POTENTIAL WELFARE GAINS FROM RURAL-URBAN WATER REALLOCATION IN SOUTHERN ALBERTA, CANADA[1]

by

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Potential Welfare Gains from Rural-Urban Water Reallocation in Southern Alberta, Canada

Abstract

Quadratic programming is used to reallocate surface water entitlements and to determine and compare (static optimum) levels of social welfare, thereby simulating the effect of new markets for transferable water entitlements on four river sub-basins in southern Alberta. The welfare comparisons are made for each of four scenarios that provide alternative definitions of the markets' scope, and under each of three property rights regimes that provide alternative endowments of the initial water entitlements. Trading behaviour is restricted to the set of feasible trades defined by river flow volumes, instream flow needs and interjurisdictional apportionment requirements under drought conditions.

Key words: quadratic programming, transferable water entitlements,
welfare gains

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Rural-urban tradeoffs are emerging as a key policy issue when governments worldwide increase their reliance upon private markets and other economic instruments to allocate resources such as water. As in many jurisdictions, a central expected outcome of water reallocation is an increase in urban and industrial uses, especially in times of shortage, directly at the expense of rural (irrigation and agricultural) uses. Not surprisingly, the way in which such reforms are introduced can determine whether they are likely to be supported by rural users, and whether they are even likely to be implemented.

For those jurisdictions such as the province of Alberta, Canada, that are only now starting to develop these market mechanisms, there are many important questions to be asked about the design, operation and anticipated outcomes of water markets. When answers to questions of this type cannot be found by observing the experience of others, such as in so-called natural experiments, computer simulation can be a valuable tool. Specifically, computer modelling can simulate the effects of a market where none currently exists. It can describe expected changes in resource usage as well as the effects of these changes on the welfare levels of the water users affected. Moreover, where there are structural or procedural alternatives for the design of new markets, the effects of these alternatives can be portrayed in advance.

Two design features that are important to the initiation of markets as a surface water allocation mechanism are (i) the geographical and sectoral scope of the markets (i.e., what is the set of agents with whom each agent can trade?); and (ii) the initial allocation of property rights or other endowments when a new market-based policy comes into force. Economic theory suggests that these features will be an important determinant of the magnitude of potential welfare gains to be achieved through use of the market mechanism, as well as of the pattern by which those gains are distributed. Indeed, from the perspective of public choice economics and legislative reforms, there comes a caution that inattention to the distributional effects of a water policy reform may well prevent it from ever being implemented.

This paper considers the case of the southern region of the province of Alberta, Canada, where surface water drawn from river flows has traditionally been allocated using a command-and-control approach that features non-transferable, use-specific licenses without any pricing or fee-based allocation mechanism. There are four major connected river sub-basins that provide the main source of fresh water for economic activity, and—at least during the summer months—about ninety percent of that usage is for the irrigation of agricultural crops, including forages, grains, and vegetables. Although most of this water is fully allocated to existing users even in a year of average moisture levels, this paper examines short-run behaviour in a period of severe moisture deficit or drought.

The questions explored here concern the magnitude of welfare gains that might arise from short-term water reallocation, such as from rural to urban users and among rural users experiencing varying degrees of moisture deficit within a single growing season. The problem's *market scope* dimension is the design issue of whether or not water can be traded across sectors, across river sub-basins, or indeed, whether public entitlements to water, such as for instream flow needs or for interjurisdictional apportionment, can also be traded in the markets (such as by a public resource agency). The problem's *property rights* dimension is the design issue of with what rights or entitlements the existing agents will be endowed when they enter a new private market.

