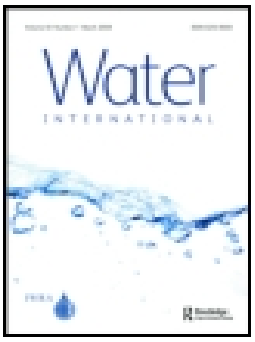

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Changing to more efficient irrigation technologies in southern Alberta (Canada): an empirical analysis

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Results from an irrigator survey in southern Alberta (Canada) indicate that more than half of irrigators changed irrigation technologies during the five-year period (crop years 2007/08–2011/12) and this potentially improved application efficiency. Changes were made from flood irrigation to wheel-move sprinklers to high- and then low-pressure pivot systems. The intended future rate of change is lower than that experienced over the previous five years. Important factors causing these changes were identified: reducing irrigation application, labour and energy inputs, and increasing crop yields and quality. Econometric modelling shows that irrigators who have commenced the process of adopting more efficient sprinklers are full-time farmers, operate their farm as corporations or partnerships, obtain information from extension agencies, and are more likely to upgrade their technologies in future.

Keywords: sprinklers; application efficiency; factors influencing change; econometric models; Alberta

Introduction

Policy-makers in Alberta, Canada, face serious challenges finding ways to share water among competing users to meet new demand. Surface water is most plentiful in north-flowing river basins, while the majority of the population and economic activity is located in the southern part of the province where water supply is most limited (Wood, 2008). Prior to the 1950s, the increase in surface water use was due mostly to the development of irrigated agriculture. After the 1950s, in addition to the continuing expansion of irrigated agriculture, non-agricultural water uses (industrial, commercial, municipal, mining and environmental) have increased greatly (Alberta Environment (AE), 2007). As a result, the share of available surface water used for irrigation declined from more than 90% in the 1950s to less than 65% in 2000. With increasing water demand, rivers in the south (mainly the South Saskatchewan River Basin – SSRB) have been rated as fully or over-allocated and many river reaches have suffered negative environmental impacts from the current level of water extraction (AE, 2005). It is expected that total surface water use in Alberta will increase by 21% by 2025, which will put additional pressure on the limited water resources in this region (AE, 2007).

Given the current conditions and prospects of increasing water scarcity, the government of Alberta has realized that new ways of managing competing uses need to be found.

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The first strains on water resources emerged in the 1980s and the government introduced guidelines in 1991 that set a cap on the amount of water that could be allocated for irrigation (AE, 2003). Under the Water Resources Act (1999), the right to extract water in Alberta is granted in the form of licensed water allocations and issued only for diversion purposes (Province of Alberta, 2014). Following severe droughts in 2001 and 2002, the Water for Life strategy was released in 2003, which proposed that water conservation should be achieved through a 30% increase in water use efficiency and productivity.[1] In 2005, the government decreed that no new applications would be accepted for licensed water allocations in the SSRB, except for the Red Deer River (AE, 2005). As the major user of surface water in Alberta, and the sector that controls the largest and most senior water licences, irrigation must play a major role in finding ways of sharing their allocated water with other sectors of the economy. However, whether or not irrigators are willing to sell part of their licensed allocation is likely to depend on whether or not they can reduce their irrigation application without reducing production. Internationally, adopting more efficient irrigation technologies has been considered as one of the most important measures to reduce the application of irrigation on fields without reducing production (Howell, 2001).

In the past 50 years, the predominant irrigation technology used in Alberta has shifted from flood (or furrow) irrigation to wheel-move sprinkler systems, to high-pressure pivot systems and, more recently, to low-pressure pivot systems. In 1965, more than 85% of the irrigated area in Alberta used flood irrigation (Agriculture and Rural Development in Alberta (ARDA), 2013). After the 1970s, the use of sprinkler irrigation systems accelerated and, by 2013, the share of irrigated area that used flood irrigation had dropped to 8.9%. Among sprinkler irrigation systems, the low-pressure centre pivot has become the dominant method, now used on 69.1% of irrigated land in Alberta (ARDA, 2013). The adoption of drip irrigation systems in Alberta is limited due to the extensive use of irrigation on large areas of relatively low-value crops such as wheat, barley, canola, hay and silage. With the shift in irrigation technologies, irrigation application efficiencies (i.e., the fraction of the water volume applied to the field that is consumed by the crop) in Alberta have increased significantly. According to ARDA (2013), the application efficiency of wheel-move sprinklers is 70%, whereas high- and low-centre pivots are 73% and 84%, respectively. However, this does not imply that efficiency of water use has improved at the system and basin level, which is outside the scope of this study.

Can irrigation technologies in Alberta continue to be improved? Answering this question will provide policy-makers with a better understanding of whether or not the objectives of the Water for Life Strategy can be achieved. Since irrigation is the largest water-consuming sector (accounting for 72% of water allocation in SSRB), the policy objective of increasing water use efficiency largely depends on the ability and willingness of irrigators to improve their irrigation application efficiency (AE, 2007). Presently, low-pressure centre pivots are used on less than 70% of the irrigated area, implying that there is still considerable room for irrigators to improve further their application efficiencies (ARDA, 2013). Based on a field survey in two irrigation districts (IDs) in Alberta, Bjornlund, Nicol, and Klein (2009) found that irrigators' intentions to improve their irrigation technologies further during the following five years were lower than what they had done during the previous five-year period; however, no follow-up studies have been undertaken to investigate the actual level of improvement that took place during that period.

