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Factors that Influence the Rate and Intensity of Adoption of Improved Irrigation Technologies in Alberta, Canada

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Despite the importance of adopting improved irrigation technologies to increase on-farm irrigation efficiency, our understanding of what determines farmers' adoption decisions in southern Alberta remains relatively poor. The overall goals of this study are to examine the extent of adoption (proportion of all irrigators that have started the adoption process), how far along they are in the adoption process, and the intensity of adoption (percentage of irrigated land on which the technology is adopted) of improved irrigation technologies in southern Alberta, and to assess the major factors that influenced farmers' adoption decisions. The data were collected in a farm-household survey conducted in the 12 largest irrigation districts (IDs) as well as among private irrigators in southern Alberta. Results show that adoption of improved irrigation technologies is widespread at various levels of intensity. By 2011, 81.3% of farmers had started the adoption process, are now using some kind of improved technology to apply water to their crops, and used it on 76.8% of all irrigated land. The most commonly used irrigation technology is a low pressure center pivot system. Receiving support services following the adoption decision played an important role in increasing the intensity of adoption. Obtaining information on irrigation technologies from individual farmers or farmers' associations, and extension agencies significantly influenced farmers' decisions to adopt. Farmers who increased their social capital through attending meetings related to agricultural production practices were more likely to adopt while farmers who participated in recreational or social organizations were less likely to adopt. Finally, the extent and intensity of adoption are higher for those with corporate farm structure, larger families, more generations of ownership and higher education.

Keywords: Improved irrigation technologies; adoption; intensity of adoption; factors influencing adoption; Alberta.

1. Introduction

Irrigation plays an important role in promoting socio-economic development in Alberta, the fourth largest province in Canada by population. It was recently estimated that Alberta's irrigation sector annually contributes about CAD$ 3.6 billion to the provincial gross domestic product (GDP) and, with related input supply and output processing sectors, contributes about 20% of the total provincial agri-food sector GDP on 4.7% of the province's cultivated land base (Paterson EWCL 2015). Most of the surface water in Alberta is found in the northern part of the province while most of the population and agricultural/industrial demand for water is in the south. Historically, the stable agricultural base created by irrigation in southern Alberta has fostered the growth of many small towns, three medium size cities and one large city that now support their own development.

A major challenge to the continuation and expansion of economic growth in Southern Alberta, especially during years of reduced precipitation, is the allocation of available water among the different groups of users. The irrigation community (made up mostly of 13 organized irrigation districts (IDs) but also a large number of private irrigators who get their water directly from rivers and streams) holds a large proportion of existing water licenses in southern Alberta. With a rapidly growing population, municipal services and the industrial base require ever more quantities of fresh, clean and safe water. Also, growing recognition of the importance of environmental quality of the surface water resource has created a demand for less commercial use of the available water.

Total surface water use in Alberta increased from less than 1 billion cubic meters in 1900 to 3 billion cubic meters in 1950, and to 9 billion cubic meters in 2000 (Piersol 2010). Prior to the 1950s, the increase in surface water use was due mostly to the development of irrigated agriculture, accounting for more than 90%

of total surface water allocation. This had fallen to about 60% by 2000 as a result of increased water use by other sectors (despite the growing area under irrigation) (Piersol 2010). It has been projected that total surface water use in Alberta will increase by 21% by 2025, which will put much additional pressure on the limited water supply in this region (Alberta Environment 2007).

The government of Alberta has recognized the increasing water challenges and adopted an integrated water management approach to cope (Ramin 2004). The government developed two important policy strategies that integrate water and land management in the province: the Water for Life strategy in 2003 and the Land Use Framework in 2009 to integrate land and water management (Bjornlund and Klein 2015). One of the key goals of the Water for Life strategy is to improve "efficiency and productivity of water use by 30%". Klein *et al.* (2012) showed that lack of baseline measurements or, indeed, of specified measurement criteria, make it difficult to assess area-wide progress in improvements of efficiency in the use of water for irrigation. As a result, most of the attention has been directed at the input side, i.e., reducing the amount of water that is applied per unit area. Bennett *et al.* (2015) found that changes in irrigation systems and water conveyance infrastructure in the IDs of southern Alberta reduced gross irrigation demand per unit area by 74 mm from 1999 to 2012, with a 55 mm reduction in on-farm irrigation demand and a 19 mm decrease in conveyance losses. Reductions in on-farm irrigation demand have been attributed to upgrades to irrigation systems that sprinkle water more uniformly with less pressure (to reduce evapotranspiration). Alberta Agriculture and Rural Development (2013) estimated that improvements in water application technologies in southern Alberta from flood to wheel move to high pressure center pivot and to low pressure center pivot have led to improvements in on-farm irrigation efficiency (defined as the percentage of water delivered to the field that reaches the root zones of irrigated crops) from 34% in 1965 to 77.5% in 2012. While that represents remarkable progress over a nearly 50 year period, further improvements to on-farm irrigation efficiency depend on irrigators' decisions to continually adopt new technologies and management practices. Surveys of irrigators in 2006/07 suggest that the rate of adoption has slowed but also showed that there was plenty of room for improvement (Bjornlund *et al.* 2008).

As the major user of surface water supplies in southern Alberta, irrigators face increasing public pressure to use less water for irrigating crops so that more water could be made available for industrial and municipal uses as well as for supporting environmental objectives. Despite the importance of adopting improved irrigation technologies to achieve this goal, our understanding of what determines farmers' irrigation strategies remains relatively poor, which limits policy makers' and water managers' ability to predict the outcomes of new water policies, such as those espoused in Alberta's Water for Life strategy. Some recent studies (e.g., Bjornlund *et al.* 2008, 2009; Nicol *et al.* 2010) have begun to analyze farmers' adoption of improved irrigation technologies in Alberta but they provided only descriptive analyses and were limited to just two of Alberta's 13 IDs. These issues could be better understood with a larger and more representative sample of irrigators across southern Alberta and more rigorous econometric analyses to identify the factors that influence adoption.

To better understand the adoption of improved irrigation technologies in southern Alberta, the focus of this study is to answer the following questions: (i) What is the extent and intensity of adoption of improved irrigation technologies in southern Alberta? (ii) Has the provision of information and other support services played a significant role in promoting adoption of improved irrigation technologies? (iii) Is adoption related to farmer and farm characteristics as well as social capital of farmers?

Answering these questions is not only important for Canada, but also for water short countries everywhere. Irrigated agriculture produces about 40% of global food production on less than 20% of the cropped land (FAO 2011). However, irrigation water supply is facing increasing challenges from other water use sectors (such as industrial, domestic and environmental water use) and risk of climate change (Hanjra and Qureshi 2010; Turral *et al.* 2010). In the last century, global water use grew at more than twice the rate of population increase and the trend is expected to continue (FAO 2011). Increasing pressure on water available for irrigation, combined with a continually rising demand for food, points to the importance of increasing the volume of food produced per unit of water used (Cai and Rosegrant 2013). Improving technologies used in irrigation has become a matter of growing concern around the world. Studying the adoption of improved irrigation technologies in the largest irrigation region in Canada will provide further insights into similar concerns in other countries.

Our paper focuses mainly on understanding the factors that influence the rate and intensity of adoption of improved irrigation technologies at the state level. We are aware of the need to take the analysis further by addressing policy interventions that would ensure that the water saved by the improved irrigation technologies are indeed saved. The reader can find more valuable discussion in (Nicol *et al.* 2010; Ward and Pullido 2008; Scheierling *et al.* 2016).

The rest of the paper is organized as follows. Section 2 summarizes the literature related to the adoption of agricultural innovations. Section 3 introduces the data sources and major variables used in the analysis. Section 4 examines the extent and intensity of adoption and the factors that influence it. In Section 5, econometric methods are employed to identify the determinants of farmers' decisions to start the adoption process, how far in the adoption process they have progressed and the adoption intensity. The final section concludes and provides some policy implications.

2. Literature Review: The Adoption of Agricultural Innovations and Factors that Influence it

Research on adoption was inspired by the desire to understand the diffusion of modern agricultural practices and the Green Revolution (Zilberman *et al.* 2012). The Green Revolution from the 1960s to the early 1980s motivated numerous studies to explain the determinants of adoption during the early stages of the diffusion process (Feder and Umali 1993). Since the early 1990s, after the "first-wave" of adoption studies, researchers have focused on drawing new lessons and strategies for developing and introducing innovative technologies. Such research has not only been a mainstay in resource, environmental and development economics, but also captured the attention of other social sciences (Feder and Umali 1993). Given a perceived output risk associated with the adoption of a certain technology and farmers' willingness to take risk, farmers seek to maximize their utility through the dichotomous choice of whether or not to adopt the technology and the decision about how large a proportion of their land they will commit to its use (Feder 1982).

