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Adoption of improved irrigation scheduling methods in Alberta: An empirical analysis

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This study examines the adoption of improved irrigation scheduling methods in Alberta and identifies the major factors that influence farmers' decisions to adopt them. The data were collected in a large farm-household survey conducted in 12 irrigation districts as well as among private irrigators in southern Alberta. Results show that the most commonly adopted improved irrigation scheduling method was the "feel and appearance (of soil) method." Only a few farmers adopted other methods. Based on descriptive and econometric analysis (logit and Tobit models), the sources of information, the size of the farm, farm succession and accessing external support significantly influenced the adoption decision of farmers.

Cette étude examine l'adoption d'une méthode améliorée de planification de l'irrigation en Alberta, et identifie les principaux facteurs qui influencent les décisions des agriculteurs. Les données ont été recueillies selon un vaste sondage conduit auprès des ménages agricoles dans 12 districts d'irrigation, ainsi que les irrigants privés dans le sud de l'Alberta. Les résultats montrent que la méthode améliorée de planification de l'irrigation la plus adoptée est la méthode de "toucher et l'aspect (de sol)." Seulement quelques agriculteurs ont adopté des autres méthodes. Basé sur l'analyse descriptive et économétrique (Les modèles Logit et Tobit), les sources d'information, la taille de la ferme, la succession de la ferme, et l'accès de soutien externe ont significativement influencé la décision d'adoption des agriculteurs.

Introduction

Agricultural production in southern Alberta is highly dependent on irrigation. The availability of surface water in Alberta is most plentiful in the north-flowing river basins, yet the majority of the population and economic activity in the province is located in the water-scarce south (Wood 2008). As a consequence, water demand is very high in areas with low water supply. In addition, in much of southern Alberta, while sunshine and heat units are abundant and agricultural land is productive, natural precipitation is insufficient to sustain agricultural crops in most years (Alberta Agriculture and Rural Development 2013a). Therefore, even early in the settlement of Alberta, it was recognized that agriculture would not be successful in the southern region without an adequate and secure supply of water for irrigation.

Irrigation is the largest consumer of water in Alberta, accounting for 60 to 65% of all water consumed in an average year (Alberta Environment 2007). More importantly, irrigators control more than 80% of the volume of all water licenses within the South Saskatchewan River Basin (SSRB). The SSRB, with more than 8000 km of conveyance works and 50 water storage reservoirs devoted to manage a finite water resource, provides water for 82% of the total irrigated area in Alberta.

Water availability for irrigation is facing increased competition from non-agricultural water users, and this has been recognized by policy makers in Alberta. From the 1950s to 2000, total water used in Alberta increased three-fold while the share of water used in agriculture declined from more than 90% to less than 65% (Alberta Environment 2007). The shift in proportional water use between agriculture and industry has not been associated with a reallocation of water between sectors; rather, a large proportion of the increase is associated with mining and other industrial uses, mainly in the north of the province. With an expected continual increase in demand from the non-agricultural sectors and increased acknowledgement that overall extraction needs to be reduced to address emerging water quality problems in many water courses within the SSRB, there is increased pressure on the irrigation sector to contribute to resolve these issues. In order to deal with increasing water scarcity, Alberta in 1991 moved to limit the water allocated to agriculture (Alberta Environment 2003) and introduced two new legislative acts: the *Water Resources Act, 1999* and the *Irrigation Districts Act, 2000*, which, among other

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Table 1. Adoption of irrigation scheduling methods and its intensity in southern Alberta.

	Adoption Percentage of households (%)	**Adoption intensity** Percentage of total irrigated area (%)
Traditional method – visual monitoring	33.17	48.46
Improved methods	66.83	51.54
Feel and appearance method	60.80	43.15
Monitoring instruments	4.52	3.24
Computer/phone	0.50	0.03
Web-based programs	1.01	0.15
Private consultants	8.04	4.97

Note: Data source: field survey data collected by the University of Lethbridge.

things, introduced the possibility of water trading as a means to meet new demand under scarcity conditions (Bjornlund et al. 2009). Following a major drought in 2001–2002, the Alberta government embarked on a public review process for developing a long-term strategy for provincial water management (Bjornlund et al. 2009). This process resulted in the release of the *Water for Life* strategy in 2003. This strategy proposes that water conservation can be achieved through a 30% increase in water use efficiency and productivity. As irrigation is the largest water-consuming sector, ways to improve water management in this sector are a prime concern of the strategy. Importantly, there is still much space to improve the scheduling methods in Alberta (Hohm et al. 2002; Nischelm et al. 2011).

Internationally, proper irrigation scheduling, based on timely measurements or estimations of soil moisture content and crop water needs, is one of the most important and best practices for irrigation management. Water stress at any plant growth stage will reduce yield and affect crop quality (Stark 2003). Therefore, to prevent water stress-induced losses, irrigation scheduling should match water applications to crop water requirements in a timely and efficient manner. According to Broner (2005), the purpose of irrigation scheduling is to determine the appropriate amount of water to apply to the crop, where it is needed and the proper timing of the application. Normally, irrigation scheduling involves regular evaluations of soil moisture, crop water use and plant status, and then scheduling irrigation to replace the depleted moisture (Alberta Agriculture and Rural Development 2013b). Evaluating soil moisture is the critical part of irrigation scheduling (Klocke and Fischbach 1984). By improving irrigation scheduling, researchers expect a reduction in overall water use. Results from case studies show that improved scheduling of irrigation has reduced water use in individual years by up to 50% and, over a number of years, reductions have averaged from 8 to 25% (Sadler et al. 2005; Yule et al. 2008; Hedley and Yule 2009). In addition, improved irrigation scheduling methods also have the potential to reduce labour and energy inputs (Alberta Agriculture and Rural Development 2013b).

Generally, irrigation scheduling methods can be categorized into three methods: soil-based, plant-based and evapotranspiration (ET)-based methods (Alberta Agriculture and Rural Development 2013b). Measuring soil water is a critical part of determining the amount of water needed to bring the soil moisture in the crop root zone to field capacity, at which crop growth is promoted most effectively. Traditionally, farmers use a visual monitoring method to assess the soil moisture, such as using a shovel to lift, kick and handle the soil, and then make a decision on irrigation scheduling. Compared with the traditional methods, the feel and appearance methods have made significant improvements in the accuracy of assessment since, by using an auger, soil probe or core sampler, soil moisture deeper in the soil profile can be sampled and assessed (National Sustainable Agriculture Information Service 2012). Internationally, feel and appearance methods remain one of the most used soil-based methods of assessing irrigation requirements (Howell 1996).