This study is conducted over the entire SSRB, which includes the two IDs reported in Bjornlund et al. (2009), but also the 10 largest of 11 other IDs as well as private irrigators in the region who do not belong to any ID. Important questions pursued in this paper are:

- What changes have irrigators made in their irrigation technologies over the 2007/08–2011/12 period?
- What are their future plans for improving irrigation technologies during the next five years (2012/13–2016/17)?
- Why have irrigators made (or intend to make) changes, i.e., what are the exogenous driving forces?
- Why do some irrigators change or intend to change irrigation technologies while others do not, i.e., what kinds of socio-economic and farm characteristics influence change or the intention to change?

The overall goal of this study is to answer these questions by exploring the behaviour and intended behaviour of irrigators. To achieve this, a survey of irrigators across southern Alberta was conducted during the summer of 2012. Based on the survey, we first examine the changes in irrigation technologies made by irrigators in the past five years (crop years 2007/08–2011/12) and what changes irrigators intend to make over the next five years (2012/13–2016/17). The major exogenous reasons why irrigators change their irrigation technologies (in both the past and future) are summarized and discussed. We then identify and quantify the socio-economic and farm characteristics that influenced irrigators' decisions to adopt improved irrigation technologies in the past and their intention to do so in future. Based on the outcome of these analyses, we identify potential policies that could accelerate technology adoption and thereby potentially improve application efficiencies.

The paper is organized as follows. The next section describes the data sources and major variables used in the analysis. The third section examines the changes in irrigation technologies made by irrigators during the five crop years that precede the survey and their intentions for the five-year period following the survey. The major reasons reported by irrigators for changing their irrigation technologies are also summarized and discussed. Econometric modelling is used in the fourth section to identify the factors that have influenced irrigators' decisions in the past and are likely to do so in future. The final section concludes and provides some policy implications.

Data

This study covers irrigators within the 12 largest (of 13) IDs (subsequently called district irrigators) as well as irrigators who hold individual licensed allocations (called private irrigators) within the SSRB. The IDs account for 82% of the irrigated area and hold the largest and most senior water licences (Bjornlund, Nicol, & Klein, 2008), while private irrigators account for the remaining 18%.[2] District irrigators have their irrigated area registered on the districts' assessment roles and thereby have the right to receive a share of the district's water allocation. District irrigators pay a flat fee per hectare to cover administration, management of the district, maintenance of its infrastructure and a minimum of 25% of the cost of rehabilitating infrastructure (with the government paying up to 75%). Private irrigators pay only a small licence fee to cover administrative expenses as they rely totally on their own infrastructure to extract the water from the river and convey it to their field. However, neither type of irrigator pays for the water itself or the cost of head works and supply infrastructure that delivers the water to the point on the river where the districts or private irrigators extract the water.

The data were collected in a farm household survey during the summer of 2012 (Zhang, 2014). A comprehensive questionnaire was pretested by several irrigation experts prior to the actual survey of farm households. The enumerators were two well-trained undergraduate students who had a farming background. The survey was completed face to face with the person responsible for the daily management of the irrigated farm operation. Respondents were recruited by a professional data collection company. For privacy reasons it was impossible to obtain a list of irrigators with names, addresses and telephone numbers. During two previous irrigator surveys in 2011, we purchased a list of people with names, addresses and telephone numbers who live in the postal codes where irrigation is practised (Hall, Bjornlund, & Wei, 2012). People with town addresses or business names clearly not related to irrigation were deleted from the list, which left 9648 potential irrigators. The data collection 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. 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 the 300 names, addresses and telephone numbers was then sent to the enumerators who arranged a time to conduct the in-person survey at a place and time of the respondent's choosing. Due to problems scheduling the survey during the available time and a change of mind by some respondents, only 208 questionnaires were completed. Of those, two had missing values, which reduced the useable sample to 206 (Appendix, Table A2). The collected data are cross-sectional, not panel.

The irrigators in the survey used either traditional flood irrigation or some type of sprinkler irrigation technology with a higher irrigation application efficiency. More efficient irrigation technologies generally have been adopted in the following order: wheel-move sprinklers; high-pressure centre pivots (over 30 psi) and low-pressure centre pivots (less than 30 psi) (Bjornlund et al., 2009). They also could have adopted drip irrigation, but since this method does not lend itself to the predominant field and forage crops in the region, this method has been adopted by only a few.

The survey collected data related to the change in irrigation technologies and reasons behind the changes during the previous five years (2007/08–2011/12 crop years) as well as their intended changes over the next five years (2012/13–2016/17 crop years). Changes in irrigation technologies were reflected in a shift from a lower to a higher application efficiencies, such as from flood to some kind of sprinkler technology or from wheel-move to centre pivots, or from high- to low-pressure centre pivots and also through the updating some components of existing technologies.