The lack of credit and limited access to relevant information about improved technologies or practices has been identified as an important factor that influences farmers' decisions to adopt (Feder *et al.* 1985; Feder and Umali 1993). Access to relevant information about the nature of improved technologies or practices can reduce the risk and uncertainty associated with adoption (Koundouri *et al.* 2005; Marra *et al.* 2003; Tsur *et al.* 1990).

In the first important adoption study in agriculture, Ryan and Gross (1943) found that interaction with the original small group of adopters ("innovators") and the spread of information, increased farmers' adoption of hybrid corn seed in the US. The role of information in the adoption of improved technologies also was discussed by Stephenson (2003); he indicated that compared to non-adopters, farmers who adopted innovations are more reliant on primary sources of information. Shampine (1998) examined the role of information externalities when non-adopters observe adopters in order to gather information. He found that with perfect observability (a positive externality), when an innovation is obviously better than what currently is being used, farmers are able to amass information fairly quickly and act upon it.

Provision of policy support (such as financial subsidies and risk-reducing programs) and information (through formal or informal channels) are effective ways of increasing the adoption rate (Abdulai *et al.* 2011; Caswell and Zilberman 1985; Dinar and Yaron 1992; Dong 2008; Feder and Umali 1993; Just *et al.* 2002; Ommani *et al.* 2009; Ryan and Gross 1943). Feder (1982) found that an input subsidy can influence the adoption of a divisible technology (e.g., a tractor that can be used in several fields on several crops) and results in higher utilization of divisible inputs (e.g., fertilizer) and the area allocated to the technology. On the other hand, the impact of a subsidy on the adoption of lumpy technology (e.g., a tube well) can be conditional on a farm size threshold above which adoption is considered justified. Farm and farmer characteristics (such as farm size, land quality and soil type, as well as age, education, experience and family size) as well as social capital have been found to be related to adoption (Abdulai *et al.* 2011; Caswell and Zilberman 1985; Itharat 1980; Lichtenberg 1989; Stephenson 2003; Warner 1981).

Fuglie and Kascak (2001) found that policy can influence the diffusion of resource-conserving agricultural technologies. For example, US federal policy has promoted the adoption of soil conservation practices since the 1930s and this policy was given renewed emphasis in the 1985 Farm Act. Based on Heckman's two-stage and ordinary least square procedures, Adeoti (2009) demonstrated that increases in the number of extension visits per year increased the probability of adopting irrigation technologies in Nigeria (Ginder *et al.* 2000).

Although some studies have analyzed the influence of support services (particularly from a policy perspective) on the adoption decision, analyses typically have focused on those services provided before the adoption (such as subsidies). That is, such support services influence mainly the decision on whether or not to adopt technologies. After making the adoption decision, adopters also need to decide how large a proportion of their irrigated area on which to use the improved technology; that is, the adoption intensity. It could be anticipated that if some "follow up" support services were accessed during the implementation phase (such as operational assistance by the dealers), the adoption intensity would increase, which then would increase the overall impact of the adoption decision on farm-level irrigation efficiency. To our knowledge, no studies have analyzed the influence of such "follow up" support services on the adoption intensity. Undoubtedly, the provision of advices and services, both before and after the adoption decision, will reduce the irrigators' perception of the risk associated with adoption and make them more comfortable with making the decision.

Traditional explanations of the differences in adoption behavior among farmers often point to farm operators and the nature of their farm operations. As summarized by Stephenson (2003), general conclusions of many early studies were that adopters (as compared to non-adopters) tended to be younger, more educated and cosmopolitan, have higher incomes, and have larger farm operations. Lindner and Pardey (1979) emphasized the importance of personal experience and experimentation in the adoption process. Abadi Ghadim (2000) highlighted skill improvement as one important consequence of experience. Caswell (1990) found that adoption is more likely among growers who have lower quality land, higher value crops, higher purchase price for water, greater depth to groundwater and more severe drainage problems. Adeoti (2009) found that lumpy technologies such as improved water lifting devices, with relatively high efficiencies such as motorized pumps, were adopted to a greater extent by larger farmers whereas smaller farmers with limited access to capital, generally can neither benefit from nor afford such technologies. Adeoti (2009) found that the ratio of family members who work off-farm is higher in non-adopter households, household size and membership in associations have negative relationships with the probability of adoption (but were not significant).

Bjornlund *et al.* (2009) found that the adoption rates of improved irrigation technologies in Alberta varied among farmers who were located in two IDs due to their different farm and farmer characteristics (such as land areas, irrigation condition, age and education). A similar survey of private irrigators in Alberta found that they were slower to adopt improved irrigation technologies and had even less intention of doing so in the future (Nicol *et al.* 2010). Financial constraints and physical farm conditions (such as soil characteristics and land form) also were found to impede farmers' adoption of improved irrigation technologies in Alberta (Bjornlund *et al.* 2009; Nicol *et al.* 2010).

Comparing adoption drivers and impediments between those who were members of IDs and those who were private irrigators, Bjornlund *et al.* (2008) identified clear differences. Those in IDs tend to be intensively irrigated with very little dry land farming and focus on higher value crops, which are their primary commodities to be sold. Irrigation is the core of their business. They were significantly more active in adopting improved irrigation technologies and driven primarily by the need to secure improved yields and crop quality. Many of them are under contractual obligations to deliver product of a certain quality. Financial constraint was found to be the main impediment to adoption of improved irrigation technologies (Bjornlund *et al.* 2008). Private irrigators, on the other hand, are mainly dry land farmers with a small irrigated component. Most of their irrigated crop is fodder production as an input into their cow/calf or feedlot operations and, generally, not their final product. Irrigation is a small part of their business and the irrigated crops can relatively easily be substituted by buying feed. Hence, private irrigators have been less aggressive in adopting new technologies. Their main motivations are saving labor and electricity cost while the main impediments are physical farm features and the fact that, while adoption might result in future cost savings, they do not justify the investment (Bjornlund *et al.* 2008).

3. Data

The data used in this study were collected from a farm household survey conducted at the University of Lethbridge during the summer of 2012. The interviewers were two well-trained undergraduate students with a farming background. Face-to-face interviews were conducted with the person responsible for the daily management of irrigation on the farm. Respondents were recruited by a professional data collection company (the company). For privacy reasons, it was impossible to obtain a list of irrigators with names, addresses and phone numbers. We purchased a list of people with names, addresses and phone numbers who live in the postal codes where irrigation is practiced (Hall *et al.* 2012). People with town addresses or business names that clearly were not related to irrigation were deleted from the list, which generated a list of 9,648 potential irrigators. The company called people from this list. Following a brief greeting, the first question asked was if the household operated an irrigation farm. If the answer was no, the call was terminated and the number was deleted from the list. Out of the 9,648 numbers called, 1,230 were identified as irrigators. For this project, the company randomly called numbers from this list until 300 irrigators were recruited and had agreed to participate. A list of names, addresses and phone numbers was then sent to the interviewers who arranged a time for the in-person interview on the farm or another place of the respondent's choosing. Due to problems of scheduling a time for the interview during the available time frame and change-of-mind by some potential respondents, only 208 interviews were completed.

The random sample included farm households that reside in the 12 largest (of 13) IDs as well some private irrigators who are not part of IDs but, rather, hold individual licensed allocations within the South Saskatchewan River Basin (SSRB) in southern Alberta. The SSRB is one of seven major river basins in Alberta and comprises four sub-basins: Red Deer River, Bow River, Oldman River and South Saskatchewan River (Alberta Environment 2003). In the SSRB, 68% of farm land is used for annual crop production, 6% for natural pastures and the remainder for summer fallow, tame hay or specialty crops (SWA 2001). The major water source for irrigation is surface water while limited available groundwater is used, mainly for stock and domestic purposes.

In this study, farmers use either the traditional flood irrigation technology (FLOOD) or have adopted some improved irrigation technology (IMP) with the potential to improve on-farm irrigation efficiency. Improved irrigation technologies generally have been adopted in the following order, with gradual increases in potential on-farm irrigation efficiency: wheel move sprinklers, high pressure center pivots (over 30 psi) and low pressure center pivots (less than 30 psi) (Bjornlund *et al.* 2009). They could also have adopted drip irrigation but, since this method does not lend itself to the predominant low-yielding field and forage crops in the region, it has been adopted by only a few. In the survey, we collected data on the kinds of irrigation technologies farmers used in their fields. If farmers used any of the improved irrigation technologies, they are considered to have commenced the adoption process. However, we did not collect data on the year in which adoption was first made and the time to partial or complete adoption.

