. When insurance becomes available, there are slight differences compared to the no-insurance case.

Table 6: Percentage Changes in Consumers’ and Producers’ surplus under Perfect Information

	No Insurance		Insurance	
	CS	PS	CS	PS
Difference from Transition Probability Case				
PDO- TAG- WPWP-	0.94	0.55	0.94	0.28
PDO- TAG+ WPWP-	-28.89	0.71	-28.89	-0.85
PDO- TAG+ WPWP+	29.54	8.89	29.54	8.49
PDO+ TAG+ WPWP+	36.70	3.16	-21.81	2.05
PDO- TAG- WPWP+	-19.65	7.40	-19.65	7.14
PDO+ TAG+ WPWP-	16.67	1.66	16.65	1.07
PDO+ TAG- WPWP-	-22.18	1.55	-22.18	-2.01
PDO+ TAG- WPWP+	-17.91	-0.49	-17.91	-0.55
Difference from Historical Frequency Case				
PDO- TAG- WPWP-	39.39	-8.12	39.39	-8.37
PDO- TAG+ WPWP-	24.16	-8.31	24.16	-9.72
PDO- TAG+ WPWP+	90.41	-7.94	90.41	-8.28
PDO+ TAG+ WPWP+	20.62	-8.18	20.62	-9.18
PDO- TAG- WPWP+	18.11	-8.19	18.11	-8.41
PDO+ TAG+ WPWP-	48.48	-8.09	48.45	-8.63
PDO+ TAG- WPWP-	-1.40	-8.26	-1.40	-11.48
PDO+ TAG- WPWP+	-0.15	-9.44	-0.16	-9.49

In Table 7, we summarize the results in the form of differences between forecast alternatives for consumers’ and producers’ surplus. The largest difference arises from the comparison between the perfect information case relative to the historical frequency. Variations occur when insurance is introduced and when compared to the transition probability case, the difference in consumers’ surplus increase but there is a sign reversal for producers’ surplus.

Table 7: Average Changes in Consumers’ and Producers’ Surplus for the Forecasts

	Without insurance		With insurance	
	CS in billion $	PS in million $	CS in billion $	PS in million $
Perfect information relative to historical frequency	5.02	-0.271	5.520	-0.00932
Perfect information relative to transition probability	0.43	0.0752	2.05	0.0641
Transition probability	4.58	-0.346	3.47	-0.0734

relative to historical frequency

Value of Information

In Table 8, when insurance is introduced, the VoI decreases for the transition probability case by 24%. This shows that insurance covers about a quarter of the welfare variation due to DCV events. In turn, with insurance VoI almost quintuples for the perfect information case relative to the transition probability. Insurance reinforces the effects of resolving uncertainty on next year’s DCV phase combination. There are important reactions on producers given the wider decision space.

Table 8: Value of DCV Information with and without insurance in billion U.S.$

	Perfect information relative to transition probabilities	Perfect information relative to historical frequency	Perfect information relative to transition probabilities
Insurance	3.471	5.520	2.050
No Insurance	4.580	5.027	0.431

Adaptation on Crop Acreage

Given the forecasts, producers may adjust plans to better their economic situation. Here we present results on the nature of the crop mix shifts. We will refer to these as adaptation. Table 9 reports total acreage by crop when agricultural actions are predicted on the historical frequency and do not vary by DCV phase combination. For space constraints we only present results for sorghum, wheat (winter and spring), soybeans and corn.

Table 9: Total Acreage in the MRB - Historical Distribution of Crops in Acres

Corn	22,155,920	Winter wheat	4,951,799
Sorghum	120,349	Spring wheat	5,148,038
Soybeans	14,165,290		

Acreage mix results under the forecasts (Table 10) show wide adaptation given the transition probability forecast. Corn shows positive acreage shifts for PDO- TAG- WPWP- and PDO- TAG+ WPWP+, with negative shifts occurring for PDO- TAG- WPWP+ and PDO+ TAG- WPWP+. Large shifts occur for sorghum under PDO- TAG- WPWP+ and PDO+ TAG+ WPWP+. For spring wheat acreage is 50% higher under PDO- TAG- WPWP+ compared to the historical case, but are almost negligible for PDO+ TAG- WPWP–.