The survey included questions related to: (1) sources of information irrigators received to help them make decisions about changing irrigation technologies, including technology extension agencies, other individual irrigators or farmer associations and other sources (such as web, newspaper, radio, television or directly from government); (2) socio-economic characteristics of the farm household, including family size (number of family members), number of generations the farm has been in family ownership, age, education, off-farm work status, whether the respondent had been involved 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); and (3) farm characteristics, including farm size, farm type (corporation, partnership or sole proprietorship), size of the irrigated area, and whether or not they had a livestock enterprise that uses an irrigated crop as forage. The descriptive statistics of these variables are shown in Tables A1 and A2 of Appendix A.

Changing to more efficient irrigation technologies

Changes in the past five years

In the past five years (2007/08–2011/12), 60% of irrigators in the survey made some changes to their irrigation technologies either by shifting to a technology with a potentially higher application efficiency (44% of irrigators) or by improving existing technologies (27% of irrigators) (Table 1). Twenty per cent of all irrigators changed from wheel-move to centre pivots and 18% changed from high- to low-pressure centre pivots. Low-pressure centre pivots have two benefits: first, they improve irrigation application efficiency and precision by reducing drift and evaporation by low-elevation spray application; and second, they save energy due to lower pressure application (King & Kincaid, 1997). Eleven per cent stopped using flood irrigation, 2% changed from flood irrigation to wheel-move sprinkler and 9% changed directly to either high- or low-pressure centre pivots. The latter category could be considered late adopters, bypassing the intermittent technology of wheel-move sprinklers. The changes in irrigation technologies were similar among district and private irrigators. Further analysis found that the rate of change was greater within IDs with larger irrigated areas than in districts with smaller irrigated areas (63% versus 50%). More than 90% of irrigators who improved their existing pivot systems purchased computer panels, added a corner system to their

Table 1. Percentage of farms that changed irrigation technologies in the past (2007/08–2011/12) and intend to do so in the next five years (2012/13–2016/17).

	District irrigators			
		Among:		
	Total	Large IDs	Small IDs	Private irrigators
Made changes in the past five years (2007/08–2011/12)	60	63	50	59
Shifted technologies	44	49	29	41
Flood irrigation to wheel move	2	1	3	0
Wheel move to centre pivot	20	22	13	23
Flood irrigation to centre pivot	9	11	3	5
High- to low-pressure centre pivot	18	21	10	18
Improved current technologies	27	25	33	18
Intend to change in the next five years (2012/13–2016/17)	46	47	45	41
Shift in technologies	28	30	21	14
Flood irrigation to wheel move	2	1	3	0
Wheel move to centre pivot	13	13	10	9
Flood irrigation to centre pivot	10	13	0	0
High- to low-pressure centre pivot	7	7	8	5
Improve current technologies	23	22	28	27

Note: The number of respondents in each cell can be calculated by multiplying the percentage value in each cell by the sample numbers reported in Table A2. Data are based on the survey carried out for this study.

Table 2. Shifting to technologies with higher application efficiencies (percentage of respondents): planned and actual (2007/08–2011/12).

	Planned by irrigators		Actual by irrigators	
Type	Small ID irrigators[a]	Private irrigators[b]	Small ID irrigators[c]	Private irrigators[c]
Shifting technologies				
Flood irrigation to wheel move	4	2	3	0
Wheel move to centre pivot	10	2	13	23
Flood irrigation to centre pivot	1	1	3	5
High- to low-pressure centre pivot	12	3	10	18

Notes: [a]Data in this column are from Bjornlund et al. (2009).
[b]Data in this column are from Nicol et al. (2010).
[c]Data in these columns are based on the survey conducted for this study.
The number of respondents in each cell can be calculated by multiplying the percentage value in each cell (columns 4 and 5) by sample numbers in Table A2.

pivot systems or replaced their entire pivot systems. These improvements to irrigation technologies represent a gradual increase in application efficiency.

One interesting finding is that actual changes in irrigation technologies by private irrigators during the 2007/08–2011/12 period was higher than previously estimated based on irrigators' intentions for that period (Nicol, Bjornlund, & Klein, 2010), but similar to estimates made for irrigators within two IDs surveyed by Bjornlund et al. (2009) (Table 2). Based on a survey of private irrigators, Nicol et al. (2010) found that few intended to change to sprinkler technologies with a higher application efficiency over the 2007/08–2011/12 period, ranging from 1% (shifting from flood irrigation to centre pivot) to 3% (shifting from high- to low-pressure centre pivots). However, the present survey found that during that period 23% of private irrigators shifted from wheel-move to centre pivots and 18% shifted from high- to low-pressure pivots. The differences between intended and actual shifts in irrigation technologies by those in small IDs were small, differing by only 1–2%.

Intended changes in the next five years

Irrigators indicated that they intend to make fewer changes in irrigation technology over the next five years (2012/13–2016/17) than they made over the previous five years but, still, 46% indicated that they intended to make some changes (Table 1). Twenty-eight per cent intend to change irrigation technology and 23% intend to improve their current technology. Specifically, 13% intend to shift from wheel-move sprinklers to centre pivots and 7% from high- to low-pressure centre pivots. While fewer irrigators indicated an intention to shift during the next five years compared with the preceding five years, the intended shifts are consistent with those reported by Bjornlund et al. (2009). The generally low level of intentions could reflect the usual conservative expectations of irrigators, particularly on shifting technologies. However, the increase from intended to actual changes over the 2007/08–2011/12 period also could be a reflection of the debate over the need for efficiency improvements and increased understanding of the value of water, while the decrease from actual to intended changes over the next five years could reflect the perceived decline in opportunities for adopting irrigation technologies that have greater application efficiency.