The theory behind the plant-based methods is that plant growth is directly related to plant water status and only indirectly related to soil moisture and atmospheric conditions (Alberta Agriculture and Rural Development 2013b). Because plant-based methods provide information only on whether or not irrigation is needed, soil based-methods have been encouraged in Alberta.

The ET-based methods (also referred to as weather-based methods) track the ET losses and water added by irrigation or from precipitation to decide on irrigation scheduling (Henggeler et al. 2011). Palmer (2005) observed that advances in weather station and data transfer by satellite, phone, radio or wireless networks have improved ET-based methods. Compared with soil-based methods, ET-based methods can save much labour input since farmers do not need to take soil samples. However, not all farmers have the financial and knowledge capacity to successfully install and operate ET-based methods.

Table 2. Information sources, support services, social capital and their association with adoption decisions.

		Adoption Adopting or not adopting[a]	Adoption intensity Proportion of irrigated area adopted[b]
Information sources			
Extension agencies	Yes	0.74***	0.58**
	No	0.55	0.42
Other government	Yes	0.58	0.53
	No	0.68	0.51
Individual farmers or farmers' associations	Yes	0.73	0.52
	No	0.63	0.51
Media	Yes	0.78*	0.57
	No	0.64	0.50
Support service			
Receiving support service	Yes		0.68***
	No		0.45
Social capital			
Member of a water planning advisory council or watershed stewardship group	Yes	0.64	0.54
	No	0.67	0.51
Member of an environmental or conservation group	Yes	0.76	0.58
	No	0.66	0.51
Member of a recreational or social organization	Yes	0.73	0.56
	No	0.62	0.48
Attending farm meetings	Yes	0.76**	0.59**
	No	0.61	0.46

Note: [a]When a household adopted the feel and appearance method, monitoring instruments, computer/phone, web-based programs or private consultants, it was thought to adopt improved irrigation scheduling methods. [b]The proportion of irrigated area with improved irrigation scheduling methods to the total irrigated area. *Absolute value of the t-statistics is significant at the 10% level; **absolute value of the t-statistics is significant at the 5% level; ***absolute value of the t-statistics is significant at the 1% level.

The development of an operational plan for implementation of improved irrigation scheduling on individual farms can be complicated (Howell 1996). Based on a comprehensive literature review, Stirzaker (2006) identified a range of barriers to the adoption of soil moisture monitoring practices, including limited information and knowledge, risk attitude, limitations due to farm layout, poor distribution uniformity and labour shortage. High fixed costs, lack of technology delivery mechanisms, lack or inaccessibility of information and demonstration sites and the nature of various irrigation systems also have been identified as major constraints to adoption of irrigation scheduling (Khanna et al. 1999; Cook et al. 2006; Alberta Agriculture and Rural Development 2013b). In addition, adoption is also closely related to the characteristics of farmers and the farms they operate. For example, studies in Arkansas (Popp and Griffin 2000) and Illinois, Indiana, Iowa and Wisconsin (Khanna et al. 1999) identified that early adopters tend to be younger and more highly educated and tend to operate larger farms.

Despite the importance of implementing improved methods of irrigation scheduling in the field, very limited information on adoption and factors that influence adoption exist in Alberta. In 2013, Alberta Agriculture and Rural Development (2013b) published the *Alberta irrigation management manual*, which summarized the major irrigation technologies and scheduling methods used in Alberta. However, as pointed out in this manual, due to the lack of a comprehensive survey, no information is available on the actual adoption rates of various scheduling methods, so guidance is provided mainly by personal experts. Indeed, only two studies on the adoption of irrigation management in Alberta were found, one based on a survey within two irrigation districts (Bjornlund et al. 2009) and another based on a survey with private irrigators (Nicol et al. 2010).

Bjornlund et al. (2009) found that a majority of irrigators in two irrigation districts monitor moisture and schedule irrigation by visual inspection of crop conditions and the use of a hand auger (the instrument most commonly used for the feel and appearance method) to physically inspect the appearance and feel the moisture content of the soil. However, the adoption of more advanced measures to schedule irrigation (such as using advanced monitoring instruments, internet sources or private consultants) remained very low until as recently as 2006. Their study concluded that there is considerable room for improvement in the area of irrigation management, which generally is much less expensive than investing in improved irrigation technologies. The reasons given for not adopting are that farmers perceived that they already used the most efficient technologies and scheduling methods and/or faced financial constraints. The main drivers of

Table 3. Farm and household characteristics and their association with adoption decisions.

		Adoption Whether or not to adopt[a]	Adoption intensity Proportion of irrigated area adopted[b]
Farm characteristics			
Farm size (ha)			
	<180	0.51	0.38
	180–560	0.70**	0.56**
	>560	0.79***	0.61***
Farm type			
	Corporation	0.83***	0.69***
	Partnership	0.63	0.45
	Sole	0.51	0.35
Irrigated land as proportion of total land area			
	<0.39	0.58	0.43
	0.39–0.94	0.69	0.55*
	>0.94	0.74**	0.57**
Has a livestock enterprise that uses output of crops or forages			
	Yes	0.67	0.51
	No	0.66	0.52
Household characteristics			
Family size (number)			
	<3	0.61	0.46
	3–4	0.7	0.54
	>4	0.82**	0.66**
Number of generations with ownership of this farm			
	0–1	0.52	0.42
	2	0.73**	0.53
	>2	0.73**	0.57**
Age (years)			
	<52	0.77	0.56
	52–58	0.7	0.57
	>58	0.54***	0.42**
Education (**b**achelor's or higher degree)			
	Yes	0.74	0.61*
	No	0.65	0.49
Off-farm work			
	Yes	0.56**	0.41**
	No	0.72	0.57
Farm experience (years)			
	<24	0.61	0.44
	24–36	0.73	0.61**
	>36	0.67	0.49
Operating the farm before taking over its management			
	Yes	0.73**	0.56*
	No	0.56	0.44
Current status of father/father-in-law (1 = working farmer; 0 = not working farmer)			
	Yes	0.65	0.5
	No	0.70	0.53

Note: [a]When a household adopted the feel and appearance method, monitoring instruments, computer/phone, web-based programs or private consultants, it was thought to adopt improved irrigation scheduling methods. [b]The proportion of irrigated area with improved irrigation scheduling methods to the total irrigated area. *Absolute value of the t-statistics is significant at the 10% level; **absolute value of the t-statistics is significant at the 5% level; ***absolute value of the t-statistics is significant at the 1% level.

adoption were identified as improving crop yield and quality, and reducing labour and energy cost. Nicol et al. (2010) found that private irrigators in Alberta also were slow to adopt improved irrigation scheduling methods in the past and had little intention of doing so in the future.