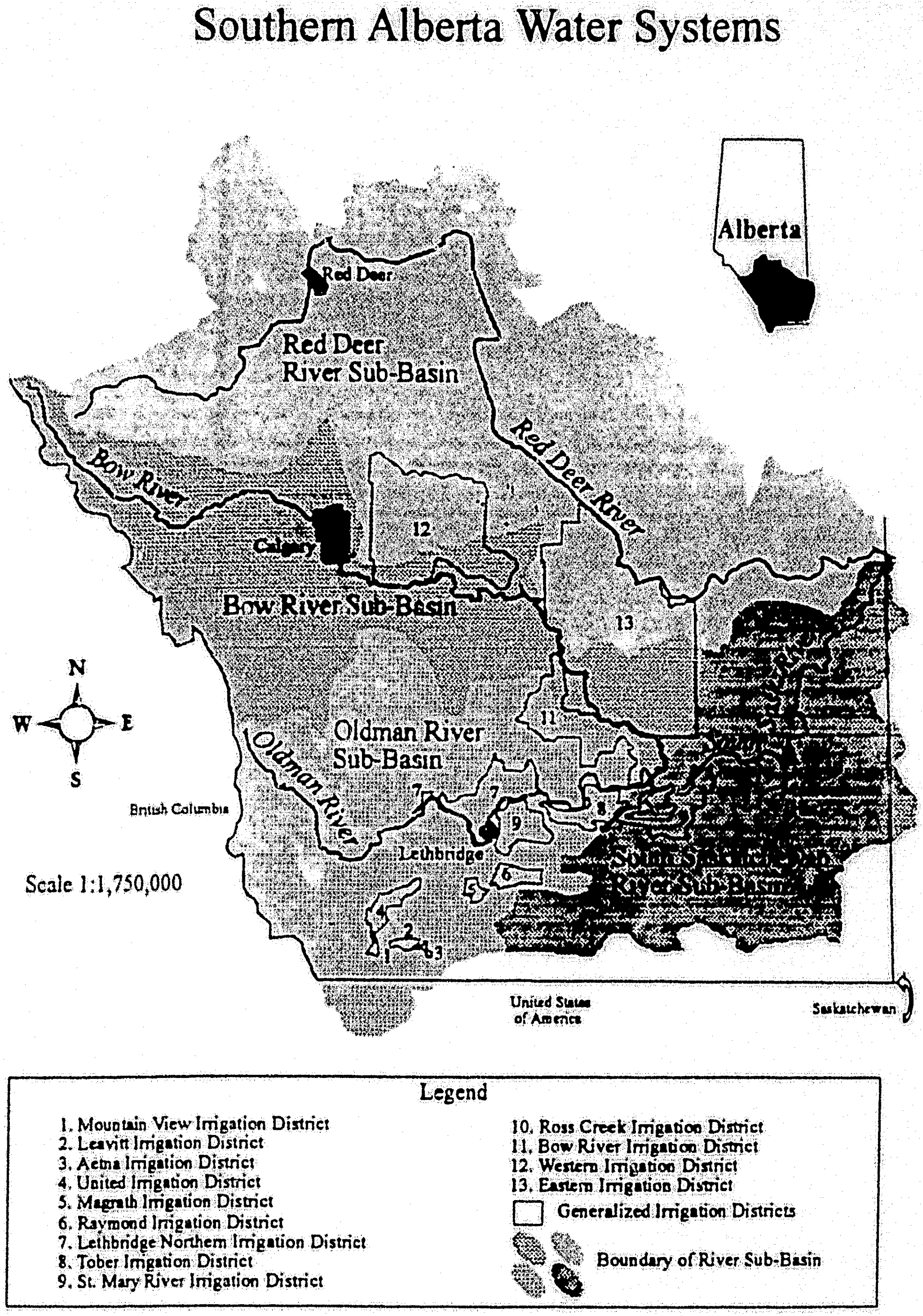
As an exercise in applied economic research, this paper builds on a rich tradition of earlier papers by Samuelson (1952), Enke (1952), Takayama and Judge (1964), Flinn and Guise (1970), Vaux and Howitt (1984), Enright and Lund (1970) and Booker and Young (1994), all of which use static optimization and mathematical programming approaches to characterize optimal allocations of water under scarcity. In addition to its exploration of scope and property rights endowments, this paper contributes an enriched model of trading behaviour in the hypothetical market it simulates. Specifically, trading behaviour is restricted to a set of feasible trades defined by river flow volumes, instream flow needs and exogenous interjurisdictional apportionment requirements.

The four main sections of the paper present the programming model, the scenarios analyzed, the welfare results compared, and the conclusions.