We also collected data that might influence farmers' decisions to adopt improved irrigation technologies. We asked farmers: (i) from which sources they received information to help them make their adoption decision, such as extension agencies, government, individual farmers or farmer associations, media or other sources; (ii) whether or not they received outside support when implementing their decision to adopt, such as from dealers, manufacturers or government; (iii) questions related to their social capital, such as membership in a Water Planning Advisory Council or Watershed Stewardship Group, environmental or conservation organization, recreational or social organization, or attended farmer meetings; (iv) questions about their socio-economic characteristics for themselves and members of the farm household, including family size, number of generations the farm has been owned by the family, age, education, off-farm work commitment, farming experience, whether or not they participated in operating the farm before taking over its management, and current status of father/father-in-law (whether actively working on the farm or not); (v) questions about the characteristics of the farm, including total farm size, farm type (corporation, partnership or sole proprietorship), size of irrigated area, and whether or not they have a livestock enterprise that uses the irrigated crop as an input. The descriptive statistics of all major variables are shown in Table A.1.

4. Adopting Improved Irrigation Technologies (IMP) and the Factors that Influence their Adoption — A Descriptive Statistical Analysis

Based on the literature, adoption can be measured either as a discrete or continuous choice (Feder 1982). We measure the adoption of improved irrigation technologies by both of these approaches. For discrete choice, both dichotomous and multiple choice indicators have been used to reflect farmers' adoption decisions. For the discrete choice, if farmers use any kinds of IMP, we define the adoption variable to be 1; otherwise, it is 0. For the multiple choices, the discrete value of this indicator

Table 1. Adoption Extent and Intensity of Irrigation Technologies in Alberta, Canada, 2012

	Adoption Extent: Proportion of Farms that Started the Adoption Process (%)	Adoption Intensity: Proportion of Crop Sown on Area Adopted (%)	Ratio of Columns 1 and 2
Traditional flood irrigation technology	18.8	23.2	0.81
Improved irrigation technology	81.3	76.8	1.06
Wheel move	26.0	18.4	1.41
High pressure pivot (30 psi or more)	13.9	9.8	1.42
Low pressure pivot (under 30 psi)	60.6	54.4	1.11
Drip system	1.9	1.1	1.75

Data sources: Field survey data collected by University of Lethbridge.

ranges from 1 to 4, where 1 is FLOOD and 2–4 are IMP (2 for wheel, move sprinklers, 3 for high pressure center pivot and 4 for low pressure center pivot). This, therefore, measures how far the irrigator has progressed in the adoption process. For the continuous indicator, we measured the adoption intensity of IMP as the percentage of the farm's irrigated area on which it is used.

Our analyses show that by far the majority of irrigators in Alberta have started the adoption process (Table 1). By 2011, only 18.8% of farmers still used FLOOD with an intensity of 23.2%, while 81.2% used some kind of IMP with an intensity of 76.8%. Most irrigators have continued the adoption process and now use the most recent IMP, low pressure center pivots (less than 30 psi): 60.6% now use this system with an average intensity of 54.4% (Table 1). Twenty six percent took only the first step in the adoption process and currently use wheel move sprinklers with an intensity of 18.4%. Almost 14% continued the adoption process to the second generation of IMP and therefore now use high pressure center pivots (30 psi or more) with an intensity of 9.8%. Drip irrigation has been adopted by only 1.9% with an intensity of 1.1%. The ratio between extent and intensity of adoption suggests that those who have not commenced the adoption process are farmers with larger and more extensive operations, likely to be mainly irrigated pastures or hay land (Table 1). Those who now use low pressure center pivots operate much larger farms than those who stopped the adoption process after having adopted either the first or second generation of IMP. This suggests that those who are continuing the adoption process as improved technology becomes available are farmers with larger and more intensively irrigated properties.

4.1. *Information sources and support services*

When considering the adoption of an improved irrigation technology, farmers can obtain information about the benefits and costs of adoption from a number of sources to help them make the decision. Based on the survey: (i) 45% received information from extension agencies; (ii) 27% from other farmers or farmer associations; (iii) 17% from media (web, newspapers, television and radio); (iv) 7% from government sources; and (v) 4% from other sources.

Clear links were identified between the source of information and the extent of adoption. For example, farmers who obtained information from extension agencies were significantly more likely to have started the adoption process than were those who did not obtain information from this source (89% versus 71%) (Table 2). When extension agencies provided information, the adoption probability for all three kinds of IMP increased. The intensity of adoption for those who obtained information from extension agencies also was higher at 86% compared to 64% for those who did not. Obtaining information from other farmers or farmer associations also increased the extent (87% compared to 78%) and intensity (80% compared to 75%) of adoption. There is also a positive relationship between adoption and receiving information through the media. However, if the information is provided by government, the extent and intensity of adoption does not seem to increase. Not all information sources are significantly associated with the extent and intensity of adoption.

Once the decision to adopt an IMP has been made, farmers also can obtain support to implement their decision, which might influence the intensity of adoption. According to the survey, 28% of farmers received some type of outside support service. Among those, 60% received support from the dealer or manufacturer and 16% from the government sector or managers of IDs (Table 2). When farmers received support services, their average adoption intensity increased from 72% to 90%.

4.2. *Social capital*

It has been noted that the extent of social capital can influence the level of collective or economic benefits derived from preferential treatment or cooperation among individuals and groups (Bourdieu 1985). Although different social sciences emphasize different aspects of social capital, they tend to share the core idea "that social networks have value". In our study, we use membership in resource, environmental or social organizations or attendance at farm meetings as proxies for social capital since such involvement increases the opportunities to engage with other farmers and experts and obtain more information on relevant technologies. We found that farmers generally participate in three kinds of organizations: (1) water management-related organizations, such as the Water Planning and Advisory Councils or Water Stewardship groups; (2) environmental protection

Table 2. Relationships among Farmers' Choices on Adopting Improved Irrigation Technologies and Adoption Intensity and Social Capital: Descriptive Statistical Analysis in Alberta, Canada

		Farmers' Choice				Adoption Intensity
		Dichotomous Choice	Multiple Choice			
		Whether or not Adopted IMP[a]	Wheel Move	High Pressure Pivot	Low Pressure Pivot	Proportion of Crop Sown Area Adopted IMP
Support services						
Received support service (1 = yes; 0 = no)	Yes					0.90***
	No					0.72
Information sources						
Extension agencies (1 = yes; 0 = no)	Yes	0.89***	0.70**	0.58**	0.86***	0.86***
	No	0.71	0.46	0.29	0.61	0.64
Government (1 = yes; 0 = no)	Yes	0.8	0.6	0.33	0.69	0.71
	No	0.81	0.58	0.44	0.77	0.77
Individual farmers or farmers' association (1 = yes; 0 = no)	Yes	0.87	0.67	0.57	0.83	0.8
	No	0.78	0.54	0.36	0.73	0.75
Media (1 = yes; 0 = no)	Yes	0.91**	0.67	0.64	0.89**	0.86**
	No	0.78	0.57	0.39	0.73	0.74
Social capital						
Member of the Water Planning Advisory Council or Watershed Stewardship Group (1 = yes; 0 = no)	Yes	0.79	0.55	0.38	0.69	0.78
	No	0.82	0.59	0.43	0.77	0.77
Member of an environmental or conservation group (1 = yes; 0 = no)	Yes	0.86	0.67	0.57	0.81	0.86
	No	0.81	0.57	0.41	0.76	0.76
Member of a recreational or social organization (1 = yes; 0 = no)	Yes	0.82	0.59	0.33	0.79	0.78
	No	0.81	0.57	0.48	0.74	0.76
Attending farm meetings (1= yes; 0 = no)	Yes	0.88**	0.68	0.47	0.85**	0.83*
	No	0.77	0.53	0.41	0.71	0.73

Note: Significance of t statistics: $*p < 0.10$, $**p < 0.05$, $***p < 0.01$. [a]When a household adopted pressure pivot, wheel move or sprinkler irrigation technology, we think he/she adopted improved modern irrigation technology.

or conservation groups, such as Ducks Unlimited, Trout Unlimited, or Alberta Eco-Trust Foundation, and (3) recreational or social organizations, such as minor hockey, 4-H youth agricultural clubs and rotary clubs. In addition to participation in these organizations, farmers can establish their social capital through attending farmer meetings.

Significant associations exist between attending farmer meetings or being a member of environmental related organizations and the probability of adoption (Table 2). Attending farm meetings increased the probability of commencing the adoption process from 77% to 88%; the probability of completing the adoption process also increased and the intensity of adoption of the latest IMP was significantly higher, increasing from 73% to 83%. This suggests that encouraging farmers to attend farmer meetings might be an effective way of increasing adoption. Being a member of an environmental or conservation group also has a positive association with extent and intensity of adoption. However, this relationship is not significant. There was no evidence that participation in water-related groups and recreational or social organizations are associated with adoption.