As one of the places trying to focus on the need to apply proper irrigation scheduling methods, Alberta provides a good opportunity to improve our understanding of the impediments to the adoption of proper irrigation scheduling. The experience in Alberta not only provides important empirical evidence to support policy makers and water managers who are trying to introduce policies or incentives for the adoption of proper scheduling methods, but also provides useful experiences and lessons for other regions in the world that face similar challenges. Based on the two existing studies (Bjornlund et al. 2009;

Table 4. Regression results of the determinants of farmers' decisions on adopting improved irrigation scheduling methods (Logit model) in Alberta, Canada.

	Adoption: whether or not to adopt (1 = yes; 0 = no)			
	Model 1		Model 2	
	Coefficient	Marginal effect	Coefficient	Marginal effect
Information sources				
Extension agencies (1 = yes; 0 = no)	0.736	0.142	0.676	0.129
	(1.50)	(1.50)	(1.35)	(1.35)
Other government (1 = yes; 0 = no)	–0.978	–0.213	–1.010	–0.219
	(1.43)	(1.43)	(1.44)	(1.44)
Individual farmers or farmers' association (1 = yes; 0 = no)	1.293***	0.220***	1.356***	0.227***
	(2.58)	(2.58)	(2.60)	(2.60)
Media (1 = yes; 0 = no)	0.590	0.101	0.457	0.079
	(1.05)	(1.05)	(0.82)	(0.82)
Social capital				
Member of a water planning advisory council or watershed stewardship group (1 = yes; 0 = no)	0.110	0.020	0.347	0.059
	(0.15)	(0.15)	(0.46)	(0.46)
Member of an environmental or conservation group (1 = yes; 0 = no)	0.727	0.116	0.897	0.135
	(1.03)	(1.03)	(1.22)	(1.22)
Member of a recreational or social organization (1 = yes; 0 = no)	–0.154	–0.029	0.097	0.018
	(0.21)	(0.21)	(0.13)	(0.13)
Attends farm meetings (1 = yes; 0 = no)	0.429	0.078	0.291	0.053
	(0.56)	(0.56)	(0.37)	(0.37)
Farm characteristics				
Farm size (ha)	0.0002	0.00004	0.002*	0.0003*
	(0.75)	(0.75)	(1.96)	(1.96)
Farm type				
Corporation (1 = yes; 0 = no)	1.652***	0.286***	2.213***	0.368***
	(2.98)	(2.98)	(3.29)	(3.29)
Partnership (1 = yes; 0 = no)	0.727	0.121	1.361*	0.199*
	(1.26)	(1.26)	(1.95)	(1.95)
Cross variables				
Farm size × corporation			–0.001*	–0.0003*
			(1.71)	(1.71)
Farm size × partnership			–0.002*	–0.0003*
			(1.83)	(1.83)
Irrigated land as proportion of total land area	1.130	0.211	1.492*	0.275*
	(1.48)	(1.48)	(1.87)	(1.87)
Has livestock enterprise that uses output of crops or forages (1 = yes; 0 = no)	0.021	0.004	–0.108	–0.020
	(0.05)	(0.05)	(0.24)	(0.24)
Household characteristics				
Family characteristics				
Family size (number)	–0.081	–0.015	–0.133	–0.024
	(0.51)	(0.51)	(0.80)	(0.80)
Number of generations who have had ownership of this farm	–0.131	–0.024	–0.078	–0.014
	(0.46)	(0.46)	(0.27)	(0.27)
Farmers' personal characteristics				
Age (years)	–0.046*	–0.009*	–0.052*	–0.010*
	(1.73)	(1.73)	(1.90)	(1.90)
Education (bachelor's or higher degree) (1 = yes; 0 = no)	0.910	0.149	0.936	0.150
	(1.62)	(1.62)	(1.62)	(1.62)
Off-farm work (1 = yes; 0 = no)	–0.605	–0.118	–0.518	–0.099
	(1.24)	(1.24)	(1.02)	(1.02)
Farm experience (years)	–0.020	–0.004	–0.017	–0.003
	(1.28)	(1.28)	(1.09)	(1.09)
Operated the farm before taking over its management (1 = yes; 0 = no)	1.093*	0.217*	1.009	0.197
	(1.81)	(1.81)	(1.63)	(1.63)
Current status of father/father-in-law (1 = working farmer; 0 = not working farmer)	–0.922**	–0.166**	–0.918**	–0.163**
	(2.08)	(2.08)	(2.02)	(2.02)

(*Continued*)

Table 4. (*Continued*).

	Adoption: whether or not to adopt (1 = yes; 0 = no)			
	Model 1		Model 2	
	Coefficient	Marginal effect	Coefficient	Marginal effect
Irrigation district dummy (versus private region)				
Bow River (1 = yes; 0 = no)	0.159	0.029	0.115	0.021
	(0.20)	(0.20)	(0.14)	(0.14)
Eastern (1 = yes; 0 = no)	–0.643	–0.128	–0.668	–0.132
	(0.83)	(0.83)	(0.84)	(0.84)
Lethbridge Northern (1 = yes; 0 = no)	1.503	0.198	1.667	0.207
	(1.40)	(1.40)	(1.52)	(1.52)
Raymond (1 = yes; 0 = no)	1.619	0.201	1.699	0.203
	(1.42)	(1.42)	(1.44)	(1.44)
St. Mary River (1 = yes; 0 = no)	0.338	0.059	0.387	0.066
	(0.37)	(0.37)	(0.41)	(0.41)
Western (1 = yes; 0 = no)	–1.276	–0.288	–1.291	–0.290
	(1.29)	(1.29)	(1.32)	(1.32)
Other irrigation district (1 = yes; 0 = no)	–1.147	–0.258	–1.131	–0.252
	(0.91)	(0.91)	(0.86)	(0.86)
Constant	1.754		1.388	
	(0.82)		(0.64)	
Observations	199		199	
Pseudo R^2	0.3259		0.3424	

Note: Model 1 does not include the interaction variables between farm size and farm type, while model 2 includes their interaction variables. Absolute value of t statistic in parentheses: *significant at 10%, **significant at 5%, ***significant at 1%.