During the next five years, a higher percentage of district than private irrigators intend to change technology (46% versus 41%) (Table 1). This is particularly the case for shifts from flood to centre pivots, which 13% of irrigators within large IDs intend to make compared with 0% for private irrigators. A slightly higher percentage of irrigators in large IDs intend to shift technologies than do those in smaller IDs (47% versus 45%). Most of this difference is a result of intended shifts from flood to centre pivot sprinklers. A higher percentage of private irrigators and those in small IDs intend to improve current technology than do those in large IDs.

Reasons for changes

When irrigators were asked to list the major reasons why they changed (or intend to change) their irrigation technologies, four reasons dominated: reduce irrigation application (56% of those who changed and 36% of those who intend to change), reduce labour (47% and 38%, respectively), reduce energy cost (44% and 27%, respectively), and improve crop yield and/or quality (31% and 24%, respectively) (Table 3). These findings are somewhat consistent with the findings of Bjornlund et al. (2009), though in the earlier study saving water was ranked fourth and far behind improving crop yield and quality. Reducing irrigation application as a major reason also is consistent with the literature that reveals that reducing evapotranspiration is one of the major reasons that drives water conservation (Liu, Li, & Duan, 2009; Pang, Li, Tao, & Yang, 2013).

The finding that reducing irrigation application is now the most frequently given reason to change irrigation technologies implies that irrigators in Alberta are starting to realize that water shortages are becoming more important and that their water assets have a significant value that could be capitalized through water trading (Bjornlund, Xu, & Wheeler, 2014). In recent years there has been considerable debate over whether

Table 3. Main reasons cited for changing irrigation technologies in the past (2007/08–2011/12) and next five years (2012/13–2016/17) (percentage of irrigators).

Reasons for changing	2001/02–2005/06[a]	Present survey results: Past five years[b]	Present survey results: Next five years[b]
Reduce irrigation application	55	56	36
Reduce labour	57	47	38
Reduce energy costs	58	44	27
Improve crop yield or quality	76	31	24
Necessary to update the existing old equipment	–	14	7
Available subsidy or low interest rate from government	–	7	3
Reduce soil erosion	42	7	0
Increase land value	–	2	4
Irrigate more land during water restriction	53	1	1

Notes: [a]Bjornlund et al. (2009) and Nicol et al. (2010).
[b]Survey carried out for this study.
The number of respondents in each cell can be calculated by multiplying the percentage value in each cell (columns 3 and 4) by sample numbers in Table A2.

adopting improved irrigation technologies really save water or simply reduce water that would otherwise stay in the environment or be used by downstream consumptive users (Bjornlund et al., 2009; Peter, Gleicka, & Cooleyc, 2009). Some studies point out that the use of more efficient irrigation technologies often increase, rather than decrease, net water consumption (English, Solomon, & Hoffman, 2002; Ward & Pulido-Velázquez, 2008; Whittlesey, 2003). However, Kumar, Dam, and Jos (2013) found that irrigation efficiencies at the field level can result in real water savings under certain conditions. In addition, whether or not improving application efficiencies really saves water depends on the perspective from which the saving is seen: that of the farm or that of the river basin (or region) (Lankford, 2013; Perry, 2011; Seckler, 1996). If water saved by an irrigator through improved application efficiency results in an increase in the area under irrigation, or a sale of water, then the overall net consumption of water in the basin or region could increase due to a reduction in return flows. From a wider societal perspective this might threaten water quality and ecosystems as well as recreational benefits from the river. However, from the perspective of the individual irrigator, this would increase productivity and profitability. It is likely that an increased understanding of the importance and value of water in its many uses has resulted in 'reducing water application' moving from being ranked as the fourth most important to the most important driver of change.

That the ability to reduce production inputs and increase the volume and quality of output also are important factors that influence irrigators' decisions is consistent with the literature. The findings by King and Kincaid (1997) indicate that improved irrigation technologies (such as centre pivot systems) not only can reduce irrigation application but also greatly reduces labour and energy inputs. Our research results also are consistent with the findings in two IDs in southern Alberta reported by Bjornlund et al. (2009).

Irrigators gave other reasons for changing their irrigation technologies. For example, 14% of irrigators stated that that they changed over the past five years because it was necessary to update their existing old irrigation equipment. This implies that these irrigators have invested in, or taken steps to, improving existing irrigation technologies. For the next five years, 7% of irrigators gave this reason for their intention to change (Table 3). Results also show that available subsidies or low interest rates can encourage some irrigators to change to more efficient irrigation technologies, but, in the context of Southern Alberta, subsidies are not an important driver. There is some evidence from other studies that a subsidy provided by an ID can have an impact on adoption (Feder & Umali, 1993; Tiwari & Dinar, 2000).