The Programming Model

The objective of the programming exercise is to determine and compare static optimum allocations of surface water from four rivers to spatially separated water users for consumption within a five month irrigation season. These allocations describe how, within an irrigation season in a severe moisture deficit, a frictionless and perfectly functioning competitive spot market for surface water (i.e., a market with full information and without transactions costs) would determine each user's price, quantity demanded, total payment, and associated consumers' surplus. These water allocations can be determined by maximizing the sum of producers' and consumers' surplus accruing to all participants in the market, subject to a series of constraints that define available water supplies, conveyancing technology, and instream flow needs.

The four (mutually exclusive) river sub-basins are those of the Bow River, the Oldman River, the Red Deer River, and the South Saskatchewan River. The first two rivers drain into the fourth within the province of Alberta whereas the Red Deer River drains into the fourth near the provincial boundary with the province of Saskatchewan (see Figure 1). An historical interprovincial agreement requires in essence that, during *each* season, half of the total surface flows emanating from these four sub-basins in Alberta must be left in the South Saskatchewan River channel for the benefit of users in the downstream province (Prairie Provinces Water Board, 1969). Given the flow pattern of the rivers, the upstream province can choose which sub-basins are to supply this requirement. (See further, Alberta (1994).)



Cartographer: Steven Waters

Figure 1. Southern Alberta Water Systems

The within-season water supply behaviour in these basins can be thought of as exogenously determined, thus independent of seasonal demand or expected water prices. Aggregate water supplies come from natural flows, unaided by storage, diversions or groundwater supplementation (although these activities could occur on-farm after surface flows have been pumped or diverted from river channels). Moreover, for the purposes of guiding actual market behaviour or of simulating it numerically in a deterministic model, much will be known about expected seasonal river flows in time to inform potential water traders prior to a water-trading spot market that precedes the irrigation season. This is because natural supplies are a direct and predictable outcome of winter precipitation levels, snowpack accumulations and other upstream hydrology. Following Flinn and Guise (1970), seasonal water supplies in each sub-basin are represented by an infinitely inelastic supply curve.

Numerous demands for consumptive and non-consumptive uses of water—represented here at the sub-basin level—can be grouped into four broad categories: (i) agricultural demands; (ii) urban and industrial demands; (iii) instream flow needs; and (iv) water required to meet the inter-provincial apportionment agreement. The demands of these first two categories are expected to be price sensitive, and can be represented by demand curves, as described presently. Instream flow needs and apportionment demands, conversely, are not price sensitive. The former act at the sub-basin level whereas the latter acts at the regional or provincial-boundary level. As shown in Figure 2, this gives rise to three demand groups or nodes in each sub-basin, plus an apportionment demand.

Following Enright and Lund, agricultural and urban demands are represented as linear inverse demand functions calibrated using data from Alberta and from elsewhere in the agricultural economics literature. Short-run factor demand curves for water use in agriculture have been derived from the work of Birch and Van Deurzen (1984). These authors use data from field studies conducted between 1949 and 1968 to estimate incremental returns to