Nicol et al. 2010), which used only descriptive statistical analysis, an improved and econometrically more rigorous understanding of the factors that influence the adoption of improved irrigation management is urgently needed. To fill the gap of quantitative analysis, the objectives of this study are to: (1) examine the decision to adopt improved irrigation scheduling methods and adoption intensity (the proportion of the irrigated area on which an improved method was adopted); (2) identify and quantify the factors that have influenced irrigators' adoption decisions; and (3) identify policy implications of the findings, i.e. how best to increase adoption.

The rest of this paper is arranged as follows. The second section discusses the sampling approach used in this study, and the data collected. The third section provides a statistical analysis of the adoption and adoption intensity as well as the factors that influence them. In the fourth section, an econometric model of the determinants of adoption is developed and estimated, followed by presentation and discussion of the results. The final section contains conclusions and policy implications.

Survey and data

This study covers 12 of the 13 irrigation districts (IDs) and private irrigators in the SSRB; the smallest ID was omitted. The IDs account for 82% of the irrigated area and hold the largest and most senior water licenses (Bjornlund et al. 2008). Irrigators within IDs have their irrigated area registered on the districts' assessment role and thereby have the right to receive a share of the district's water allocation. Irrigators pay a flat fee per hectare to cover administration and a minimum of 25% of the cost of rehabilitating infrastructure. However, irrigators do not pay for the water itself or for the cost of head works and supply infrastructure that delivers the water to the IDs. Unlike district irrigators, private irrigators are responsible for the installation and maintenance of the infrastructure needed to extract the water from the river and convey it to their fields. Presently, there are more than 2800 private irrigators within the SSRB, accounting for 18% of the irrigated area.

The data were collected by a farm household survey during the summer of 2012 (Zhang 2014). A comprehensive questionnaire was prepared, pre-tested by several irrigation experts, then revised and printed. Following approval by the University of Lethbridge Human Subjects Committee, preparations were made to conduct interviews. The interviewers were two well-trained undergraduate students with farming backgrounds. Face-to-face interviews were conducted with the person responsible for the daily management of the irrigated farm operation. Respondents were recruited by a professional data collection company (Advanis Company). For privacy reasons, it was impossible to obtain a list of irrigators with names, addresses and phone numbers. To conduct a previous irrigator survey in 2011, a list of people, with names, addresses and phone numbers, who live

Table 5. Regression results of the determinants of the adoption intensity of farmers' decisions on adopting improved irrigation scheduling methods (Tobit model) in Alberta, Canada.

	Adoption intensity Proportion of irrigated area adopted	
	Model 1	**Model 2**
Information sources		
Extension agencies (1 = yes; 0 = no)	0.108	0.089
	(1.23)	(1.02)
Other government (1 = yes; 0 = no)	–0.136	–0.133
	(1.01)	(1.00)
Individual farmers or farmers' association (1 = yes; 0 = no)	0.197**	0.201**
	(2.28)	(2.35)
Media (1 = yes; 0 = no)	0.108	0.080
	(1.11)	(0.83)
Support services		
Access to support service (1 = yes; 0 = no)	0.224**	0.200**
	(2.54)	(2.28)
Social capital		
Member of a water planning advisory council or watershed stewardship group (1 = yes; 0 = no)	–0.052	–0.020
	(0.41)	(0.16)
Member of an environmental or conservation group (1 = yes; 0 = no)	0.176	0.196
	(1.40)	(1.54)
Member of a recreational or social organization (1 = yes; 0 = no)	–0.071	–0.045
	(0.56)	(0.36)
Attends farm meetings (1 = yes; 0 = no)	0.142	0.137
	(1.10)	(1.07)
Farm characteristics		
Farm size (ha)	0.000	0.000**
	(1.16)	(2.27)
Farm type		
Corporation (1 = yes; 0 = no)	0.341***	0.447***
	(3.74)	(4.09)
Partnership (1 = yes; 0 = no)	0.125	0.270**
	(1.13)	(2.04)
Cross variables		
Farm size × corporation		–0.0003*
		(1.92)
Farm size × partnership		–0.0004**
		(2.10)
Irrigated land as proportion of total land area	0.284**	0.336**
	(2.01)	(2.36)
Has a livestock enterprise that uses output of crops or forages (1 = yes; 0 = no)	–0.061	–0.083
	(0.76)	(1.03)
Household characteristics		
Family characteristics		
Family size (number)	–0.003	–0.007
	(0.11)	(0.27)
Number of generations who have had ownership of this farm	–0.026	–0.016
	(0.55)	(0.35)
Farmers' personal characteristics		
Age (years)	–0.005	–0.005
	(1.09)	(1.14)
Education (bachelor's or higher degree) (1 = yes; 0 = no)	0.196**	0.192**
	(2.17)	(2.15)
Off-farm work (1 = yes; 0 = no)	–0.120	–0.098
	(1.35)	(1.09)
Farm experience (years)	–0.004	–0.004
	(1.65)	(1.47)
Operated the farm before taking over its management (1 = yes; 0 = no)	0.114	0.105
	(1.09)	(1.02)
Current status of father/father-in-law (1 = working farmer; 0 = not working farmer)	–0.134*	–0.120
	(1.69)	(1.54)

(*Continued*)

Table 5. (*Continued*).