In summary, it seems that a combination of factors such as the ability to reduce input costs and improve crop output has influenced irrigators' decisions to adopt more efficient irrigation technologies. As rational economic persons who operate in conditions of (near) perfect competition, irrigators are driven mainly by financial considerations. Although the above discussion has provided some understanding about why irrigators adopt improved irrigation technologies, we still do not know why some irrigators have adopted, or intend to adopt, while others do not, when faced with similar opportunities to change irrigation technologies. Based on previously published literature, irrigators' decisions are influenced also by socio-economic characteristics of their farms and households (Stephenson, 2003). In addition, it is known that irrigators' past behaviour can significantly influence their intended behaviour (Conner & Armitage, 1998; Wheeler, Zuo, & Bjornlund, 2013). Therefore, whether or not irrigators intend to change their irrigation technologies also depends on their existing technologies. Access to relevant information about the nature of new technologies or practices is another important factor that likely influences irrigators' behaviour (Feder & Slade, 1984; Koundouri, Nauges, & Tzouvelekas, 2006). The following section use an econometric model to explore these issues further.

Econometric model and estimation results

Specification of econometric model

To identify and quantify the impacts of different factors on irrigators' past and future decisions to change technologies, the following two econometric models were specified:

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

$$Y_{ij} = \kappa_{ij} + \eta_1 N_{ij} + \eta_2 I_{ij} + \eta_3 \mathrm{F}_{ij} + \eta_4 H_{ij} + \eta_5 D_{ij} + \zeta_{ij} \quad (2)$$

Model (1) analyzes irrigators' past behaviour and model (2) examines plans for future changes in irrigation technology. In the models, i and j indicate the ith farm in the jth ID or a private irrigator. The dependent variables in the two models measure irrigators' dichotomous choices on changes in the past (W_{ij}) and next (Y_{ij}) five years: the values of the dependent variables are 1 if the change has been (or planned to be) made; and 0 otherwise.

On the right side of model (1) are the four categories of independent variables discussed in the previous section: (a) I_{ij} is a set of three dummy variables that measure the information sources: technology extension agencies, individual irrigators and farmers' associations with other sources being the default; (b) F_{ij} is a set of four variables that measure farm characteristics, farm size, farm type, irrigated areas and whether or not the farm has a livestock enterprise. Considering the possible relationship between farm size and farm type, we also included interactive variables (farm size*corporation and farm size*partnership); (c) H_{ij} is a set of seven variables that measure irrigator and household characteristics: family size, number of generations the farm has been in the family's ownership, age, education, off-farm work, whether or not the respondent was involved in operating the farm before taking over its management, and current status of father/father-in-law; and (d) D_{ij} is a set of regional dummy variables that control for the impacts of regional characteristics that do not change over time but might affect irrigators' decisions to change irrigation technologies. There are 12 IDs as well as private irrigators in the study area. In order to examine whether irrigators' decisions differ between those who are private irrigators and those in large and small IDs, we have included two regional dummy variables: large and small IDs. The comparison basis is private irrigators.

In addition to four categories of independent variables in model (1), model (2) includes another variable (N_{ij}) that measures the impacts of existing irrigation technologies on irrigators' intentions for the future. This variable consists of four dummy variables: whether or not using flood irrigation, wheel move, low- or high-pressure centre pivot sprinkler systems. In the models, $\beta_1 - \beta_4$, $\eta_1 - \eta_5$ are the parameters to be estimated; α_{ij} and κ_{ij} are the constants; and ε_{ij} and ζ_{ij} are the random error terms and all are assumed to have independent identical distributions.

As the dependent variables are dummy variables, a logit model is used (Wooldridge, 2002). For the logit model, the estimated coefficients reflect the direction of influence of the independent variables on the dependent variable. The magnitude of the influence cannot be indicated by the coefficients. Therefore, based on the estimated coefficients, we computed the marginal effect of independent variables on the dependent variables.

Estimation results

The estimated models performed reasonably well considering this multivariate analysis is based on cross-sectional data collected from quite a disparate sample of irrigators spread over a large (650,000 ha) area where irrigation is practised in Alberta (Table 4). The pseudo-R^2's are 0.159 and 0.172 for the two models. The estimation results show that the two dummy variables for large and small IDs are not statistically significant. This implies that irrigators' decisions to change irrigation technologies do not differ by size of ID or if the irrigator is a private irrigator.

Influence of the existing irrigation technologies

Irrigators who currently use technologies that have lower application efficiencies are more likely to intend to change their technologies in the next five years (Table 4). The estimated coefficients for wheel-move sprinkler systems and high-pressure centre pivots are positive and statistically significant. Although the estimated coefficients for low-pressure centre pivot and drip system are positive, they are not statistically significant. This confirms the earlier observation that irrigators who have started the change process by moving from flood irrigation to wheel-move sprinklers or high-pressure pivots are more likely to continue the change process in future. It also suggests that those who have taken the second step in the change process and now use high-pressure centre pivot are more likely to continue the change process than those who still use the wheel-move system (24.4% versus 17.3%). The results also confirm that irrigators' decisions are path dependent and their past behaviour significantly influences their expected future changes, as noticed and reported by Conner and Armitage (1998) and Wheeler et al. (2013). Finally, those who still use flood irrigation are least likely to change in future. This might indicate that some physical constraints on land limit their ability to change irrigation technology, that irrigation is a small and unimportant part of their operation, or they are preparing for retirement without a successor and therefore do not have a long-term interest in improving their technology.