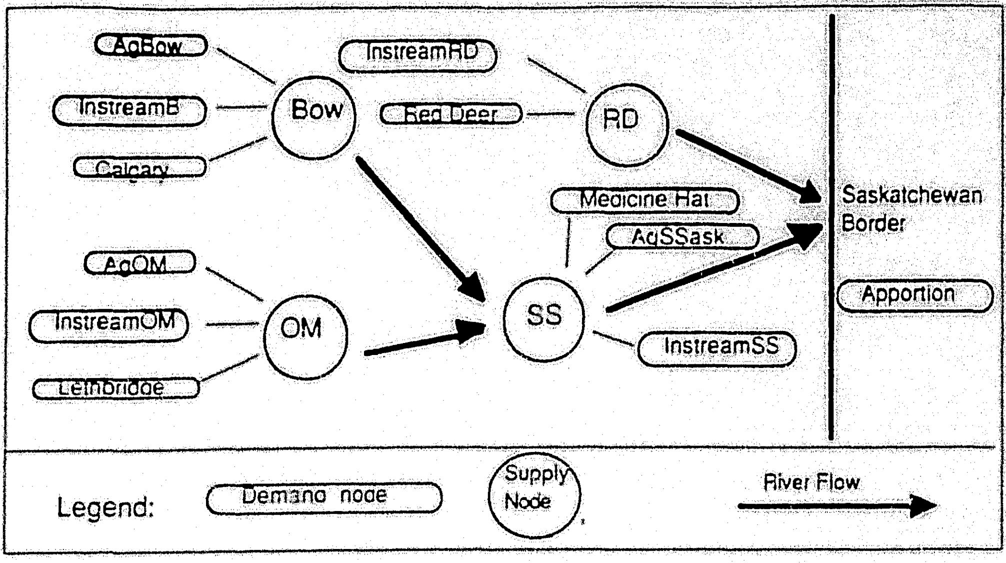


Figure 2. Schematic Representation of Southern Alberta Water Supply and Demand

irrigation water on-farm, for a mix of the principal irrigated crops in each of the four river sub-basins. The regional inverse demand functions derived from these data were scaled up as means of calibrating historical data to current water usage levels in each region and in aggregate.[1]

Urban and industrial demand curves were derived for the principal city in each sub-basin by observing current quantities demanded and municipal water rates. A linear curve was extrapolated by applying published own-price elasticity of demand values from the western United States (Gibbons, 1986).

With this basis for representing a series of four supply nodes with supply curves and twelve demand nodes with demand curves (five of which are infinitely price inelastic), the objective of the static optimization problem is to maximize the post-trade sum of producers' and consumers' surplus associated with a feasible equilibrium allocation. This choice of objective function parallels that of Enright and Lund (1991), although in the present case, a richer set of constraints binds the set of feasible outcomes.

The constraints at work here describe the physical relationships among of the four sub-basins, where any short-term trading or reallocation can only occur by using the free and costless gravitational downstream flow of each river.[2] Within limits, a downstream user can sell water to an upstream user on the same watercourse by reducing downstream consumption; and vice versa. Again, within limits, such trades might also occur between users on different interconnected watercourses if they have a common trading partner to act as intermediary. An algebraic representation of the programming problem is coded and solved using GAMS (1995).

An important point in allowing inter-sectoral or inter-sub-basin trading is one's choice of units by which to measure water withdrawals and consumption. For the numerical analysis, all usages, supplies and demands have been reported on a net consumption basis; that is, adjusting total diversions for the average return flows that result in each specific urban or agricultural usage.[3]

The Scenarios Analyzed

Four scenarios are used to portray the scope of spot markets that allocate seasonal surface flows with the four sub-basins. In Scenario One, there is no scope for markets. This "base case" is modeled by restricting water allocations to historical values representing those that are typical of a drought year in the absence of pricing or markets for river withdrawals. The maximized value of total consumers' and producers' surplus (economic welfare, hereinafter) forms the benchmark for subsequent comparison with functional markets. [Scenario One calculates prices that would clear any markets that generated these allocations—in practice water is unpriced in Alberta.]

The scope of trade in Scenario Two is between neighbours (i.e., rural to urban) in a sub-basin holding constant historical total consumption in each basin and holding constant each basin's flow contribution to instream flows and interjurisdictional apportionment. Whereas in Scenario One there are no markets, in Scenario Two there are four local ones.[4] Scenario Three broadens market scope to allow (otherwise feasible) trades of water across sub-basins,

Table 1. Reallocation of Available Supplies Under Three Alternative Scenarios (net surface flows in millions of cubic meters per season)

Water Users	Scenario One Base Case (level)	Magnitude of Change from Scenario One to:		
		Scenario Two (% change)	Scenario Three (% change)	Scenario Four (% change)
Bow River				
-Rural	853	-17.7	-26.4	-31.9
-Urban	73	+206.9	+206.9	+205.4
-Instream	755	0.0	0.0	0.0
-Apportionment	83	0.0	0.0	+77.1
Sub-total	*1,764*	*0.0*	*-4.2*	*-3.2*
Oldman River				
-Rural	686	-21.3	-22.0	-26.5
-Urban	84	+173.8	+173.8	+171.4
-Instream	835	0.0	0.0	+1.9
-Apportionment	0			
Sub-total	*1,605*	*0.0*	*-0.3*	*-1.4*
S. Sask River				
-Rural	307	-12.7	+12.4	+8.1
-Urban	20	+195.0	+205.0	+205.0
-Instream	1,604	0.0	0.0	1.9
-Apportionment	0			
Sub-total	*1,931*	*0.0*	*+4.1*	*+5.0*
Red Deer River				
-Rural	0			
-Urban	50	0.0	0.0	+190.0
-Instream	175	0.0	0.0	0.0
-Apportionment	212	0.0	0.0	-45.3
Sub-total	*437*	*0.0*	*0.0*	*-0.2*
RURAL TOTAL	1,846	-18.2	-18.3	-23.2
URBAN TOTAL	227	+148.0	+148.9	+189.4
INSTREAM TOTAL[a]	1,779	0.0	0.0	1.7
APPORTIONMENT	295	0.0	0.0	-10.9
SCENARIO TOTAL	4,147	0.0	0.0	0.0