	Adoption intensity Proportion of irrigated area adopted	
	Model 1	**Model 2**
Irrigation district dummy (versus private region)		
Bow River (1 = yes; 0 = no)	–0.053	–0.083
	(0.37)	(0.59)
Eastern (1 = yes; 0 = no)	–0.249*	–0.271*
	(1.71)	(1.88)
Lethbridge Northern (1 = yes; 0 = no)	0.074	0.074
	(0.44)	(0.45)
Raymond (1 = yes; 0 = no)	0.228	0.209
	(1.19)	(1.10)
St. Mary River (1 = yes; 0 = no)	0.112	0.098
	(0.69)	(0.61)
Western (1 = yes; 0 = no)	–0.442**	–0.443**
	(2.15)	(2.20)
Other irrigation district (1 = yes; 0 = no)	–0.298	–0.310
	(1.28)	(1.35)
Constant	0.351	0.230
	(0.98)	(0.64)
Observations	199	199
Pseudo R^2	0.2576	0.2701

Note: Model 1 does not include the interaction variables between farm size and farm type, while model 2 includes their interaction variables. Absolute value of t statistic in parentheses: *significant at 10%, **significant at 5%, ***significant at 1%.

in postal codes where irrigation is practiced was purchased (Hall et al. 2012). People with town addresses or business names clearly not related to irrigation were deleted from the list, which generated a list of 9648 potential irrigators. The company called people from this list. Following a brief greeting, the first question asked if the household operated an irrigated farm. If the answer was no, the call was terminated and the number deleted from the list. Out of the 9648 numbers called, 1230 were identified as irrigators. For this project, the company randomly called numbers from this list until 300 irrigators were recruited and agreed to participate. A list of names, addresses and phone numbers were then sent to the interviewers who arranged a time for the in-person interview at a place of the respondent's choosing. Due to problems scheduling the interviews during the available time and a change of mind by some respondents, only 208 interviews were completed. Out of those, a few had missing values, which reduced the sample to 199.

The survey gathered data about the irrigation scheduling methods that were used for each crop on the farm. Bjornlund et al. (2009) found that farmers in the region use several methods to schedule irrigation: visual monitoring methods and the feel and appearance methods through use of an auger (soil-based methods), monitoring instruments (plant-based methods) and computers/phones or web-based programs (ET-based methods). Some farmers also hire a consultant for their irrigation. In addition to asking farmers what kinds of irrigation scheduling methods that they used for their crops, we also collected information on the irrigated areas applying each kind of method.

Participating farmers also were asked about factors that might influence them to adopt improved practices. These include sources of information about water scheduling methods (such as extension agencies, other government sources, individual farmers or farmer associations, media or other sources), whether or not farmers accessed support when implementing their adoption decision (from dealers, manufacturers or the government), the extent of farmers' social capital or social networking activities (such as membership in a water planning advisory council, watershed stewardship group or environmental, conservation, recreational or social organization, or attendance at farmer meetings), and particular farm characteristics (such as farmed areas, farm type [corporation, partnership or sole proprietorship], size of irrigated area and whether or not they had a livestock enterprise that uses the irrigated crop as an input). The survey also included questions related to the socioeconomic characteristics of the farmers and their households, such as family size (number of family members), number of generations the farm has been in the family's ownership, farm succession plan, age, education, farming experience, off-farm work status, whether the respondent took part in operating the farm before taking over its management and current status of father/father-in-law (whether still working on the farm or not).

Adoption of improved irrigation scheduling methods: A descriptive analysis

Two thirds of irrigators have adopted some improved irrigation scheduling methods, while one-third still used the traditional method of visual inspection of soil conditions (Table 1). Decisions about irrigating just under half of the total irrigated area were made based on the traditional method, while just over half were based on the use of some improved method.

The most commonly adopted improved method was the feel and appearance method, which is the least expensive and simplest method to use to improve accuracy over that of the traditional method. This method was used by more than 60% of farmers and had an adoption intensity (percentage of total irrigated area on which it was used) of 43.2% (Table 1). Only a small number of farms have adopted some more advanced method. For example, just 8% hired a private consultant (with an adoption intensity of 4.5%). Just over 4% applied monitoring instruments to check the soil moisture level (with an adoption intensity of just over 3%). Adoption of the other methods – applying web-based programs or computer/phone for monitoring the ET and turning irrigation on and off – was near to or less than 1% for both adoption and level of intensity.

Information sources and support services

When considering the adoption of improved irrigation scheduling methods, farmers can obtain information about the benefits and cost of adoption from a number of sources to inform the adoption decision. The results show that 61% of farmers received their information from extension agencies, 37% from individual farmers or farmer associations and 23% from the media. Only 10% obtained their information from other government sources.

There were clear associations between the source of information and the level of adoption. When farmers obtained information from extension agencies, 74% adopted an improved method, significantly more than the 55% adoption rate for those who did not obtain information from this source. Farmers who obtained information from the media had the highest adoption at 78%, which was significantly more than the 64% adoption rate for those who did not. Finally, those who obtained information from farmers or farmer organizations also had enhanced adoption of 73% compared to 63% for those who did not, but this difference is not statistically significant. Only 10% obtained information from other government sources and, unlike the other three information sources, this had a negative but statistically insignificant impact on adoption (Table 2).

Once the decision to adopt has been made, farmers can obtain support to implement it, which might influence the intensity of adoption. Of the 29% who did access such support, 60% obtained the support from dealers or manufacturers, and 16% from the government sector or staff from the irrigation districts. Those who accessed post-decision support had a significantly higher adoption intensity of 68%, compared to 45% for those who did not (Table 2).

Social capital

The level of social capital can influence the expected collective or economic benefits derived from preferential treatment and cooperation between individuals and groups (Bourdieu 1985). Although different social science disciplines emphasize different aspects of social capital, they tend to share the core idea that "social networks have value." As revealed by the analysis of the survey, there are significant associations between social capital variables and adoption. The proxies for social capital in this study include membership in resource, environmental or social organizations and attendance at farm meetings. Participating in these types of groups brings farmers into contact with more people, which offers opportunities for exchange of information that improves their understanding of the benefits of increasing irrigation efficiency. Among those who attend farm meetings, adoption was significantly higher at 71%, compared to 61% among those who did not attend (Table 2). There is a positive but statistically insignificant association between membership in environmental and recreational organizations and the level and intensity of adoption. However, while also statistically insignificant, membership in water management organizations had a negative impact on adoption but a positive influence on the intensity of adoption.