Table 10: Adaptation in Total MRB Acreage under information on Transition Probabilities without Insurance compared to Historical Distribution (Percentage Change)

	PDO- TAG- WPWP-	PDO- TAG- WPWP+	PDO- TAG+ WPWP-	PDO- TAG+ WPWP+	PDO+ TAG- WPWP-	PDO+ TAG- WPWP+	PDO+ TAG+ WPWP-	PDO+ TAG+ WPWP+
Corn	3.45	-10.98	3.06	4.05	-0.01	-0.62	1.58	0.93
Sorghum	4.62	1788	4.13	4.28	0.06	5.00	5.13	1241
Soybeans	-0.14	-37.39	0.09	-0.38	-0.05	-0.04	-3.66	-26.07
Winter wheat	-14.23	59.23	-10.70	-15.99	-0.14	-18.14	-15.48	13.46
Spring wheat	5.60	50.08	3.33	3.20	0.08	6.75	7.01	22.18

As observed in

Table 11, crop insurance modifies adaptation described in Table 10. In some of the cases, there are larger acreage shifts, such as for winter wheat and sorghum. This does not occur for spring wheat because insurance motivates opposite sign adaptations under PDO- TAG- WPWP- and PDO- TAG- WPWP+. For soybeans, the only case where greater adaptation occurs is for DCV phase combination PDO+ TAG+ WPWP+.

Table 11: Adaptation in Total MRB Acreage under information on Transition Probabilities with Insurance compared to Historical Distribution (Percentage Change)

	PDO- TAG- WPWP-	PDO- TAG- WPWP+	PDO- TAG+ WPWP-	PDO- TAG+ WPWP+	PDO+ TAG- WPWP-	PDO+ TAG- WPWP+	PDO+ TAG+ WPWP-	PDO+ TAG+ WPWP+
Corn	-0.73	-5.93	3.03	-3.83	-0.28	-0.02	-4.83	-2.86
Sorghum	543.19	1040	-25.52	-31.50	-28.15	-27.22	759.70	161.54
Soybeans	-11.69	-19.31	-0.01	-8.64	-5.22	-0.24	-18.85	2.91
Winter wheat	5.09	26.38	-9.68	-21.01	-13.23	-17.61	3.00	-13.78
Spring wheat	-16.37	-37.21	2.63	-5.18	-34.69	5.65	-56.30	9.84

Table 12 reports adaptation under the perfect forecasts relative to the transition probability case. Winter wheat acreage decreases occur for all DCV phase combinations, whereas for soybeans the only large changes are for DCV phase combination PDO+ TAG+ WPWP+. On the other hand, Table 13 reports the results under insurance. Relative to the no insurance case corn acreage adaptation is positive across all phase combinations but PDO- TAG+ WPWP-. Acreage reduction occurs across all DCV phase combinations for winter wheat, whereas spring wheat acreage increases occur across all phase combinations except for PDO+ TAG- WPWP+ and PDO+ TAG+ WPWP+.

Table 12: Adaptation in Total MRB Acreage under Perfect Information relative to plans under Transition Probabilities without Insurance (Percentage Change)

	PDO- TAG- WPWP-	PDO- TAG- WPWP+	PDO- TAG+ WPWP-	PDO- TAG+ WPWP+	PDO+ TAG- WPWP-	PDO+ TAG- WPWP+	PDO+ TAG+ WPWP-	PDO+ TAG+ WPWP+
Corn	-2.52	13.26	-1.94	-2.93	1.96	1.42	-0.76	-0.13
Sorghum	1.43	-94.51	1.88	-0.48	0.97	-0.50	1.41	-92.24
Soybeans	-0.78	58.68	-1.09	-0.29	4.54	-0.39	2.97	34.38
Winter wheat	-8.87	-51.06	-12.64	-7.10	-10.75	-6.11	-8.93	-32.20
Spring wheat	-1.40	-30.41	1.04	1.57	-3.81	-2.02	-2.12	-14.28

Table 13: Adaptation in Total MRB Acreage under perfect information relative to plans under Transition Probabilities with Insurance (Percentage Change)

	PDO- TAG- WPWP-	PDO- TAG- WPWP+	PDO- TAG+ WPWP-	PDO- TAG+ WPWP+	PDO+ TAG- WPWP-	PDO+ TAG- WPWP+	PDO+ TAG+ WPWP-	PDO+ TAG+ WPWP+
Corn	1.58	7.18	-1.91	5.02	1.28	0.82	5.93	3.77
Sorghum	-83.50	-90.91	42.43	51.50	48.95	43.54	-87.60	-60.21
Soybeans	12.18	23.12	-0.98	8.73	4.90	-0.18	22.26	-3.47
Winter wheat	-25.63	-38.34	-13.64	-1.20	-11.11	-6.71	-25.26	-10.78
Spring wheat	24.50	66.34	1.73	10.54	59.72	-1.01	139.68	-4.65

Land Conversion from Irrigated to Dryland

In the historical frequency case, the amount of converted land reaches 219,200 acres.