4.3. *Farm characteristics*

Our analyses indicate that those with larger farms are more likely to adopt. Only 61% of farmers with less than 180 ha started the adoption process compared to 90% of those with more than 180 ha (Table 3). Reflecting the findings in Table 1, we found that those with the largest farms (more than 560 ha) were more likely to adopt low pressure pivots. Irrigators with larger and more highly capitalized farms are likely to have more financial capacity to adopt the newest irrigation technology and, therefore, also are more likely to adopt it more intensively. With increased farm size, intensity of adoption also increased significantly from less than 57% to more than 80%. This further supports the findings discussed under Table 1 that once a decision has been made to commence the adoption process, larger farmers are more likely to continue the process.

Adoption also seems to be related to farm type (legal organization) (Table 3). In the study region, there are three main legal structures of farm businesses: corporations, partnerships and sole proprietors. Extent and intensity of adoption by corporations are significantly higher than for sole proprietors; the extent of adoption for corporations is 92% compared with 69% for sole proprietors. Extent and intensity of adoption also are higher for partnerships than for sole proprietors but the difference in intensity is not statistically significant and the extent is statistically significant only at the 10% level. Reflecting this, only the extent of adoption of low pressure center pivots is statistically significant. Although not

Table 3. Relationships among Farmers' Choices on Adopting Improved Irrigation Technologies (IMP) and Adoption Intensity and Farm Characteristics: Descriptive Statistical Analysis in Alberta, Canada

		Farmers' Choice				Adoption Intensity
		Dichotomous	Multiple Choice			Proportion of Irrigated Area on Which IMP is Adopted
		Whether or not Adopting IMP[a]	Wheel Move	High Pressure Pivot	Low Pressure Pivot	
Farm size (ha)	<180	0.61	0.39	0.18	0.45	0.57
	180–560	0.93***	0.84***	0.64***	0.91***	0.84***
	>560	0.90***	0.59	0.67***	0.88***	0.89***
Farm type (legal structure)	Corporation	0.92***	0.70*	0.68***	0.90***	0.89***
	Partnership	0.84*	0.67	0.3	0.79**	0.77
	Sole	0.69	0.49	0.31	0.58	0.64
Irrigated land as proportion of total land area	<0.365	0.74	0.49	0.4	0.62	0.73
	0.365–0.895	0.86*	0.58	0.5	0.84**	0.81
	>0.895	0.84	0.68	0.39	0.80**	0.77
Have livestock enterprise that uses output of crops or forages (1 = yes; 0 = no)	Yes	0.82	0.64*	0.43	0.77	0.77
	No	0.8	0.44	0.42	0.75	0.76

Note: Significance of t statistics: $^{*}p < 0.10$, $^{**}p < 0.05$, $^{***}p < 0.01$. [a]When a household adopted pressure pivot, wheel move or sprinkler irrigation technology, we think he/she adopted improved modern irrigation technology.

Table 4. Relationships among Farmers' Choices on Adopting Improved Irrigation Technologies (IMP) and Adoption Intensity and Household Characteristics: Descriptive Statistical Analysis in Alberta, Canada

		Farmers' Choice				Adoption Intensity
		Dichotomous Choice	Multiple Choice			
		Whether or not Adopted IMP[a]	Wheel Move	High Pressure Pivot	Low Pressure Pivot	Proportion of Irrigated Area on Which IMP is Adopted
Family characteristics						
Family size (number)	<3	0.74	0.52	0.36	0.65	0.7
	3–4	0.87**	0.63	0.53	0.84***	0.8
	>4	0.97***	0.89**	0.75	0.96***	0.94***
Number of generations in which this farm has been in the family ownership	0–1	0.73	0.45	0.36	0.63	0.65
	2	0.83	0.6	0.38	0.80*	0.78*
	>2	0.87**	0.69*	0.54	0.84**	0.85***
Farmers' personal characteristics						
Age (years)	<52	0.92	0.79	0.58	0.91	0.88
	52–59	0.76***	0.45***	0.4	0.70***	0.72**
	>59	0.76**	0.56*	0.38	0.68***	0.71***
Education (Bachelor's or higher degree) (1 = yes; 0 = no)	Yes	0.82	0.53	0.47	0.78	0.78
	No	0.81	0.59	0.41	0.76	0.76
Off-farm work (1 = yes; 0 = no)	Yes	0.73**	0.47*	0.39	0.63**	0.70*
	No	0.85	0.65	0.46	0.82	0.81
Farming experience (years)	<24	0.81	0.57	0.46	0.76	0.76
	24–36	0.84	0.63	0.5	0.79	0.8
	>36	0.79	0.55	0.32	0.75	0.75
Operating the farm before taking over its management (1 = yes; 0 = no)	Yes	0.85	0.64	0.43	0.82**	0.81**
	No	0.75	0.49	0.42	0.66	0.69
Current status of father/father-in-law (1 = working farmer; 0 = not working farmer)	Yes	0.82	0.58	0.38	0.79	0.79
	No	0.8	0.58	0.47	0.73	0.75

Notes: Significance of t statistics: *$p < 0.10$, **$p < 0.05$, ***$p < 0.01$. [a]When a household adopted pressure pivot, wheel move or sprinkler irrigation technology, we think he/she adopted improved modern irrigation technology.

shown in Table 3, the extent and intensity of adoption also are significantly higher for corporations than for partnerships. The level of irrigation intensity has limited association with adoption as farmers with more than 36.5% of their land under irrigation are slightly more likely to start the adoption process (more than 80% versus 74%). Finally, there was no significant relationship between having some livestock enterprises to use the output of irrigated crops or forages and adoption.

4.4. *Household characteristics*

Consistent with the literature, we found that adoption is related to household characteristics. Larger families are more likely to adopt and have higher adoption intensity (Table 4). Families with fewer than three members are significantly less likely to adopt than families with three or more members (74% compared to 87% and 97%, respectively). Larger families also are more likely to have adopted wheel move or low pressure center pivot and with a higher intensity. The same is the case for those whose farm has been in the family ownership for more than two generations.

Age also is significantly associated with adoption. Farmers who are older than 52 years are significantly less likely to adopt and have a lower intensity. For example, for farmers less than 52 years old, the adoption rate is 92% while for those older than 52 it is 76% (Table 4). Off-farm work also is significantly associated with adoption. Farmers who have off-farm work are significantly less likely to adopt (85% versus 73%) with a lower intensity (81% versus 70%). There is no significant association between having a bachelor's degree or higher education and the extent and intensity of adoption. There are significant associations between farming experience and the adoption of IMP. Farmers who operated the farm before taking over its management have a higher adoption rate of low pressure center pivots and a higher intensity.

Since all the analyses discussed in Section 4 are based on associations only and thus do not prove causation, Section 5 discusses the results of econometric analysis to establish causation.

5. Econometric Model and Estimation Results

5.1. *Specification of econometric model*

To establish causal relationships between farmer and farm characteristics and farmers' adoption behavior, we followed the methods used by Feder (2003). In his study, Feder (2003) assumed that given a perceived output risk and farmer risk aversion, farmers maximize their expected utility through the dichotomous choice of whether or not to adopt the innovated technology (versus traditional technology) and the choice of the proportion of land to which it was allocated. We specified the following three econometric models to examine farmers' dichotomous or multiple choice (models 1 and 2) of irrigation technologies, and the choice of the proportion of land to be allocated to improved irrigation technologies (model 3):

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

$$M_{ij} = \alpha_{ij} + \gamma_1 I_{ij} + \gamma_2 S_{ij} + \gamma_3 F_{ij} + \gamma_4 H_{ij} + \gamma_5 D_{ij} + \varepsilon_{ij}, \quad (2)$$

$$Y_{ij} = \alpha_{ij} + \partial_1 P_{ij} + \partial_2 I_{ij} + \partial_3 S_{ij} + \partial_4 F_{ij} + \partial_5 H_{ij} + \partial_6 D_{ij} + \varepsilon_{ij}. \quad (3)$$

In these three models, i and j indicate the ith farm in the jth irrigation district or private irrigator. The major difference among the above three models is their dependent variables. In the first model, the dependent variable (W_{ij}) measures farmers' dichotomous choice, whether to start the adoption process or not; the value of this variable is 1 if the farmer has commenced and 0 otherwise. The dependent variable in the second model (M_{ij}) measures farmers' multiple choice of adopting various irrigation technologies. The discrete value of this indicator ranges from 1 to 4 where 1 represents the choice of traditional flood irrigation, 2–4 the choice of an IMP (2 for wheel move, 3 for low pressure center pivot and 4 for high pressure center pivot). In the regression, we treat traditional flood irrigation as the base for comparison. The dependent variable in the third model is a continuous indicator that measures the intensity of adoption as the proportion of the irrigated area on which an improved technology is used.