Farm characteristics

Farmers' adoption decision is associated with the characteristics of the farm they operate. First, farmers with larger farms are more likely to adopt than those with smaller farms. Among farmers with less than 180 ha, 51% adopted; this increased to 70% for farmers with 180 to 560 ha and to 79% for farmers with more than 560 ha (Table 3). Adoption intensity among farmers with less than 180 ha was 38%, increasing to 56% for farmers with 180 to 560 ha and to 61% for farmers with more than 560 ha. The more intensely the farm is irrigated the more likely the farmer is to adopt, and the greater the adoption intensity.

The legal structure of the farm was also significantly associated with adoption and intensity of adoption. In the study region, there are three main types of farm businesses: corporations, partnerships and sole proprietors. Both adoption and intensity of adoption increased with more legally complex farm organizations. Corporations had a significantly higher adoption rate (83%) than partnerships (68%) and sole proprietors (51%), and a significantly higher adoption intensity (69% compared to 35% for sole proprietors and 45% for partnerships) (Table 3). Finally, the analysis found no statistically significant relationships between adoption or intensity of adoption and the presence of some livestock enterprises that use the output from irrigation.

Household characteristics

Adoption is also associated with household characteristics, either those of the family or those of the farmer. Larger families had significantly higher levels of adoption and intensity of adoption. For families with less than three members, 61% had adopted; this increased to 70% for families with 3–4 members and 82% for families with more than four members (Table 3). Similar relationships can be found for intensity of adoption. Adoption and intensity of adoption also increased significantly the more generations the farm had been in the family's ownership. If the household was the first generation on the farm, 52% adopted; this increased to 73% for those with two or more generations. Intensity of adoption increased more gradually from 42% for first-generation to 53% for second-generation and to 57% for third- or higher-generation farmers. Adoption is an ongoing process, first taking place on a relatively small area while the intensity of adoption continues to increase over time, as the farm family consolidates its hold on the farm by increasing both its social and economic capital and thereby its ability to adopt more efficient management techniques. The fact that both larger farm families and families with a longer relationship with the farm are more likely to adopt improved methods suggests that they have a higher expectation of continued farm succession.

Both the extent and the intensity of adoption are significantly higher among younger farmers than among older farmers (Table 3). Among farmers who are less than 52 years of age, 77% have adopted improved methods, compared to 54% of those over 58; the intensity of adoption also dropped from 56% to 42% between these two age groups. Off-farm work commitment significantly decreased adoption, from 72% for those who commit all their time to farming to 56% for those who spend time working off the farm, and the intensity of adoption decreased from 56% to 44%. While having a higher education insignificantly increased adoption from 65% to 74%, the increase in intensity of adoption from 49% to 61% was statistically significant.

The relationships between farm experience and continued involvement of the father or father-in-law in the farm operations and adoption are not statistically significant. However, continued involvement of the father/father-in-law decreased adoption by 10%, while an increase in farm experience initially (from less than 24 years to 24–36 years) increased adoption by 12%, although it dropped again by 6% with more than 36 years of experience. Intensity of adoption followed the same pattern and was statistically significant. Having been part of operating the farm before taking over its management significantly increased both the adoption and the intensity of adoption by 17 and 12%, respectively.

Econometric model and estimation results

Specification of econometric model

Descriptive statistics do not control for the influence of other factors, making it impossible to separate the impacts of various factors on the adoption of improved irrigation management methods. Therefore, to better identify and quantify the impacts of different factors on farmers' adoption decisions and the intensity of their adoption, the following two econometric models were specified:

$$W_{ij} = \alpha_{ij} + \beta_1 I_{ij} + \beta_2 S_{ij} + \beta_3 F_{ij} + \beta_4 H_{ij} + \beta_5 D_{ij} + \varepsilon_{ij} \quad (1)$$

$$Y_{ij} = \omega_{ij} + \partial_1 P_{ij} + \partial_2 I_{ij} + \partial_3 S_{ij} + \partial_4 F_{ij} + \partial_5 H_{ij} + \partial_6 D_{ij} + \varepsilon_{ij} \quad (2)$$

In the two models, i and j indicate the ith farm in the jth irrigation district or private irrigators. The major difference between the two models is their dependent variable. In the first model, the dependent variable (W_{ij}) measures the farmers' dichotomous choices of whether or not to adopt any kind of improved irrigation scheduling method: 1 if adopted, 0 otherwise. The dependent variable in the second model is continuous and measures the intensity of adoption.

On the right side of the two equations, the following independent variables identify and measure their effects on farmers' adoption behaviour: (i) P_{ij} is a dummy variable that measures the support service accessed by farmers when implementing the adoption decision (1 if that farmer accessed the assistance; 0 otherwise); this variable is included only in the intensity model as it is a post-decision variable; (ii) I_{ij} is a set of four dummy variables that measure the information sources: extension agencies, government, individual farmers or farmers' associations, and media; (iii) S_i is a set of four dummy variables that measure the social capital of farmers, whether or not a member of water, environmental or social organizations; (iv) F_{ij} is a set of four variables that measure farm characteristics (farm size, farm type, irrigated areas and whether having a livestock enterprise). Considering the possible relationship between farm size and farm type (since their correlation is 0.33), this study also included two interactive variables (farm size × corporation and farm size × partnership) into the models; and (v) H_{ij} is a set of eight variables that measure farmer and household characteristics: family size, number of generations, age, education, off-farm work, farming experience, whether or not they operated the farm before taking over its management, and current status of father/father-in-law.

The models also included a set of dummy variables D_i to control for the impact of regional characteristics that do not change over time but might affect the adoption of scheduling methods among irrigation districts. There are 12 irrigation districts as well as private irrigators in the sample. Since five of the irrigation districts are very small and the number of respondents to the survey within each of those was low, the analysis combined these five into a single variable. The models therefore had seven dummy variables that represented the 12 districts, leaving private irrigation as the default category. In the two models, $\beta_1 - \beta_5$ and $\partial_1 - \partial_6$ are the parameters to be estimated; α_{ij} and ω_{ij} are the constant. ε_{ij} is a random error term, and all are assumed to be subjected to independent identical distribution.