When insurance is available and under the transition probability case (

Table **14**), percentage changes are relatively small and almost all of them are negative, excepting for PDO- TAG+ WPWP- where there is an expansion. Without insurance, the amount of converted land greatly increases with respect to the historical distribution particularly for PDO- TAG+ WPWP+ where because of the persistent droughts associated producers may be forced to convert.

Table 14: Percentage Changes in Irrigated Land Converted to Dryland in the MRB under Transition Probabilities compared to the Historical Frequency

	Insurance	No Insurance
PDO- TAG- WPWP-	-10.54	650.18
PDO- TAG+ WPWP-	4.94	638.16
PDO- TAG+ WPWP+	-6.01	727.28
PDO+ TAG+ WPWP+	-39.41	349.56
PDO- TAG- WPWP+	-61.54	128.17
PDO+ TAG+ WPWP-	-7.77	494.32
PDO+ TAG- WPWP-	-2.85	507.27
PDO+ TAG- WPWP+	-32.62	600.20

Table 15 reports converted land under perfect information. Compared to the transition probability case and with insurance, there are large expansions for PDO- TAG+ WPWP- and PDO- TAG- WPWP+, whereas for the rest the changes are smaller or even negative. Without insurance, there are sign reversals for PDO- TAG- WPWP- and PDO- TAG+ WPWP+, while the expansion is even larger for PDO- TAG- WPWP+ and the decrease is smaller for PDO+ TAG- WPWP+. Compared to the historical frequency case without insurance, there are expansions across all phase combinations. With insurance introduction, shifts are smaller and often of different signs. Expansions occur for phase combinations PDO- TAG+ WPWP- and PDO+ TAG- WPWP-, whereas decreases occur for PDO- TAG- WPWP- and PDO+ TAG+ WPWP-.

Table 15: Percentage Changes in Converted Irrigated Land to Dryland in the MRB under Perfect Information relative to plans under Transition Probabilities and Historical Frequency

	Insurance	No Insurance	Insurance	No Insurance
	Difference from transition probability case		Difference from historical frequency case	
PDO- TAG- WPWP-	-11.37	26.36	-20.71	847.96
PDO- TAG+ WPWP-	61.67	0.47	69.66	641.61
PDO- TAG+ WPWP+	17.70	-3.62	10.63	697.35
PDO+ TAG+ WPWP+	15.69	50.21	-29.90	575.27
PDO- TAG- WPWP+	102.04	229.14	-22.29	651.00
PDO+ TAG+ WPWP-	-30.65	-7.05	-36.04	452.42
PDO+ TAG- WPWP-	43.36	-19.02	39.28	391.79
PDO+ TAG- WPWP+	-8.32	-4.91	-38.23	565.83

Insurance Payouts

Under the historical distribution the size of the insurance payouts reaches 382 million dollars. When the forecast occurs under the transition probabilities (Table 16), we find that the payouts are the highest for DCV phase combinations PDO- TAG+ WPWP+ and PDO- TAG- WPWP+ which reflects their association to persistent droughts and large negative effects on crop yields. This concurs with the idea that droughts are widespread across the MRB affecting dryland crops and generating losses that are covered by insurance (Mehta el al 2012). The payouts are the lowest for DCV phase combination PDO+ TAG- WPWP- where no extreme anomalous events are typically reported. Results suggest that insurance may stabilize revenues and protect producers from exposures to weather-related risk associated with DCV. Interaction between insurance and forecasts operate such that under the transition probabilities, insurance payouts are 402 million dollars whereas under perfect forecast they are 395 million.