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[a] Since water left for instream uses in the Bow and Oldman Rivers is also available for instream or consumptive uses in the South Saskatchewan Sub-Basin, the former amounts are subtracted from the total to avoid double counting.

thus establishing one regional market. As in Scenario Two, Scenario Three holds constant each basin's flow contribution to instream flows and interjurisdictional apportionment, allowing only agricultural and urban users to trade their previous (Scenario One) "entitlements." Scenario Four relaxes a constraint present in the previous scenarios: it also allows an optimal reallocation of water supply for the purposes of instream and apportionment needs. This outcome is achieved "as if" the water regulator also entered the market, trading with other agents to reduce the public cost of meeting fixed instream and apportionment demands.

Table 1 characterizes the pattern of reallocation of net surface flows (within season) in the four river sub-basins. There is an aggregate net supply of 4,147 million cubic meters per season, of which half must be allowed to flow to the downstream province in each scenario. Scenarios Two, Three and Four transfer increasingly more of the available supply from rural to urban users in times of drought. That is, 8.1%, 8.2% and 10.4%, respectively, of the available supplies are transferred from rural to urban uses. Overall, this represents about 23% of rural users' Scenario One consumption, yet since urban consumption is so much smaller, this is equivalent to nearly doubling (a 190% increase) the water that would be made available to urban (residential and industrial) users.

Figures 3 and 4 portray graphically the water allocations and the main welfare gains that accrue from water allocation across the four scenarios.[5] The effect giving rise to the progressive changes across scenarios is the increasing market scope of the proposed markets. More than ninety percent of the potential short-term welfare gains from water reallocation are due to the simplest introduction of markets and market forces within individual sub-basins. This may be an important outcome if policy makers are concerned about other unspecified costs or problems associated with inter-basin transfers, for example.

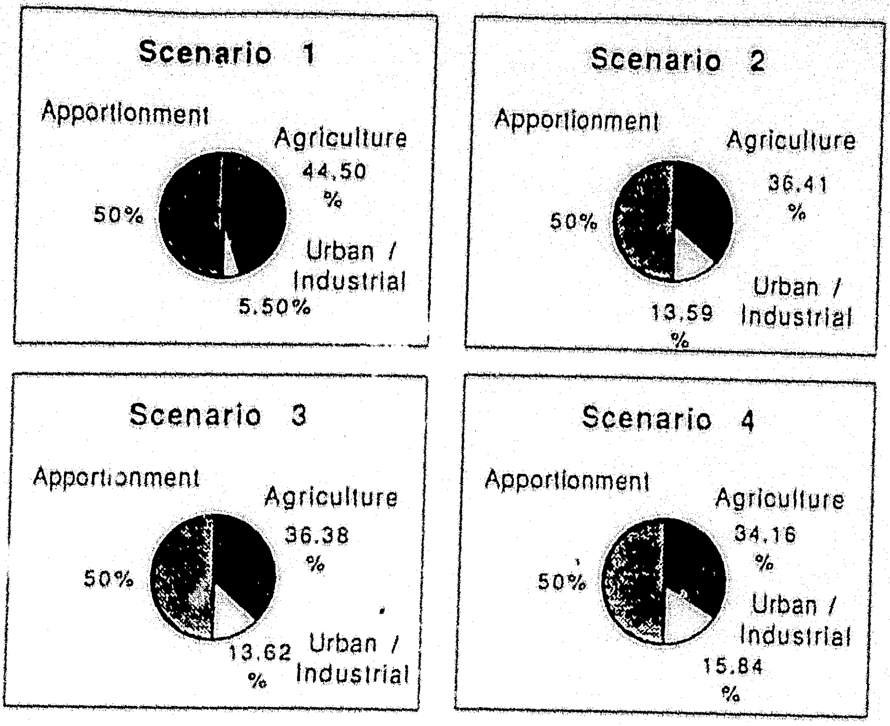

Figure 3. Water Consumption by Sector as a Percentage of Total Consumption in Each Scenario