Influence of information sources

Obtaining information from technology extension agencies significantly increases the probability that irrigators changed their irrigation technologies in the past or expect to do so in future (Table 4). The estimated coefficient for technology extension agencies is positive and statistically significant in both models. When holding other factors constant, if irrigators obtain relevant information from technology extension agencies, the probability that they changed irrigation technology in the past increased by 16.9% and the probability that they intend to change in future increases by 18.5%. Other information sources have no significant effects on irrigators' decisions to change. This indicates that the information from technology extension agencies is more easily accepted or trusted by irrigators. The estimation results further confirm the importance of information on irrigators' decisions that has been identified by others. Feder and Slade (1984) pointed out that

Table 4. Logit regression results of the determinants of irrigators' decisions about making changes to irrigation technologies in the past (2007/08–2011/12) and the next five years (2012/13–2016/17).

	Changed in the past five years (1 = yes; 0 = no)		Expect to change in the next five years (1 = yes; 0 = no)	
	Regression results	Marginal effect	Regression results	Marginal effect
Existing irrigation technology				
Sprinkler system				
Wheel move (1 = yes; 0 = no)			0.928* (1.90)	0.228
High-pressure centre pivot (1 = yes; 0 = no)			1.102* (1.91)	0.267
Low-pressure centre pivot (1 = yes; 0 = no)			0.645 (1.11)	0.157
Flood irrigation (1 = yes; 0 = no)			0.836 (1.16)	0.206
Information sources				
Technology extension agencies (1 = yes; 0 = no)	0.714* (1.92)	0.169	0.765** (2.03)	0.185
Individual irrigators or farmers' association (1 = yes; 0 = no)	0.429 (1.14)	0.099	−0.353 (0.93)	−0.087
Other (1 = yes; 0 = no)	−0.092 (0.25)	−0.022	0.391 (1.09)	0.097
Farm characteristics				
Farm size (ha)	0.001 (1.03)	0.0002	0.001 (1.15)	0.0002
Farm type				
Corporation (1 = yes; 0 = no)	1.271*** (2.58)	0.284	0.276 (0.52)	0.068
Partnership (1 = yes; 0 = no)	1.106* (1.89)	0.232	0.846 (1.45)	0.208
Interactive variables				
Farm size*corporation	−0.001 (0.84)	−0.0001	−0.001 (1.51)	−0.0003
Farm size*partnership	−0.000 (0.24)	−0.0001	−0.001 (1.40)	−0.0003
Irrigated land as a proportion of total land area	−0.008 (0.01)	−0.002	0.394 (0.63)	0.097
Have a livestock enterprise that uses output of crops or forages (1 = yes; 0 = no)	0.682* (1.96)	0.163	0.786** (2.16)	0.189
Household characteristics				
Family characteristics				
Family size (number)	−0.002 (0.02)	−0.001	−0.173 (1.48)	−0.043
Number of generations who had ownership of this farm	−0.396* (1.90)	−0.093	−0.360* (1.70)	−0.089

(*continued*)

Table 4. (*Continued*).

	Changed in the past five years (1 = yes; 0 = no)		Expect to change in the next five years (1 = yes; 0 = no)	
	Regression results	Marginal effect	Regression results	Marginal effect
Irrigators' personal characteristics				
Age (years)	−0.005 (0.29)	−0.001	−0.048*** (2.88)	−0.012
Education (bachelor's or higher degree) (1 = yes; 0 = no)	0.112 (0.28)	0.026	0.061 (0.15)	0.015
Off-farm work (1 = yes; 0 = no)	−0.950** (2.43)	−0.227	−0.736* (1.82)	−0.177
Involved in operating the farm before taking over its management (1 = yes; 0 = no)	0.890** (2.04)	0.212	1.120** (2.46)	0.265
Current status of the father/father-in-law (1 = working irrigator; 0 = not working irrigator)	−0.305 (0.88)	−0.072	−0.248 (0.72)	−0.061
Irrigation district (ID) dummy				
Large IDs (1 = yes; 0 = no)	0.443 (0.75)	0.106	0.485 (0.84)	0.118
Small IDs (1 = yes; 0 = no)	0.294 (0.43)	0.068	0.795 (1.15)	0.196
Constant	−0.801 (0.53)		0.525 (0.33)	
Number of observations	206		206	
Pseudo-R^2	0.1590		0.1720	

Note: *Absolute value of the *t*-statistic is significant at the 10% level; **absolute value of the *t*-statistic is significant at the 5% level; ***absolute value of the *t*-statistic is significant at the 1% level. Data are based on the survey carried out for this study.

the availability of relevant information about new technologies or practices is one of the important factors that influence irrigators' decisions. Clark, William, and Finley (2008) found that a general lack of knowledge among residents regarding water-saving devices and practices is one of the major obstacles that influences farmers' decision on water conservation. It also has been found that access to relevant information about the nature of new technologies or practices can reduce the risk and uncertainty associated with irrigators' decisions (Koundouri et al., 2006; Marra, Pannell, & Ghadim, 2003; Tsur, Sternberg, & Hochman, 1990).