On the right side of the three models, we include the categories of independent variables discussed in the previous section: (i) P_{ij} is a dummy variable that measures whether the farmer used some kind of support service (this variable reflects a post-adoption decision and is included only in the model of adoption intensity) (Table 2); (ii) I_{ij} are four dummy variables that measure the source of information used in the decision to commence the adoption process (Table 2)[1]; (iii) S_i are four dummy variables that measure the social capital of farmers (Table 3); (iv) F_{ij} are

[1]The data in Table A.1. show that the percentage using each type adds up to more than 100, which means that the same farmer could have accessed information through multiple sources; i.e., 58.2% of farmers accessed information only through one source, 21.6% of farmers accessed information through two sources and 8.2% of farmers accessed information through three or more sources. We are interested in which information sources (extension agencies, government, individual farmers or farmers' association or media) are most influential on farmers' decisions to adopt irrigation technologies. Therefore, we included the information sources separately in the models, not considering whether farmers could have accessed information through multiple sources. We also run an alternative model to test whether it makes a difference if farmers access information from one source only. We found that farmers who accessed information from only one source were less likely to adopt wheel move.

farm characteristics (Table 3); considering the possible relationship between farm size and farm type, we also included interactive variables (farm size * corporation and farm size * partnership) in the models; (v) H_{ij} are farmer and household characteristics (Table 4); and (vi) D_i is a regional dummy variable that controls for the impact of regional characteristics that do not change over time but may affect the adoption of irrigation technologies across the region.

Our survey covers the 12 largest IDs in southern Alberta as well as private irrigators in the region. Since there were few respondents in some small IDs, five small districts were grouped together for the econometric analysis. Hence, nine dummy variables were included for IDs with private irrigators being the base for comparison. In the three models, $\beta_1 - \beta_5, \gamma_1 - \gamma_5$ and $\partial_1 - \partial_6$ are the parameters to be estimated, α_{ij} is the constant and ε_{ij} is a random error term. All are assumed to be independently and identically distributed.

Given the nature of the dependent variables, different estimation methods were used for each. As the dependent variable in model 1 is a dummy variable, a logit model is used (Wooldridge 2002). In model 2, the dependent variable is made up of four discrete values (1–4), so a multinomial logit (MNL) model was used as it facilitates the analysis of the determinants of various choice possibilities. In model 3, the dependent variable is continuous (proportion of irrigated land on which the IMP is used); hence ordinary least squares (OLS) could be used for estimation. However, our dependent variable (adoption intensity) is always positive. In such a case, OLS techniques could generate downward biased coefficients (Wooldridge 2002). A Tobit model should avoid these biases and provide robustness to the analysis. Therefore, we also apply the TOBIT to test whether our model is robust.

5.2. *Estimation results*

The three estimated models performed well. The pseudo R^2 ranges from 0.38 to 0.42 for the Logit models, is 0.28 for the MNL model (Table 5), 0.26 for the Tobit model (Table 6), and the adjusted R^2 is 0.21 for the OLS model (Table 6). These are reasonably high values for multivariate analysis based on cross-sectional data. Importantly, the regression results are generally consistent with our descriptive analysis and the major findings are summarized below. For the regression of adoption intensity, no obvious differences in coefficient signs of independent variables or their statistical significance between the Tobit and OLS models were identified. The following discussion is therefore based on the Tobit model.

First, obtaining information from other farmers or farmer organizations significantly increases the probability of a decision being made to commence the adoption process (by 5.5%); the other sources of information also increase adoption

Table 5. Logit and MNL Regression Results of the Determinants of Farmers' Choices on Adopting Improved Irrigation Technologies (IMP) and their Marginal Effects in Alberta, Canada

	Farmers' Dichotomous Choice on Whether or not to Adopt IMP (1 = yes; 0 = no)		Farmers' Multiple Choices on IMP (Versus Traditional Flood Irrigation)		
	Model 1	Model 2	Wheel Move	High Pressure Pivot	Low Pressure Pivot
Information sources					
Extension agencies (1 = yes; 0 = no)	0.083**	0.081**	0.038**	0.028**	0.040**
	(2.18)	(2.19)	(2.07)	(2.08)	(2.11)
Government (1 = yes; 0 = no)	−0.043	−0.037	−0.038	0.058	−0.134
	(0.80)	(0.77)	(0.44)	(0.06)	(0.93)
Individual farmers or farmers' association	0.072**	0.069**	0.096***	0.046***	0.039**
(1 = yes; 0 = no)	(2.43)	(2.45)	(2.73)	(2.85)	(2.55)
Media (1 = yes; 0 = no)	0.048	0.042	0.067	0.004	0.122
	(1.43)	(1.34)	(0.95)	(1.03)	(1.47)
Social capital					
Member of Water Planning Advisory Council or	−0.031	−0.013	−0.009	0.036	−0.061
Watershed Stewardship Group (1 = yes; 0 = no)	(0.58)	(0.29)	(0.21)	(0.15)	(0.37)
Member of an environmental or conservation group	−0.011	−0.029	−0.051	−0.010	−0.065
(1 = yes; 0 = no)	(0.22)	(0.56)	(0.22)	(0.41)	(0.49)
Member of a recreational or social organization	−0.197***	−0.190***	−0.056*	−0.084***	−0.161**
(1 = yes; 0 = no)	(2.88)	(2.88)	(1.91)	(2.68)	(2.56)
Attending farm meetings (1 = yes; 0 = no)	0.128***	0.120***	0.030**	0.040**	0.121***
	(2.77)	(2.88)	(2.07)	(2.18)	(2.59)
Farm characteristics					
Farm size (ha)	0.00005*	0.0001*	0.0001	0.0001**	0.0001*
	(1.67)	(1.84)	(1.47)	(2.14)	(1.76)

Table 5. (*Continued*)

	Farmers' Dichotomous Choice on Whether or not to Adopt IMP (1 = yes; 0 = no)		Farmers' Multiple Choices on IMP (Versus Traditional Flood Irrigation)		
	Model 1	Model 2	Wheel Move	High Pressure Pivot	Low Pressure Pivot
Farm type					
Corporation (1 = yes; 0 = no)	0.080**	0.141***	0.196**	0.149***	0.221***
	(2.35)	(3.21)	(2.25)	(3.94)	(3.48)
Partnership (1 = yes; 0 = no)	0.052**	0.050*	0.064	0.017	0.147**
	(1.97)	(1.78)	(1.49)	(1.09)	(2.03)
Interactive variables					
Farm size * corporation		−0.0001*	−0.00002	−0.0001**	−0.0001*
		(1.93)	(1.61)	(2.57)	(1.76)
Farm size * partnership		−0.00004	−0.00003	−0.0001	−0.00001
		(0.42)	(0.28)	(0.60)	(0.32)
Irrigated land as proportion of total land area	0.098**	0.093**	0.118**	0.100	0.106**
	(1.96)	(2.03)	(2.10)	(0.56)	(2.19)
Having livestock enterprise that use output of crops or forages (1 = yes; 0 = no)	0.023	0.011	0.177	0.002	0.155
	(0.79)	(0.41)	(1.42)	(0.58)	(0.16)
Household characteristics					
Family characteristics					
Family size (number)	0.034**	0.033***	0.011*	0.001*	0.046**
	(2.52)	(2.58)	(1.91)	(1.89)	(2.36)
Number of generations in ownership of this farm	0.024	0.024	0.042	0.028*	0.038
	(1.16)	(1.24)	(1.42)	(1.85)	(1.05)
Farmers' personal characteristics					
Age (years)	0.002	0.001	0.003	0.002	0.003
	(1.03)	(1.08)	(1.19)	(1.42)	(0.82)

Table 5. (*Continued*)

	Farmers' Dichotomous Choice on Whether or not to Adopt IMP (1 = yes; 0 = no)		Farmers' Multiple Choices on IMP (Versus Traditional Flood Irrigation)		
	Model 1	Model 2	Wheel Move	High Pressure Pivot	Low Pressure Pivot
Education (Bachelor's or higher degree) (1 = yes; 0 = no)	0.053*	0.054**	0.199	0.081**	0.173*
	(1.82)	(2.10)	(0.70)	(2.29)	(1.96)
Off-farm work (1 = yes; 0 = no)	−0.038	−0.034	−0.077	−0.017	−0.008
	(1.18)	(1.11)	(1.47)	(0.70)	(1.17)
Farming experience (years)	−0.002*	−0.002*	−0.001**	−0.001**	−0.001**
	(1.88)	(1.94)	(2.02)	(2.08)	(2.05)
Operating the farm before taking over its management	0.003	−0.004	−0.060	−0.101	0.162
(1 = yes; 0 = no)	(0.08)	(0.13)	(0.17)	(1.17)	(0.45)
Current status of father/father-in-law (1 = working farmer;	−0.024	−0.019	−0.041	−0.041	−0.015
0 = not working farmer)	(0.92)	(0.76)	(0.26)	(1.15)	(0.52)
Irrigation district dummy (versus private region)	Omitted	Omitted	Omitted	Omitted	Omitted
Constant	−3.948	−4.995**	−6.288**	−8.313**	−4.556*
	(1.64)	(1.98)	(2.34)	(2.48)	(1.82)
Observations	208	208	248	248	248
Pseudo R^2	0.3815	0.4187		0.2800	

Notes: (1) Model 1 does not include the interactive variables between farm size and farm type, while model 2 includes their cross variables.
(2) Instead of reporting estimated coefficients, we reported marginal effects.
(3) Absolute t statistics for estimated coefficients (not reported) in parentheses; $^{*}p < 0.10$, $^{**}p < 0.05$, $^{***}p < 0.01$.