Table 16: Insurance Payouts in the MRB (U.S. dollars)

	Transition Probabilities	Perfect Forecast	Historical
PDO- TAG- WPWP-	411,064,800	455,482,000	386,683,400
PDO- TAG+ WPWP-	401,743,800	312,484,500	369,996,400
PDO- TAG+ WPWP+	432,296,100	453,736,400	406,282,500
PDO+ TAG+ WPWP+	410,280,800	395,021,300	376,070,700
PDO- TAG- WPWP+	421,644,100	445,023,800	410,237,100
PDO+ TAG+ WPWP-	374,336,800	367,634,800	347,650,900
PDO+ TAG- WPWP-	367,478,800	333,651,300	354,604,400
PDO+ TAG- WPWP+	397,787,800	395,730,500	383,735,300

Water Usage

With respect to water for agricultural purposes, under the historical distribution, the average amount of water utilized for agricultural purposes is 866,869 acre feet. Table 17 reports water use adaptation when using the transition probabilities relative to the historical frequency. When no insurance is available the largest deviation, in absolute value, is for PDO- TAG- WPWP+, whereas the only positive deviation is for PDO+ TAG- WPWP-. In turn, when insurance is available, water quantity for agriculture decreases across all DCV phase combinations. The largest variation is for PDO+ TAG+ WPWP+ which is associated with high levels of precipitation. These large deviations also imply land conversion to dryland since it becomes more profitable to get the insurance indemnity plus the revenue from dryland crop yields. Besides, the proper effects of decaying water sources for agriculture, particularly for PDO- TAG+ WPWP+ and PDO- TAG- WPWP-, may imply as well negative effects on irrigated crop yields so that they are not large enough to justify the cost of irrigation.

Table 17: Percentage Changes in Agriculture Irrigation Water Usage in the MRB under the Transition Probabilities relative to the Historical case

	No Insurance	Insurance
PDO- TAG- WPWP-	-4.83	-9.01
PDO- TAG+ WPWP-	-22.16	-6.00
PDO- TAG+ WPWP+	-17.20	-23.24
PDO+ TAG+ WPWP+	-18.14	-24.10
PDO- TAG- WPWP+	-26.33	-9.13
PDO+ TAG+ WPWP-	-14.58	-16.48
PDO+ TAG- WPWP-	0.14	-1.09
PDO+ TAG- WPWP+	-1.10	-6.27

Table 18 reports the deviations of agricultural water usage under a perfect forecast relative to the transition probabilities. Across all DCV phase combinations, regardless insurance availability, the amount of water used is significantly larger. For drought-related phase combinations, since it becomes known with complete certainty water sources will be scarce, producers may anticipate and invest in water storage infrastructure to cope with the droughts.

Table 18: Percentage Changes in Agriculture Irrigation in the MRB under a Perfect Forecast relative to Transition Probabilities

	No Insurance	Insurance
PDO- TAG- WPWP-	66.28	58.98
PDO- TAG+ WPWP-	36.43	64.76
PDO- TAG+ WPWP+	53.80	51.20
PDO+ TAG+ WPWP+	43.08	32.66
PDO- TAG- WPWP+	28.47	58.47
PDO+ TAG+ WPWP-	49.30	45.99
PDO+ TAG- WPWP-	75.39	73.24
PDO+ TAG- WPWP+	72.52	63.51

For residential water usage, under the historical distribution, and on a yearly basis, the total diversions are 1.189 million gallons. Under the transition probabilities case the percentage deviations for each DCV phase combination are in Table 19. Across all phase combinations, water deviations are positive. The highest deviation corresponds to PDO+ TAG+ WPWP+ which is associated with large precipitation, and then for PDO- TAG+ WPWP+ where temperatures are relatively higher and stream flows are scarce. On average, deviations are 9.6% larger than under the historical case. The lowest deviations are found in PDO- TAG+ WPWP- and PDO- TAG- WPWP+. In absolute value, adaptation for residential usage is 6.45%, whereas for agricultural purposes it reaches 13% without insurance and 12% with insurance, that is, in both cases adaptation almost doubles the reaction on residential usage for the introduction of forecasts.