Influence of farm characteristics

Two farm characteristics significantly influence the decision to change (Table 4). The first is farm type. The estimated coefficients for corporation and partnership are positive and significant in the past change model and positive but not statistically significant in the future change model. This indicates that, compared with sole proprietors, irrigators who operate corporate or partnership farms were more likely to have changed irrigation technologies (29% and 23%, respectively). Although the importance of farm size on irrigators' decisions has been found in some studies (Adeoti, 2009; Stephenson, 2003), our study finds that farm size itself did not significantly influence irrigators' decisions to change technologies. However, the interaction between farm size and corporation is statistically significant in the future change model. The probability of changing irrigation technologies for corporate farms declines as the farm size increases. This suggests that as sole proprietor farms increase in size the irrigators behave more like a corporate or partnership farm.

The coefficient of having a livestock enterprise to utilize the irrigated crop as forage is positive and statistically significant in both models. Therefore, if an irrigator has a livestock enterprise, it is more likely s/he has changed, or intends to change, irrigation technology by 16.2% and 19.6%, respectively. This is consistent with expectations. Since irrigation farms with livestock enterprises use their field crops to feed their animals, increasing the application efficiency could reduce their feed cost and increase the added value in their livestock production. Therefore, irrigation farms with livestock enterprises have greater incentive to invest in technologies that have higher application efficiencies. In addition, if farms have a livestock enterprise, generally they are more capable of investing in technologies based on their extra revenue from livestock production.

Influence of household characteristics

It is apparent that some household characteristics also influence irrigators' decisions to change irrigation technologies. First, the coefficient for the number of generations during which the farm has been in the family's ownership is negative and statistically significant in both models (Table 4). This suggests that farms that have been in the family's ownership for fewer generations are more likely to change irrigation technologies, and the probability of change is increased by 9% (in the past) or 11.9% (in future), respectively. This could reflect that many third- and later generation irrigators already have adopted newer technology.

Age has a significantly negative influence on irrigators' intention to change technologies in the future (Table 4). This could reflect that younger irrigators are more aggressive in developing their farms as they find it easier to accept new technologies and, also, they have more time to gain the benefits. This finding is consistent with Stephenson (2003) who found that in many studies adopters of new technologies tend to be younger than non-adopters. Also, it has been found that the interest in adopting new technologies declines with age if it becomes clear that there is no family member willing to take over the farm (e.g., Kuehne & Bjornlund, 2006).

In addition, irrigators' decisions to change technologies are influenced by whether or not they have off-farm work. The coefficient for off-farm work is negative and statistically significant in the two models (Table 4). This implies that if irrigators do not have off-farm work, they can put more effort into the farming activities and the incentive to improve irrigation technologies are higher. When irrigators have off-farm employment, the probability of changing irrigation technologies in the past five years is 22.7% lower and the probability of changing irrigation technologies in the future is 17.7% lower.

Finally, the coefficient for having been involved in operating the farm before taking over its management is positive and statistically significant in the two models (Table 4). This indicates that if the current irrigator were involved in the farm operation before taking over its management, the probability of changing irrigation technologies increases by 23% (in the past) and 22.1% (in future). This stresses the importance of succession planning for irrigators' decisions to adopt new technologies. This variable also reflects the importance of irrigators' experience. Irrigators who have experience in operating the farm before taking over its management generally have a better understanding of the potential benefits of adopting improved technologies. The importance of experience also has been found by other scholars (e.g., Abadi Ghadim, 2000; Lindner & Pardey, 1979).

Conclusions

The purpose of this study is to understand the changing trends of irrigation technologies and factors that influence irrigators to make changes in the irrigation region of southern Alberta. Data were collected in a large farm-household survey conducted face to face on 206 randomly chosen irrigators in the 12 largest of 13 IDs and among private irrigators outside the IDs.

Research results show that in the past five years (2007/08–2011/12) more than half of all irrigators have changed their irrigation technologies, either by shifting to one that has higher application efficiency (44%) or by improving existing technologies (27%). Over the next five years (2012/13–2016/17), fewer irrigators (but still 28%) intend to make changes to the technology they currently use. The major benefits that irrigators expect to receive from changing technologies (in order of stated importance) are reduced irrigation application, reduced labour and energy inputs, and increased crop yields and quality. Compared with a survey carried out in 2006 in a small part of the same region, the importance of saving water has increased and is now rated as the most important benefit of changing irrigation technology. This implies that the intensifying debate over water shortage in the region has increased irrigators' awareness of future water shortage issues, and also their awareness of the potential value of their water asset.

Irrigators who already have moved away from flood irrigation are more likely to intend to make further changes to their technologies in the next five years. Obtaining information from technology extension agencies significantly increases the probability that irrigators changed their irrigation technologies in the past or intend to do so in future. In addition, some characteristics of farms and irrigators significantly influence irrigators' decisions. Compared with irrigators who are sole proprietors, those who operate corporate or partnership farms are more likely to have changed irrigation technologies in the past. If their farm has some livestock enterprise that uses the output of irrigated crops, the probability of change also is higher. Younger irrigators and those who do not have off-farm employment also are more likely to adopt technologies that have higher application efficiencies. Having fewer generations of ownership of the farm or if the current irrigator was involved in the farm operation before taking over its management significantly increases the probability of change.