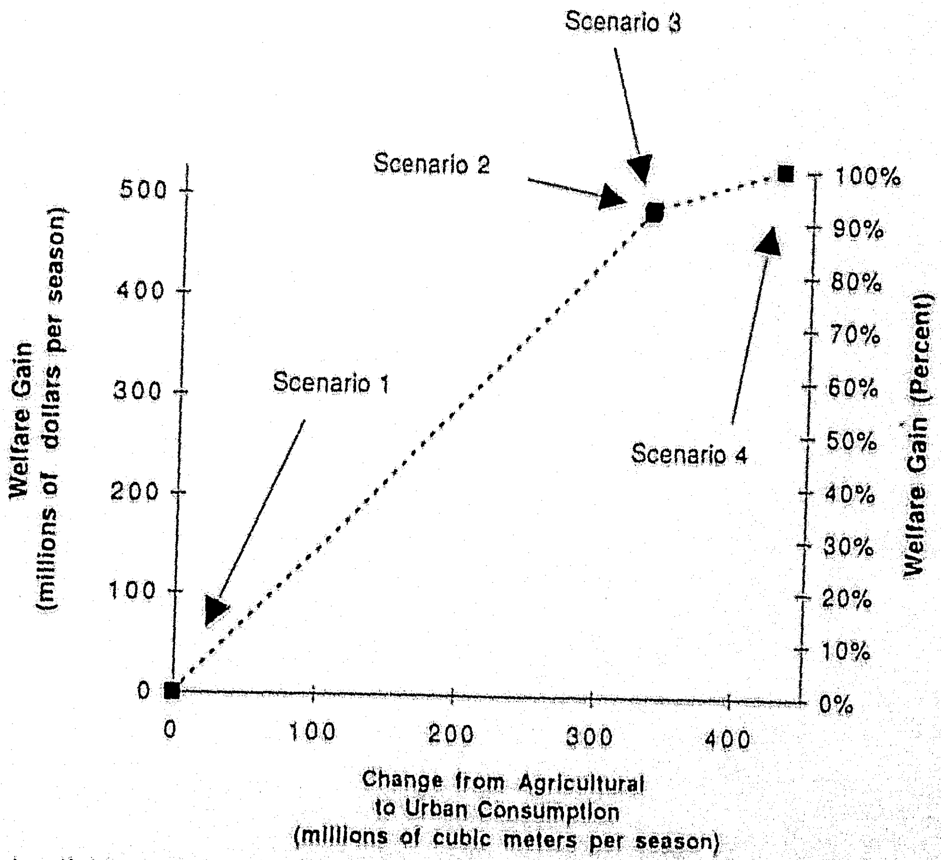

Figure 4. Welfare Gains in Relation to Volume of Agricultural to Urban Transfer

Table 2. Scenario Four Welfare Distributions Under Three Property Rights Regimes (all values in millions of dollars per season)

Water Users	Scenario One Base Case (level)	Effect of Change to Scenario Four Under: Regime One (change)	Regime Two (change)	Regime Three (change)
Bow River				
-Rural	102.8	-11.8	-58.0	9.8
-Urban	484.1	405.4	387.7	393.5
Sub-total	*596.9*	*393.6*	*329.7*	*403.3*
Oldman River				
-Rural	98.2	-7.9	-47.9	6.6
-Urban	87.9	64.6	46.6	53.3
Sub-total	*186.1*	*56.7*	*-1.4*	*59.9*
S Sask River				
-Rural	76.5	2.3	-24.1	0.3
-Urban	34.2	28.9	24.1	25.7
Sub-total	*110.7*	*31.27*	*0.0*	*26.0*
Red Deer River				
-Rural	n/a	n/a	n/a	n/a
-Urban	55.5	46.2	34.7	38.7
Sub-total	*55.5*	*46.2*	*34.7*	*38.7*
RURAL TOTAL	277.5	-17.3	-129.9	16.7
URBAN TOTAL	661.8	545.2	49[illegible].0	511.1
GOV'T REVENUE			164.8	
SCENARIO TOTAL	939.3	527.8	527.8	527.8