For model (1), since the dependent variable is one binary choice (dummy) variable, the logit model was applied to run the regression (Wooldridge 2002). The logit model can be expressed as the following two equations:

$$\mathrm{Prob}(W_{ij} = 1) = \mathrm{F}(\beta_{\mathrm{i}}'\mathrm{M}_{\mathrm{ij}}) \tag{3}$$

$$\mathrm{Prob}(W_{ij} = 0) = 1 - \mathrm{F}(\beta_{\mathrm{i}}'\mathrm{M}_{\mathrm{ij}}) \tag{4}$$

In equations (3) and (4), the definition of W_{ij} is similar to that in model (1), the key dependent variable that we are interested in. The set of variables M_{ij} includes all the independent variables included in model (1). The set of parameters β_i reflects the impacts of changes in M_{ij} on the probabilities of adoption, but not the marginal effects, of the independent variables. The marginal effects need to be calculated based on the estimated parameters (β_i). Specifically, when the dependent variable W_{ij} is observed (W_{ij} = 1), its probability can be expressed as the following:

$$\mathrm{Prob}(W_{ij} = 1) = \mathrm{e}^{\beta' X_{ij}}/(1 + \mathrm{e}^{\beta' X_{ij}}) \tag{5}$$

Based on the estimated coefficients of the logit model, the marginal effects of each of the independent variables were calculated and are shown in Table 4. Details of the calculation of marginal effects of a logit model can be found in Wooldridge (2002). We used Stata to run the regression and this software applies maximum likelihood methods for Logit models.

For model (2), since our dependent variable (adoption intensity) is always positive, a Tobit model (or censored regression model) was used to estimate the determinants of adoption intensity. A Tobit model avoids the downward biases generated by ordinary least squares techniques (Wooldridge 2002). The general formulation of a Tobit model is usually given in the following equations (or index function):

$$Y_{ij}^{*} = \partial_i' X_{ij} + \varepsilon_{ij} \tag{6}$$

$$Y_{ij} = 0 \text{ if } Y_{ij}^{*} < 0 \text{ or } Y_{ij}^{*} = 0 \tag{7}$$

$$Y_{ij} = Y_{ij}^{*} \text{ if } Y_{ij}^{*} > 0 \tag{8}$$

In equations (6), (7) and (8), Y^{*}_{ij} is a latent variable and its expected value is $\partial_{ij}' X_{ij}$. Y_{ij} is the censored variable that is observed. The set of variables X_{ij} includes all the independent variables included in model (2). The set of parameters ∂_i reflects the marginal impacts of changes in M_{ij} on the dependent variable. In the analysis, the Tobit model was specified using two forms: with and without the interactive variables (Table 5).

Estimation results

The pseudo R^2 values of the two Logit models were 0.33 and 0.34, respectively, and for the two Tobit models 0.26 and 0.27, respectively (Table 4). These are reasonably high values for multivariate analysis based on cross-sectional data. Importantly, the regression results generally are consistent with the descriptive analysis, and the major findings are summarized below. In addition, the estimated regression results were mostly consistent for models with and without the interaction variables, but including them increased the performance of the models. Therefore, the following discussions use the models with interaction variables. Since all variables that represent social capital are not statistically significant, they are excluded from the discussion.

Source of information

The source of information influenced the adoption decision. Out of the four information sources tested, only obtaining information from individual farmers or farmers' associations was statistically significant in all four models (Table 4). If a farmer obtained information from fellow irrigators or farmer organizations, the probability of adoption increased by 23% and the intensity of adoption increased by 20%. Obtaining information from extension agents or the media had positive impacts on adoption and intensity of adoption, but the impacts were not statistically significant. While it is insignificant, its t value is 1.44 and the sign is consistent with our statistical results. On the other hand, obtaining information from other government sources had a negative but insignificant influence on adoption (22% less likely to adopt).

The variations in impact reflect the different levels of trust that irrigators have in the different sources. Farmers clearly place more trust in their peers and their organizations, followed by extension agents who have some practical experience. Farmers in the study area generally have a high level of distrust in the government and would like to see its role in water management reduced, as found by Bjornlund et al. (2014). While the coefficient of government was statistically insignificant at the 5% level, its t-value was 1.44 and the policy implication is important: the government should increase extension services, promote their use, encourage farmers to establish local peer groups to discuss farm management issues, and support such attempts financially and logistically. It also should encourage farm organizations to engage farmers in farm management discussions.

The use of support services to implement the adoption decision

Accessing support services to assist in the implementation of the adoption decision significantly increased adoption intensity by 20%, and is consistent with the descriptive statistics (Table 4). This is a very important finding and suggests that access to support services should be improved and their use promoted by government initiatives to increase the benefits from the farmers' adoption decisions. Most existing studies focus on the influence of support services provided before adoption (such as subsidies), and such support services influence mainly the adoption decision. This research did not find any studies that have analyzed the influence of such "follow-up" support on the intensity of adoption. Therefore, our results should encourage researchers to also focus on the "follow-up" support services.

The influence of farm characteristics

The adoption of improved irrigation management was significantly affected by some socio-economic and farm characteristics. First, the coefficient of farm size was positive and statistically significant in models that include the interactive variables. Consistent with the study by Bjornlund et al. (2009), the probability and intensity of adoption increased with the size of the farm. The reason for this might be that farmers with larger farms are more likely to have better financial and human capital and are more likely to benefit from economies of scale.

Second, the coefficients for the two variables that reflect the legal structure of the farm business (corporations and partnerships) were both significant and positive. This suggests that farmers who manage their farms under both of these farm business structures are more likely to adopt improved irrigation scheduling methods and adopt them more intensively than sole proprietors. The adoption probability of corporate farms was 36.8% higher and adoption intensity 44.7% higher than for sole proprietors. Partnerships also adopted at a higher intensity but less so than corporations (Table 4). The adoption probability for partnerships was 19.9% and the adoption intensity 27% higher than for sole proprietors. This is probably because the financial and time cost associated with forming these legal structures can be justified only if the farm is viable in the long term, and has been and is expected to continue to be in the family ownership. This is supported by the finding reported in the next paragraph.