The results have several policy implications. First, there are still opportunities for further improvements in irrigation application efficiency by adopting improved irrigation technologies. Second, government should continue to support the development and adoption of more efficient technologies that can reduce water, labour and energy inputs as well as increase production. Third, in order to encourage irrigators to improve irrigation technologies, supplying information about irrigation technologies and their potential benefits and costs through technology extension agencies should be further enhanced. Fourth, government should support those irrigators who are more likely to change irrigation technologies, such as irrigators who have livestock enterprises that use the output of irrigated crops, and those who are younger and have no off-farm employment. Considering the significant debate in the literature challenging the benefits of improving irrigation application technologies without some measures to ensure that this does not result in reduced stream flow and third-party impacts, as well as the significant debate in Alberta over these issues, it is important that the government seriously considers how to control and minimize these impacts.

The results of this study also are relevant to developing countries that face increased water shortages, such as China. Compared with Alberta, the adoption rates of irrigation technologies (particularly for the technologies discussed in this paper) are much lower in developing countries (Blanke, Rozelle, Lohmar, Wang, & Huang, 2007). Therefore, how to increase further the adoption rate of irrigation technologies has been a high priority for the Chinese government. These issues also have been noticed by some Chinese scholars (e.g., Liu, Wang, Li, & Zhang, 2011; Wang, Liu, & Li, 2013). Policy-makers and scholars in China can learn the following important lessons from experiences in Alberta. First, irrigators' decisions to adopt improved irrigation technologies depend on the extent to which the technologies provide the following benefits: reduce irrigation application and labour and energy inputs, and increase crop yields and quality. Second, governments can play a significant role in encouraging irrigators to adopt improved irrigation technologies, such as providing suitable and accurate information on the costs and benefits of irrigation technologies. Third, government supports should target those irrigators who are most likely to adopt irrigation technologies, and those irrigators least likely to adopt.

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Notes

1. For the irrigation sector, water-use efficiency includes both application efficiency and conveyance efficiency.
2. The term 'irrigators' refers to irrigators in general. 'District irrigators' refer to irrigators locating in irrigation districts (IDs), and 'private irrigators' refer to irrigators located in private irrigation regions. In addition, we have divided district irrigators into two groups: large ID irrigators who locate in large IDs and small ID irrigators who locate in small IDs. Large IDs include Bow River, Eastern, Lethbridge Northern and St. Mary River IDs; and small IDs include Aetna, Leavitt, Magrath, Mountain View, Raymond, Ross Creek, Taber, United and Western IDs.

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Appendix

Table A1. Statistical characteristics of major variables.

	Mean	Standard deviation (SD)
Dependent variable		
Changed irrigation technologies in the past five years (1 = yes; 0 = no)	0.60	0.49
Expect to change irrigation technologies in the next five years (1 = yes; 0 = no)	0.46	0.50
Independent variables		
Irrigation technology		
Sprinkler systems		
Wheel move	0.26	0.44
High-pressure centre pivot (30 psi or more)	0.14	0.35
Low-pressure centre pivot (under 30 psi)	0.63	0.48
Flood/furrow irrigation	0.18	0.38
Information sources		
Extension agencies (1 = yes; 0 = no)	0.60	0.49
Individual irrigators or farmers' associations (1 = yes; 0 = no)	0.36	0.48
Others (1 = yes; 0 = no)	0.34	0.47
Farm characteristics		
Farm size (ha)	706	1052
Farm type		
Corporation (1 = yes; 0 = no)	0.41	0.49
Partnership (1 = yes; 0 = no)	0.20	0.40
Irrigated land as a proportion of total land area	0.61	0.35
Having livestock enterprise that use output of crops as forages (1 = yes; 0 = no)	0.65	0.48
Household characteristics		
Family characteristics		
Family size (number)	3.00	1.64
Number of generations with ownership of this farm	2.21	1.08
Irrigators' personal characteristics		
Age of respondent (years)	55.49	12.28
Education of respondent (Bachelor's or higher degree) (1 = yes; 0 = no)	0.24	0.43
Off-farm work status of respondent (1 = yes; 0 = no)	0.34	0.47
Involved in 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 irrigator; 0 = not working irrigator)	0.55	0.50
Irrigation district dummy		
Large irrigation district (1 = yes; 0 = no)	0.70	0.46
Small irrigation district (1 = yes; 0 = no)	0.19	0.40

Note: Number of observations is 206.

Table A2. Number of respondents in the survey of district and private irrigators.

	Total number	Percentage over total sample
Total number of respondents	206	–
Among the total sample		
District irrigators	184	89
Private irrigators	22	11
Among district irrigators		
Located in large IDs	144	70
Located in small IDs	44	19

Note: Large irrigation districts (IDs) include Bow River, Eastern, Lethbridge Northern and St. Mary River IDs; small IDs include Aetna, Leavitt, Magrath, Mountain View, Raymond, Ross Creek, Taber, United and Western IDs. Data are based on the survey carried out for this study.