

ADAPTATION IN CANADIAN AGRICULTURE TO CLIMATIC VARIABILITY AND CHANGE

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Abstract. The effects of climatic variability and change on Canadian agriculture have become an important research field since the early 1980s. In this paper, we seek to synthesize this research, focusing on agricultural adaptation, a purposeful proactive or reactive response to changes associated with climate, and influenced by many factors. A distinctive feature of methods used in research on adaptation in Canadian agriculture is the focus on the important role of human agency. Many individual farmers perceive they are well adapted to climate, because of their extensive 'technological' tool-kit, giving them confidence in dealing with climatic change. In many regions, little concern is expressed over climatic change, except where there are particular types of climatic vulnerability. Farmers respond to biophysical factors, including climate, as they interact with a complex of human factors. Several of these, notably institutional and political ones, have tended to diminish the farm-level risks stemming from climatic variability and change, but may well increase the long term vulnerability of Canadian agriculture. Notwithstanding the technological and management adaptation measures available to producers, Canadian agriculture remains vulnerable to climatic variability and to climate change.



1. Introduction

Agriculture remains a significant export activity for Canada's economy; furthermore, it is a mainstay of several regional economies, e.g. the Prairies, southern Quebec and Southwest Ontario. Canadian agriculture has also evolved under a variety of climatic regimes and soil resource contexts. Over the twentieth century, Canadian agriculture has changed dramatically and there has been a long standing research, political and public interest in the underlying forces. Frequently, the changes have been seen with some degree of alarm, being linked to rural depopulation and the ability of many regions to maintain their economic and demographic bases.

As the climatic change debate gained scientific and public attention in the late 1970s, Canadian agriculture became the focal point of several early climatic change studies. Part of the practical concern over agricultural adaptation is related to the potential damages or costs of climatic change and variability to Canadian agriculture and Canadian society in general (e.g. Wheaton et al., 1990). This includes concern over the costs of measures to mitigate the climate change itself. On the other hand, adaptation of the agricultural system also has the potential to reduce other costs, because adaptation implies a 'better fit' to changed conditions (Arthur and Van Kooten, 1992; Smit et al., 1999).

The concern and interest in the question of climatic change/variability and its agricultural impacts has resulted in a considerable research effort directed at Canadian agriculture since the early 1980s (see Brklacich et al., 1998). Research on adaptation in Canadian agriculture to climatic change and variability has been informed from a variety of research fields, notably the natural hazards field (e.g. Liverman, 1987), rural and agricultural change (e.g. Bryant and Johnston, 1992; Marsden et al., 1993) and climatic change (e.g. Easterling et al., 1992; Glantz, 1988, 1991; IPCC, 1996). Social science researchers and approaches have become increasingly involved. Concomitantly, the concern has shifted from an earlier focus on the potential impacts of climatic change on crop yields (e.g. Brklacich and Smit, 1992; Singh et al., 1998) to actual and potential adaptations of agriculture to climatic change and variability (e.g. Smit et al., 1996; Bryant et al., 1997). The role of human agency - how farmers, their associations, the crop insurance industry and a whole host of government and political actors, as well as the scientific community itself mediate between external stimuli such as climatic change and actual results in terms of agricultural change - is now explicitly recognized as an essential ingredient in adaptation processes (e.g. Mortsch and Mills, 1996; Rayner and Malone, 1998). The human agency perspective explicitly acknowledges that human decision-making cannot be assumed away. It is purposeful and thoughtful.

Our objective is to present a synthesis of research on adaptation in Canadian agriculture to climatic change and variability. In section 2, we present the building blocks of the evolving conceptual framework that has guided this body of research.

In section 3, we review and illustrate the methods used to investigate agricultural adaptation, particularly in relation to how they analyze actual adaptation behaviour in addition to assumed-adaptation behaviour. In section 4, the principal types of findings are presented, drawing primarily on research on the southern Prairies, Ontario, Quebec and the Canadian Northwest. We draw upon a representative cross-section of the research in our synthesis.

2. Adaptation in Agriculture

Research on adaptation to climate in Canadian agriculture, particularly in the 1990s, has focused very explicitly on the role of human agency in adapting to changes in the decision-making environment. This contrasts with much of the earlier research on agriculture in Canada (and elsewhere, e.g. Rosenzweig and Parry, 1994; Rosenberg et al., 1993), in which particular types of farmer behaviour were assumed to be operative without being tested empirically.

Agricultural change does not involve a simple linear relationship between changes in the farmer's decision-making environment (e.g. environmental change, policy changes, and economic and social changes) and farm level change. Furthermore, the changes can be analyzed at a variety of geographic scales (Bryant et al., 1997; Smit and Smithers, 1993), for each of which it is necessary to tease out the key forces affecting agriculture, how they are perceived by farmers and other actors, and how these perceptions are translated into agricultural decisions.

Other research into agricultural change under a variety of pressures has recognized how varied farmer responses can be when faced by certain stimuli. For example, Bryant and Johnston's (1992) synthesis of research on agricultural change and adaptation in areas under urban development pressure in Canada, the U.S., Australia and New Zealand, and Western Europe underscores this variety of farmer responses, including selling off the land with the intention to quit, developing various new investment strategies and simply making do. Explanations for such varied responses, even within the same geographic area, are partly related to the variety of agricultural systems involved and the different exchange systems in which farmers operate. Thus, while all farmers in a given area may face a similar environment regarding urban development pressures, some farms are exposed to different sets of forces because they are involved in different market systems (contrast production for a regional market with that for an international market).