Third, the coefficients for the two interactive variables in all models were significantly negative (Table 4). The negative coefficients for the interactive variable in the adoption model for both partnerships and corporations are identical to the positive coefficient for farm size, suggesting that size is an important influence only for sole proprietors. The coefficients for adoption intensity suggest that size still has a minor influence on intensity for both corporations and partnerships but is especially important for sole proprietors.

The final farm characteristic that significantly affected adoption and intensity of adoption is irrigation intensity (proportion of farm land under irrigation). The estimated coefficient for the variable that represents irrigation intensity was positive and statistically significant. Therefore, the more intensely the farm is irrigated, the higher the probability of adoption and the intensity of adoption. When the irrigated land as proportion of total land area increased by 10%, the probability of adoption increased by 2.75% and the intensity of adoption by 3.36%. Our results are consistent with the findings of Bjornlund et al. (2008) that private irrigators depend less on irrigation than do district irrigators, as irrigation often is only a small proportion of their business. Therefore, private irrigators have less incentive to adopt more advanced scheduling methods. Our results add evidence to this finding and indicate that for all irrigators (either private or members of irrigation districts), the greater the extent to which their agricultural production depends on irrigation, the more likely they are to adopt improved scheduling methods.

The influence of socioeconomic characteristics of households

A number of socioeconomic characteristics of the farm household significantly influence adoption and adoption intensity. First, consistent with the literature (e.g. Khanna et al. 1999), age had a significant negative influence on the adoption decision, but not on adoption intensity (although its estimated coefficient was negative) (Table 4). Possibly, younger farmers find it easier to learn new methods and are more likely to have a higher education. This also is consistent with Stephenson (2003) who found that in many studies, adopters tended to be younger than non-adopters. Also, it has been found that the interest in adopting new behaviour or methods declines with age if it becomes clear that there are no family members who are willing to take over the farm (e.g. Kuehne and Bjornlund 2006).

Second, the intensity of adoption was closely related to farmers' education level. The coefficient for the education variable was positive and statistically significant for adoption intensity and also positive for adoption (t = 1.62, just below the 10% significance level) (Table 4). If farmers have a bachelor's or higher degree, it was more probable that they had adopted an improved irrigation management practice at a higher level of intensity. This suggests that farmers with a higher education have more capacity to implement improved methods and are better able to understand their benefits. Our finding is consistent with large parts of the literature on the adoption of new technologies. For example, Fuglie (1989) found that early adopters tended to be farmers who had above-average education, and Stephenson (2003) found that adopters are more highly educated than non-adopters.

The final significant variable with a negative coefficient is the current involvement of the father or father-in-law in the farm operation (Table 4). If he is still actively working on the farm, the farmer is significantly less likely to adopt, and likely to do so at a lower level of intensity. One possible reason is that if fathers or fathers-in-law still work on the farm, they will continue to have an influence on the younger operators' farm management decisions and, since older farmers are less likely to adopt new methods, this influence is likely to have a negative influence on adoption.

Conclusions

This study examined the adoption of improved irrigation scheduling methods in southern Alberta, and explored major factors that influence the adoption decision and the intensity of adoption. The results show that, on average, 67% of famers have adopted improved irrigation scheduling methods, and these methods are applied on 51.5% of the total irrigated area. However, despite the relatively high rate of adoption of the most simple method of using a hand auger and manually assessing the appearance and feeling the moisture level of the soil, only a few farmers adopted more advanced measures (such as private consultants, monitoring instruments, web-based or computer-based programs, or using the phone to turn irrigation on and off). Compared with the adoption of improved irrigation technologies, such as low-pressure centre pivots, the adoption of improved scheduling methods is lower, not only in the past several years (Bjornlund et al. 2009), but also currently (Wang et al. 2014). This suggests that there is still substantial potential for improvement in the area of adoption of improved irrigation scheduling methods.

In order to examine the factors that influence farmers' decisions to adopt improved irrigation scheduling methods, both descriptive statistics and econometric models were applied to data collected in an extensive farmer survey. The results show that farmers' decisions are influenced by several major factors. The three most important influences on adoption are the source of information that farmers use when deciding whether or not to adopt, the legal organization of the farm and whether or not a succession plan is in place. Farmers' distrust of the government in Alberta is well documented and is reflected in this study by the fact that seeking advice from government sources had a negative impact on adoption, while obtaining advice from fellow farmers or farmer organizations increased the probability of adoption by 20%. Farmers who operate their farm business as a corporation were 37% more likely to adopt than sole proprietors, and those who operate as a partnership were 20% more likely than sole proprietors. If the current farmer actively participated in operating the farm before taking over management responsibilities the probability increased by 20%, while if the father or father-in-law is still involved in the farm operations, adoption deceased by 16%. Farm size also had a significant and positive impact on adoption if the farm business was operated as a sole proprietor. Finally, younger farmers were more likely to adopt.

The intensity of adoption was influenced by the same factors as adoption and with the same reasoning except for age. In addition to these factors, the intensity of adoption was significantly influenced by accessing external support in the implementation process of the adoption decision. The irrigated area under new scheduling methods was 20% higher where continuing external support was accessed. Farmers with a bachelor's degree or higher were 19% more likely to adopt.

The findings of this study suggest that there is still considerable room to adopt improved methods for irrigation scheduling in Alberta. There are several policy implications of these findings. Policy makers should introduce policies and incentives that encourage adoption. The findings suggest a number of important areas that such policies should focus on. First, the government should promote the flow of information to inform farmers in the decision-making process to adopt. According to the findings, there are two main ways of doing this: (1) promote and support the formation of farmer peer groups that can continually discuss the pros and cons of their farming practices, including demonstrations on their farms and encouragement of farmers to participate; and (2) increase the provision of extension services and their interaction with farmers. The second significant area is to support the provision and uptake of support services to assist farmers in the implementation of improved irrigation scheduling method they have decided to adopt. The third major area is that support and guidance should be provided in the area of succession planning that encourages the next generation of farmers to be more fully integrated in the farm operation before the time of intergenerational change, and that the role of the retiring farmer should be well defined before this transition takes place. Finally, assistance should be provided for farm operators to effectively and inexpensively choose the most appropriate legal structure for their operation.

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