Table 19: Percentage Changes on Water Diversions for Residential Usage under Transition Probabilities relative to Historical Frequency

PDO- TAG- WPWP-	6.40	PDO- TAG- WPWP+	3.77
PDO- TAG+ WPWP-	3.54	PDO+ TAG+ WPWP-	4.58
PDO- TAG+ WPWP+	9.61	PDO+ TAG- WPWP-	4.39
PDO+ TAG+ WPWP+	15.53	PDO+ TAG- WPWP+	3.83

5. CONCLUSIONS

It has long been known that the ocean has effects on the global climate and in turn on agricultural yields and water availability. Select ocean phenomena, like ENSO, have been widely discussed and analyzed in terms of their implications for agriculture, and water supply. There has also been substantial work on the value of forecasts and the nature of adaptive actions. This paper addresses another case of ocean effects, namely decadal climate variability (DCV). DCV phases may persist for seven to twenty years with long lasting effects on water supply and agriculture (Mehta, Rosenberg and Mendoza 2011). The influence of a particular DCV phenomena and phase may remain despite phase changes in other DCV phenomena. This introduces a complication to the VoI framework because of possible dominance of one DCV-phase over the others (Gan and Wu 2012). We examine phase combinations plus transition probabilities between phase combinations estimated from the time sample. These probabilities reflect the likelihood of a shift to another DCV phase combination while simultaneously considering the interaction of all three DCV phenomena.

An examination is implemented on the nature of adaptations and the associated value of information with and without DCV information. In doing this, we rely on yield and water DCV impact estimates provided by Mehta, Rosenberg and Mendoza (2012) and Srinivasan et al. (unpublished). This is done in a Missouri River Basin case study and in order to simulate adaptation under uncertain yield outcomes we incorporate DCV impacts on spring wheat, winter wheat, sorghum, soybeans and corn into a mathematical programming model along with water data. We also include yield insurance as an additional risk management alternative and observe the interaction of insurance use with forecast information.

Overall, we find of the possible welfare increases achieved by a perfect forecast, which averages 5.02 billion dollars. The vast majority of this, 4.58 billion dollars, can be obtained by simply relying on a forecast based on historical transitions. We find that crop insurance lowers the returns to DCV forecasts under transition probabilities by 24% as they in part manage the same risks as do the forecasts. The interaction of insurance and perfect forecasts, relative to the transition probabilities, causes the VoI to almost triple. Insurance and forecasts reinforce each other in the formation of the optimal producers' responses. Because of the long-term and insurable nature of DCV perturbations, the value of information in this case is diminished.

In terms of adaptation, the results in this paper are a signal on how the use of forecasts may permit valuable adaptive responses. We find important adaptations in crop mixes and water use. Relative to the historical frequency, under the transition probability information, without insurance, there are significant acreage expansion in the acreage of sorghum, whereas important reductions occur for the rest of crops. Once insurance is introduced sign reversals appear for spring wheat and winter wheat across all DCV phase combinations. When perfect information is available without insurance, acreage reductions occur for winter wheat and increases appear for spring wheat. The interaction of insurance with a perfect forecast motivates reductions in sorghum along with increases for corn, sorghum and soybeans. It appears that insurance modifies the nature of adaptation to DCV forecasts and introduces a somewhat larger reaction in terms of acreage choice.

In terms of agricultural water usage adaptation, the largest deviations in water consumption are for phase combinations PDO- TAG+ WPWP- and PDO- TAG- WPWP+, both mildly associated with persistent droughts. These adaptations are much smaller (60%) when insurance is present. In regard to phase combinations PDO- TAG+ WPWP+ and PDO+ TAG+ WPWP+ insurance has the opposite effect where it reinforces the effects of DCV forecasts causing larger deviations in irrigation water.

Examination of insurance payouts reveals an interaction between insurance and DCV forecasts. When no forecast is available, that is, under the historical distribution, payouts reach 382 million dollars; but under the transition probability forecast and the perfect information forecast, payouts reach 402 million and 395 million dollars, respectively. This is consistent with the results above in the sense that insurance modifies not only the nature of adaptation on crop acreage, but also the expectations on losses and the necessary adjustments to cope with DCV effects.

Some limitations of this work and associated research needs are worth mentioning. First, the analysis is confined to the MRB and to 12 crops with DCV yield impacts only included for 5 of those crops. A more comprehensive analysis could expand RIVERSIM to the entire continental U.S. plus coverage of more crops. Second, data on water diversion locations and their categorization by economic sectors do not exist. To overcome this, more detailed hydrological modeling like that done in SWAT is needed. Third, the insurance scheme utilized is relatively simple and could be improved. Fourth, the paper analyzes DCV on its own without any interaction with greenhouse gas related climate change. Fifth, no information on water rights is included, and such considerations could modify the results. A closer look across spatial locations would give additional information on adaptive responses.

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