Table 6. Regression Results of the Determinants of Adoption Intensity of Improved Irrigation Technologies in Alberta, Canada

	Adoption Intensity: Proportion of Irrigated Area on Which IMP is Adopted	
	Tobit	OLS
Support services		
Received support service (1 = yes; 0 = no)	0.146**	0.115*
	(2.03)	(1.79)
Information sources		
Extension agencies (1 = yes; 0 = no)	0.157**	0.134**
	(2.29)	(2.19)
Government (1 = yes; 0 = no)	−0.134	−0.120
	(1.28)	(1.30)
Individual farmers or farmers' association (1 = yes; 0 = no)	0.189***	0.152**
	(2.77)	(2.52)
Media (1 = yes; 0 = no)	0.070	0.060
	(0.89)	(0.86)
Social capital		
Member of Water Planning Advisory Council or Watershed Stewardship Group (1 = yes; 0 = no)	−0.010	−0.003
	(0.11)	(0.03)
Member of an environmental or conservation group (1 = yes; 0 = no)	0.010	0.015
	(0.10)	(0.16)
Member of a recreational or social organization (1 = yes; 0 = no)	−0.244**	−0.194**
	(2.41)	(2.20)
Attending farm meetings (1 = yes; 0 = no)	0.263**	0.203**
	(2.57)	(2.26)
Farm characteristics		
Farm size (ha)	0.0002	0.0001
	(1.60)	(1.28)
Farm type		
Corporation (1 = yes; 0 = no)	0.285***	0.227***
	(3.30)	(2.98)
Partnership (1 = yes; 0 = no)	0.105	0.068
	(1.04)	(0.77)
Cross variables		
Farm size * corporation	−0.0002	−0.0001
	(1.44)	(1.16)
Farm size * partnership	−0.0001	−0.00002
	(0.41)	(0.17)
Irrigated land as proportion of total land area	0.234**	0.182*
	(2.08)	(1.82)
Having livestock enterprise that use output of crops or forages (1 = yes; 0 = no)	−0.008	−0.003
	(0.13)	(0.05)

Table 6. (*Continued*)

	Adoption Intensity: Proportion of Irrigated Area on Which IMP is Adopted	
	Tobit	OLS
Household characteristics		
Family characteristics		
Family size (number)	0.043**	0.035*
	(2.14)	(1.97)
Number of generations who has ownership of this farm	0.043**	0.035*
	(2.14)	(1.97)
Farmers' personal characteristics		
Age (years)	0.005	0.003
	(1.36)	(1.11)
Education (Bachelor's or higher degree) (1 = yes; 0 = no)	0.090	0.075
	(1.26)	(1.19)
Off-farm work (1 = yes; 0 = no)	−0.050	−0.038
	(0.71)	(0.61)
Farming experience (years)	−0.006***	−0.005***
	(2.89)	(2.61)
Operating the farm before taking over its management (1 = yes; 0 = no)	0.039	0.029
	(0.48)	(0.40)
Current status of father/father-in-law (1 = working farmer; 0 = not working farmer)	−0.025	−0.019
	(0.41)	(0.34)
Irrigation district dummy	Omitted	Omitted
Constant	−0.036	0.170
	(0.12)	(0.67)
Observations	208	208
Pseudo R^2	0.2573	–
Adj R^2	–	0.2111

Note: Absolute t statistics in parentheses; *$p < 0.10$, **$p < 0.05$, ***$p < 0.01$.

but are not statistically significant (Table 5). The adoption intensity also is significantly increased by 18.9% when information is obtained from individual farmers or farmer associations and 15.7% when obtained from extension officers (Table 6). That information from fellow farmers is most influential probably reflects that farmers trust the experience of their fellow farmers. The second most important information source is extension agencies, which might reflect that farmers have known these professionals for a longer period and have learned to trust their advice (Table 6). Government-provided information has an insignificant influence on adoption. One possible explanation could be that only 10% of farmers have accessed information from government (Table A.1) but this result should be researched further in the future. Obtaining information through the media has a minor and insignificant influence on adoption except for low pressure center pivots where it is significant and explains 13.9% of adoption (significant at the 10% level) (Table 5).

Second, receiving support services to assist in implementation of the adoption of an improved irrigation technology significantly increases adoption intensity. Estimation results show that the coefficient of the support service variable is positive and statistically significant in the intensity model (Table 6). If farmers can receive the assistance of support services, their adoption intensity is increased by 14.6%. Therefore, the use of such support services should be promoted and supported by government initiatives to increase the benefit of the farmers' adoption decisions.

Not all social capital variables make a positive contribution to adoption. Attending meetings related to agricultural production practices significantly increase the probability of both commencing the adoption process (especially the adoption of low pressure center pivots) by 11% (Table 5) and the intensity of adoption by 26.3% (Table 6). One possible explanation is that farmers who attend agricultural meetings tend to be more concerned about production and water issues and therefore more likely to adopt improved technology to increase productivity. Membership in recreational or social organizations has a significant and negative effect in all models; such membership reduced the probability of commencing the adoption process by 11.9% and lowered the adoption intensity by 24.4% (Tables 5 and 6). This suggests that farmers who take time to attend activities arranged by recreational or social organizations might be less dependent on irrigated production or less interested in adopting improved technologies. The results are consistent with our expectation. Farmers who are members of a recreational or social organization have a smaller farm size (average 588 ha) and percentage of irrigated areas over total cultivated land areas (58%) compared to those farmers who did not participate in such organizations (857 ha and 62%).

Finally, adoption is significantly affected by both socio-economic and farm characteristics. Farm size has only a limited impact on the extent and intensity of adoption. While all estimated coefficients are positive, only the one for high pressure center pivot is statistically significant (Table 5). The lack of significance likely reflects the dual impacts of size discussed under Table 1. Adoption also differs by farm types with corporate farms having both a significantly higher rate and intensity of adoption across all improved irrigation technologies (Tables 5 and 6). Partnerships have a higher adoption rate than private proprietors, but they are statistically significant only for intensity of adopting low pressure center pivots. This implies that most partnerships likely have completed the adoption process and now use low pressure center pivots. The finding that the interactive variables between farm size and farm type had little or no influence on adoption suggest that the influences of farm size and farm type are independent and separate.

Despite the findings that many household characteristics have important influences on adoption of improved technologies (as noted in Stephenson 2003; Abdulai *et al.* 2011), our study finds that only a few household characteristics have a significant influence on adoption (Tables 5 and 6). This is likely because of the focus on the adoption process. Since we measure the farmers' participation in the adoption process by current use, it could be many years after the adoption took place, during which time many personal and family characteristics might have changed. Supporting this is the fact that those variables that are significant are those with a more long-term influence. Family size has a positive and statistically significant influence on both extent and intensity of adoption: larger families are more likely to adopt on a larger part of their irrigated area. This could be because these families are more likely to have a successor in place and hence have a more longitudinal view of the viability of the property.

The number of generations in which the property has been in the ownership of the farm family has a positive impact on both extent and intensity of adoption but is statistically significant only for intensity and adoption of high pressure center pivots (Tables 5 and 6). This could reflect that the more generations the property has been in the family ownership, the more likely it is that it will be passed on to the next generation. Hence, the current farmers have a greater incentive to invest in the long-term viability of the farm. Also, these farmers are likely to have a larger asset base that enables continuous investment in the adoption process.