Resulting Welfare Comparisons

The distribution of welfare changes resulting from a move to markets as the principal water allocation mechanism will depend critically on the property rights or entitlements with which the existing agents will be endowed when they enter a new private market. In this analysis, the agents in question are the collectivity of r[illegible]l (agricultural) or urban users in each sub-basin, plus the public w[illegible]y that has an opportunity to price or tax resource usage in a way that transfers some benefit to other citizens and taxpayers, for example. Thus, when simulating a future move to markets, the analysis can also portray many of the alternative ways of distributing the economic welfare gains that derive directly from the resource reallocation.

Three alternative *property rights regimes* are considered in the following, where in all cases the same (physical) water allocations obtain (per Figure 3). The first regime supposes that water is reallocated "as if" by a market, but that, then, as now, no prices are actually charged.[6] Thus, it is an implementation of the "social planner's solution" yet no money changes hands. Predictably, when water is transferred from rural to urban users without cost or compensation, the former are losers and the latter winners.

Regime Two requires all users to pay the government for the privilege of drawing water at the equilibrium (spot-market-determined prices), such as if an auction were used. The government collects all the revenue for the benefit of some unspecified third parties. For those agents whose consumption levels fall, the welfare effect on them is unambiguously negative, whereas for agents whose consumption levels rise, a gain or loss of welfare is possible.

Regime Three allocates or vests ownership in historical usage levels with all agents when markets are introduced. The new "resource owners" can use historical amounts without charge; pay for additional consumption; or gain from the sale of any water not used. Since all moves away from the status quo are voluntary market transactions, everyone's welfare rises from reallocation.

The nature of these redistributions of economic surplus across the three property rights regimes are shown in Table 2. This table shows the water allocations for Scenario Four, the single market with the broadest scope and with the largest total welfare gain from surface water usage. Similar tabulations can be derived for the other scenarios as a guide to policy formation.

Conclusion

Water reallocation away from historical command-and-control apportionments, such as by the use of well-functioning spot markets, can have a large short-term positive impact on the levels of economic welfare derived from use of this resource, especially in times of drought. Policy makers considering the move to such resource allocation mechanisms would be wise to heed the qualitative and quantitative lessons to be learned from economic simulations of these policy changes before the fact.

Where the scope of the markets to be created is at issue, either in geographic or sectoral terms, the varying effects can be illustrated. In the case of southern Alberta, the largest welfare gains arise from even the smallest introductions of market exchange. As with many policy changes, there is a possibility of infringing on existing property rights, be they legally established or socially perceived, and, once again, models of the type employed here are capable of identifying potential winners and losers and the magnitudes of their welfare change. ■

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Footnotes

[1] Agricultural water demand for the Red Deer River sub-basin is included with the Bow River sub-basin to reflect the inter-basin transfers and aggregation which now occur in practice.

[2] A study of welfare gains in the long term would want to include other capital-intensive strategies including the use of storages, diversions, and available water-conserving technologies. There might also be increased exploitation of groundwater which currently accounts for only about three percent of irrigation supply. See Knapp and Olson (1995), for example.

[3] Some states in the U.S. measure water entitlements on such a net use basis, whereas others, like Alberta, license withdrawals on a gross diversion basis without user credit for the (potentially endogenous) return flows.

[4] The Red Deer River sub-basin does not have an effective market in Scenario Two since there is no agricultural demand there, leaving one urban demander from a fixed supply, as in Scenario One.

[5] Space limitations prevent a full description or tabulation of the basin by basin allocations, prices and welfare changes for each agent.

[6] This might be implemented by using a spot market or auction mechanism but then rebating any and all water charges paid on a lump-sum basis. As a description of property rights, this regime says users can only use those water volumes for which they hold a licence (and that no price or fee needs be paid). However, the state recognizes no property right or need for compensation when reallocating the historical licence holdings.