Farming experience has a significant negative effect on both extent and intensity of adoption (Tables 5 and 6). The more years of experience the current farmer has, the less likely s/he is to have adopted any kind of improved irrigation technology and the lower the intensity of adoption. This could suggest reluctance among older farmers to embrace improved technologies in the absence of the expectation of intergenerational change, and younger farmers are more likely to adopt improved technologies. There is also some evidence that education influences adoption. Those with a post-secondary university degree are significantly more likely to adopt low and high pressure pivots and have a positive but insignificant influence on intensity. This suggests that a higher education provides a better understanding of the potential benefits of improved technologies.

6. Concluding Remarks

About 97% of all allocated water resources in Alberta is from surface water (Alberta Environment 2014). Irrigation activities account for about 75% of surface water allocations in the SSRB in Alberta (Alberta Environment 2002). As demand for clean and safe water continues to increase for commercial, industrial, municipal and environmental activities, there is increasing political pressure to reduce water used in agriculture. The Water for Life strategy and its subsequent renewal and related documents acknowledges the need to use Alberta's limited water resources more efficiently and productively to generate water savings as a source of supply to meet new demands and relies on voluntary reallocations to move the saved water to new users.

While traditional flood irrigation was the predominant technology used in the first half of the 20th century, the agricultural and environmental branches of the Alberta government have long promoted the adoption of irrigation equipment that has higher on-farm irrigation efficiencies, especially low pressure sprinklers on center pivots. Their apparent hope is that if less water is used to irrigate crops, more will be available for other uses. Although changes in Alberta's Water Act (1999) permitted trading of water rights, few trades have been made due to a number of constraints in the market (Nicol *et al.* 2008). Rather, the hope seems to be for voluntary transfers of unused (and unneeded) water from agriculture to other parties.

This study examined the extent and intensity of adoption of irrigation technologies that have higher on-farm irrigation efficiencies. The extent of adoption was defined as the proportion of all irrigators who have commenced the adoption process and now use some method other than flood irrigation to apply water; the intensity of adoption was defined as the percentage of irrigated land on which the technology has been adopted in southern Alberta. The data were collected in a farm-household survey conducted in the 12 largest IDs as well as among private irrigators in southern Alberta. A survey was conducted using face-to-face interviews of 208 randomly chosen irrigation farm operators.

We found that, by 2011, 81.3% of farmers had commenced the adoption process, now use some method other than flood irrigation, and use it on 76.8% of all irrigated land. The most commonly used irrigation technology is low pressure center pivot systems (which is the newest and potentially most efficient application technology currently sold widely in southern Alberta) with 61% of farmers having used it on 54% of their irrigated land. However, this finding also implies that there is still room for further improvement.

Obtaining information on irrigation technologies from other farmers (either individual farmers or farmers' associations) and extension agencies significantly influences farmers' decisions to adopt. Receiving support services following the adoption decision also plays an important role in increasing the intensity of adoption. Farmers who increased their social capital through attending meetings related to agricultural production practices were more likely to adopt and to adopt more intensively while farmers who participated in recreational or social organizations were less likely to adopt. Finally, the extent and intensity of adoption are higher for those with a corporate farm structure, larger families, more generations of farm ownership and higher education.

Therefore, to ensure a higher and more intensive rate of adoption of potentially more efficient irrigation technologies, and to encourage farmers to continue to adopt improved technologies as they are introduced over time, policy makers should: (i) provide more effective support services for farmers once an adoption decision has been made and deliver it in a timely manner to reduce their perception of risk; (ii) focus on supplying information about improved technologies and their potential benefits and costs through extension officers and farmer organizations; (iii) facilitate and encourage the development of farmer peer groups to exchange experiences; (iv) expand the provision of extension officers; (v) provide advice and services that support farmers in developing the most efficient business structure for their farm business and secure farm succession and (vi) provide programs that particularly target and accommodate small-scale farmers.

In the literature, there is concern that improvements in on-farm irrigation efficiency could exacerbate water scarcity concerns at a basin level, where consumptive use is increased and irrigation returns flows are reduced (Perry 2011; Seckler 1996). This is unlikely to become a serious issue in southern Alberta, at least for a long time. Although IDs and individual farmers outside of IDs have licenses to extract and consume specific quantities of water each year, the area with water rights on each farm is strictly regulated and applications to direct any water saved to further economic use are thoroughly vetted (and seldom approved). Furthermore, irrigators have extracted, on average, only 59% of their licensed water allocation over the period 1976–2014 (AAF 2015).

While no significant amount of groundwater currently is used for irrigation in Alberta, new research should explore the relationship between ground water and surface water flow in the hydrological basin. While continuing to promote the adoption of improved irrigation technologies, it is important that the government consider additional institutional measures to incent adoption and promote the redistribution of saved water to other uses. Studies on various redistribution schemes, especially improved water marketing provisions (e.g., He *et al.* 2012; Ali and Klein 2014) show the possibility of quite big socio-economic gains in welfare from redistribution of some water away from agriculture.

Our paper focuses mainly on understanding the factors that influence the rate and intensity of adoption of improved irrigation technologies at the state level. We are aware of the need to take the analysis further by addressing policy interventions that would ensure that the water saved by the improved irrigation technologies are indeed saved. The reader can find more valuable discussion in (Nicol *et al.* 2010; Ward and Pullido 2008; Scheierling *et al.* 2016).

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Appendix A

Table A.1. Characteristics of Major Variables

	Mean	Std. Dev.
Dependent variables		
Farmers' dichotomous choice on whether or not adopted improved irrigation technologies (IMP) (1 = yes; 0 = no)	0.81	0.39
Proportion of irrigated area on which IMP is adopted (adoption intensity)	0.77	0.40
Independent variables		
Support service		
Received support service (1 = yes; 0 = no)	0.28	0.45
Information sources		
Extension agencies (1 = yes; 0 = no)	0.59	0.49
Government (1 = yes; 0 = no)	0.10	0.30
Individual farmers or farmers' associations (1 = yes; 0 = no)	0.36	0.48
Media (1 = yes; 0 = no)	0.22	0.42
Other sources (1 = yes; 0 = no)	0.06	0.23
Social capital		
Member of the Water Planning Advisory Council or Watershed Stewardship Group (1 = yes; 0 = no)	0.12	0.32
Member of an environmental or conservation group (1 = yes; 0 = no)	0.10	0.30
Member of a recreational or social organization (1 = yes; 0 = no)	0.42	0.50
Attending farm meetings (1 = yes; 0 = no)	0.39	0.49
Farm characteristics		
Farm size (ha)	702	1,048
Farm type		
Corporation (1 = yes; 0 = no)	0.41	0.49
Partnership (1 = yes; 0 = no)	0.21	0.41
Irrigated land as proportion of total land area	0.60	0.35
Having livestock enterprise that use output of crops or forages (1 = yes; 0 = no)	0.64	0.48
Household characteristics		
Family characteristics		
Family size (number)	3.00	1.64

Table A.1. (*Continued*)

	Mean	Std. Dev.
Number of generations with ownership of this farm	2.21	1.08
Farmers' personal characteristics		
Age of respondent (years)	55.52	12.23
Education of respondent (Bachelor's or higher degree) (1 = yes; 0 = no)	0.25	0.43
Off-farm work status of respondent (1 = yes; 0 = no)	0.34	0.48
Farming experience of operator (years)	32.34	19.30
Operating the farm before taking over its management (1 = yes; 0 = no)	0.63	0.48
Current status of father/father-in-law (1 = working farmer; 0 = not working farmer)	0.55	0.50

Note: Observation number is 208.

References

Abadi Ghadim, AK (2000). Water repellency: A whole-farm bio-economic perspective. *Journal of Hydrology*, 231–232, 396–405.

Abdulai, A, V Owusu and JEA Bakang (2011). Adoption of safer irrigation technologies and cropping patterns: Evidence from Southern Ghana. *Ecological Economics*, 70(7), 1415–1423.

Adeoti, AI (2009). Factors influencing irrigation technology adoption and its impact on household poverty in Ghana. *Journal of Agriculture and Rural Development in the Tropics and Subtropics*, 10(1), 51–63.

Ginder B, & Hofer, K Woolf and AF Technology & Information Branch (2000). Irrigation in Alberta. Lethbridge, Alberta. Technology & Innovation Branch of Alberta Agriculture and Food (AF).

Alberta Agriculture and Forestry (AAF) (2015). Alberta irrigation information: Facts and figures for the year 2014. Lethbridge.

Alberta Environment (2002). Water for Life — Facts and Information on Water in Alberta Publication #I/930. Alberta Environment, Edmonton, Alberta.

Alberta Environment (2003). Water for life: Alberta's strategy for sustainability. Available at: http://environment.gov.ab.ca/info/library/6190.pdf.

Alberta Environment (2007). Current and future water use in Alberta. Available at: http://www.assembly.ab.ca/lao/library/egovdocs/2007/alen/164708.pdf [16 September 2009].

Alberta Environment (2014). Water allocation. Available at: http://environment.alberta.ca/03134.html [27 March 2014].

Alberta Agriculture and Rural Development (2013). Irrigation in Alberta: A statistical overview — 2012. Edmonton, Alberta: Alberta Agriculture and Rural Development.

Ali, MK and KK Klein (2014). Implications of current and alternative water allocation policies in the Bow River Sub Basin of Southern Alberta. *Agricultural Water Management*, 133, 1–11.

Bennett, DR, RV Riewe, T Entz and SA Woods (2015). Water conveyance and on farm irrigation system efficiency gains in southern Alberta irrigation districts from 1999 to 2012. *Canadian Water Resources Journal*, 40:(2), 173–186, doi: 10.1080/07011784.2015.1006686.

Bjornlund, H, L Nicol and K Klein. (2008). Economic instrument and irrigation water management — A comparative study of private and district irrigators in Alberta, Canada. In *Sustainable Irrigation Management, Technologies and Policies II*, YV Esteve, CA Brebbia and CP Rico (eds.), pp. 3–14. Southampton: WIT Press.

Bjornlund, H, L Nicol and KK Klein (2009). The adoption of improved irrigation technology and management practices — A study of two irrigation districts in Alberta, Canada. *Agricultural Water Management*, 96, 121–131.

Bjornlund, H and KK Klein (2015). Water Conservation and trading – policy challenges in Alberta Canada. Chapter 23 in *Routledge Handbook of Water Economics and Institutions*, K Burnett, R Howitt, JA Roumasset and CA Wada (eds.), pp. 381–396. Routledge Publishers.

Bourdieu, P (1985). The forms of capital. In *Handbook of Theory and Research for the Sociology of Education*, JG Richardson (ed.), pp. 241–258. New York: Greenwood.

Canada Year Book (2012). Ottawa: Statistics Canada.

Caswell, M, E Lichtenberg and D Zilberman (1990). The effects of pricing policies on water conservation and drainage. *American Agricultural Economics Association*, 72(4), 884–893.

Caswell, MF and D Zilberman (1985). The choices of irrigation technologies in California. *American Journal of Agricultural Economics*, 67, 223–235.

Cai, X and MW Rosegrant (2013). World water productivity: Current situation and future options. In *Water Productivity in Agriculture: Limits and Opportunities for Improvement*, JW Kijne, R Barker and D Molden (eds.). CAB International 2003, pp. 163–178.

Dinar, A and D Yaron (1992). Adoption and abandonment of irrigation technology. *Agricultural Economics*, 6(4), 315–332.

Dong, B (2008). Food and agriculture organization of the United Nations. Study on environmental implication of water saving irrigation in Zhanghe irrigation system. Available at: www.fao.org/nr/water/espim/.../Study_environment_water_saving.pdf [8 January 2011].

Feder, G (1982). Adoption of interrelated agricultural innovations: Complementarity and the impact of risk, scale and credit. *American Journal of Agricultural Economies*, 64, 94–101.

Feder, G and D Umali (1993). The adoption of agricultural innovations: A review. *Technological Forecasting and Social Change*, 43, 215–239.

Feder, G, RE Just and D Zilberman (1985). Adoption of agricultural innovations in developing countries: A survey. *Economic Development and Cultural Change*, 33, 255–298.

Fuglie, KO and CA Kascak (2001). Adoption and diffusion of natural-resource-conserving agricultural technology. *Review of Agricultural Economics*, 23(2), 386–403.

Hall, M, H Bjornlund and X Wei (2012). Exploring private and district irrigators' perceptions towards water trading in the South Saskatchewan river basin. SAREC Report 2012–1, University of Lethbridge.

He, L, TM Horbulyk, MK Ali, DG Le Roy and KK Klein (2012). Proportional water sharing vs. seniority-based allocation in the Bow River Basin of Southern Alberta. *Agricultural Water Management*, 104, 21–31.

Itharat, C (1980). Adoption of agricultural innovations: An analysis of socioeconomic characteristics, personality variables, and communications behaviour in the north-eastern region of Thailand. Dissertation Abstracts, 42/02A, 507.

Just, DR, SA Wolf, S Wu and D Zilberman (2002). Consumption of economic information in agriculture. *American Journal of Agricultural Economics*, 84(1), 39–52.

Klein, KK, R Bewer, MK Ali and SN Kulshreshtha (2012). Estimating water use efficiencies for water management reform in Southern Alberta irrigated agriculture. *Water Policy*, 14(6), 1015–1032.

Koundouri, P, C Nauges and V Tzouvelekas (2005). Technology adoption under production uncertainty: Theory and application to irrigation technology. *American Journal of Agricultural Economics*, 88(3), 657–670.

Lichtenberg, E (1989). Land quality, irrigation development, and cropping patterns in the northern high plains. *American Journal of Agricultural Economics*, 71(1), 187–194.

Lindner, RK and PG Pardey (1979). The micro processes of adoption — A model. In *9th Congress of the Australian and New Zealand Association for the Advancement of Science*, Auckland.

Liu, C, Q Li and Y Duan (2009). The study on water saving technology with reducing ET, river basin research and planning approach, H Zhang, R Zhao and H Zhao (eds.), *Proc. Int. Symp. HAI Basin Integrated Water and Environ. Management*, pp. 341–346.

Marra, M, DJ Pannell and AA Ghadim (2003). The economics of risk, uncertainty and learning in the adoption of new agricultural technologies: Where are we on the learning curve? *Agricultural Systems*, 75, 215–234.

Nicol, L, KK Klein and H Bjornlund (2008). Permanent transfers of water rights: A study of the southern alberta market. *Prairie Forum*, 33(2), 341–356.

Nicol, L, H Bjornlund and KK Klein (2010). Private irrigators in southern Alberta: A survey of their adoption of improved irrigation technologies and management practices. *Canadian Water Resources Journal*, 35(3), 339–350.

Ommani, AR, M Chizari, C Salmanzadeh and JFA Hosaini (2009). Predicting adoption behavior of farmers regarding on-farm sustainable water resources management (SWRM): Comparison of models. *Journal of Sustainable Agriculture*, 33(5), 595–616.

Paterson Earth & Water Consulting Ltd (Paterson EWCL) (2015). Economic value of irrigation in Alberta. Lethbridge, Alberta: Alberta Irrigation Projects Association. Available at: http://www.aipa.ca/wp-content/uploads/2015/10/EconomicValueIrrigationAlberta.pdf [14 March 2016].

Piersol, L (2010). Water: There is no substitute. Available at: http://www.lethbridge.ca/Things-To-Do/Nature-Center/Documents/WaterConservation.pdf [30 September 2013].

Perry, C (2011). Accounting for water use: Terminology and implications for saving water and increasing production. *Agricultural Water Management*, 98, 1840–1846.

Ramin, V (2004). The status of integrated water resources management in Canada. In *Canadian Perspectives on Integrated Water Resources Management*, D Shrubsole (ed.), pp. 1–32. Cambridge, Ontario: Canadian Water Resources Association.

Ryan, B and N Gross (1943). The diffusion of hybrid seed corn in two Iowa communities. *Rural Sociology*, 8, 15–24.

SWA (Saskatchewan Watershed Authority) (2001). South Saskatchewan River watershed, background report South Saskatchewan River watershed. Available at: http://www.southsaskriverstewards.ca/ckfinder/userfiles/files/SSRWSI%20Background%20Report%20for%20SWPP.pdf?PHPSESSID=9gjkgsunrbubo7unqto4kj9lr0.

Seckler, D (1996). The new era of water resources management (Research Report 1). Colombo, Sri Lanka: International Irrigation Management Institute (IIMI).

Shampine, A (1998). Compensating for information externalities in technology diffusion models. *American Journal of Agricultural Economics*, 80, 337–346.

Stephenson, G (2003). The somewhat flawed theoretical foundation of the extension service. *Journal of Extension*, 41, 1–10.

Scheierling, S, DO Treguer and JF Booker (2016). Water productivity in agriculture: Looking for water in the agricultural productivity and efficiency literature. *Water Economics and Policy*, 2(3), 1650007.

Tsur, Y, M Sternberg and E Hochman (1990). Dynamic modeling of innovation process adoption with risk aversion and learning. *Oxford Economic Papers*, 42, 336–355.

Warner, RE (1981). Factors affecting the adoption of wildlife conservation practices by east-central Illinois farmers and their educational implications. Dissertation Abstracts, 42/07A, 2978.

Wooldridge, JM (2002). *Econometric Analysis of Cross Section and Panel Data*. Cambridge: MIT Press.

Zilberman, D, J Zhao and A Heiman. (2012). Adoption versus adaptation: With emphasis on climate change. *Annual Review of Resource Economics*, 4, 27–206.