However, even this is not sufficient to explain the whole variety of responses. To go further, we need to acknowledge the differences between farmers in terms of personal managerial and entrepreneurial capacities and family circumstances. Furthermore, farmers can be influenced by their peers' perceptions and by values present in their communities as well as their professional associations.

Agricultural adaptation thus involves a purposeful proactive or reactive

response to changes or risks. Climate change impact studies in agriculture now frequently go beyond crop yield modelling to estimate production and economic implications. Increasingly, the studies include adaptation, most commonly by assuming that farmers employ certain adaptive practices better suited to specified climate scenarios. There is clearly a need to test these assumptions by empirically examining actual adaptive behaviour of farmers, to identify the pertinent stimuli, the relevant constraints, and the general adaptive response functions to variations in climatic conditions over time. Agricultural adaptation research in Canada has also included adaptation strategies undertaken at the political and institutional levels (Smit, 1994; Smithers and Smit, 1998).

These comments suggest that the multi-dimensional and multi-scale nature of the farm / agricultural adaptation process must be recognized as well when we investigate the effects of the environmental stimulus of climatic variability and change. This is, in fact, reflected in several of the key components of the conceptual frameworks used in adaptation research on Canadian agriculture (e.g. Brklacich et al., 1998; Chiotti and Johnston, 1995; Smit, 1993, 1994; Smithers and Smit, 1997a; Smit et al., 1998; Bryant et al., 1997), which in turn parallel or draw upon similar research elsewhere or upon research of a more global character (e.g. Liverman, 1987; Glantz, 1988, 1991; IPCC, 1996). The key components of these frameworks are summarized in Table 1.

One component relates to characteristics of the stress, notably climatic change, including variability associated with climatic change, but also including the other external conditions that interact with climate at the farm level. These characteristics include the temporal (time-frame - progressive, abrupt change, isolated extreme), spatial (scale of impact) and severity characteristics involved in the change in climatic regime or event and how these are reflected in agroclimatic properties (e.g. growing season length, temperature, precipitation, seasonal distribution of temperature and precipitation); this component also includes the variability of climatic conditions (cf. Smithers and Smit, 1997a). Finally, it includes the notion of physical threshold values in relation to crop growth and development. The key adaptation question is clear: What are the attributes of climate to which farming systems are most sensitive?

System characteristics refer to factors that affect the sensitivity of an agricultural system, influence the adaptive capacity of the system and affect the degree and type of agricultural responses. These include cultural, economic, political, institutional and local biophysical factors. Perception of the stress by farmers can be influenced by individual farmer and farm family characteristics and prior experiences, the total set of pressures faced by a given farm and by cultural, political and institutional filters that can alter the perceived risk linked to a stress. Behavioural research shows that responses are greatly influenced by perceptions of risk, rather than probabilistic measurements of risk.

The scale component (Table 1) is important because agriculture can be analyzed at scales: plant, plot, field, farm, region, sector, nation, and international

scales. Adaptive responses can be undertaken at different scales: a farm-level response, responses collectively from a locality or community, a particular agricultural sector, or a provincial or the national system.

The component dealing with Responses (Table 1) refers to the types of adaptations themselves, recognizing that responses differ according to their form, intent and effect. Two types of response are important here (Smit et al., 1999):

a) autonomous responses which need to be understood in order to evaluate or predict impacts and identify the most likely trajectories of change in regional agricultural systems, e.g. strategic and proactive, reactive or coping responses on the part of farmers and others involved in the actual production process. These include the management strategies available and used for dealing with climatic change and variability, e.g. modification of resource potential through drainage and irrigation, purchasing more insurance, altering crop mix and/or hybrids and diversification. The adaptation 'tool-kit' varies also according to the farming system (Chiotti et al., 1997);

b) responses representing adaptation as part of conscious public policy. Adaptations involving public policy involve strategies aimed at altering the adaptive capacity of the agricultural system or facilitating particular adaptations, e.g. aid for research and development, taxation incentive strategies and infrastructure measures. While a growing body of international scholarship deals with criteria by which adaptation policy options might be evaluated, very little research of this kind has been undertaken in the context of adaptation in Canadian agriculture.

Adaptive responses can also be categorized along other dimensions, e.g. tactical versus strategic decisions (Smit et al., 1996), whether they are reactive, anticipatory or concurrent with the stress, or whether they are broad trend or year-to-year adjustments. They can also be classed, following Carter et al. (1994), as structural / infrastructural, legal / administrative, institutional / administrative / organizational, regulatory, educational, financial incentives and subsidies, research and development, taxes / user fees, market mechanisms and/or technological changes. Finally, another important distinction (Chiotti and Johnston, 1995; Chiotti et al., 1997) is between land management adaptations and farm management adaptations.

There is significant regional variation within Canada in the manifestations of several of the components of the framework, notably various system characteristics, farmer evaluations of different stresses and the appropriateness of different strategies. This suggests the importance of undertaking regional scale studies in the investigation of agricultural adaptation, and even studies of particular localities because of the potential for strong intercommunity variation (Chiotti et al., 1997). This converges with one of the emerging themes in research into rural dynamics generally, *i.e.* the increasing attention given to the construction of locality through social, cultural and political processes and thus the role of human agency (Marsden et al., 1993).

Table I
Components of Agricultural Adaptation

Component	Elements or Examples
Stresses and their Characteristics	Climatic change and variability Government policies Consumer pressure Economic conditions Other environmental factors
Agricultural System Characteristics or Filters	Cultural Economic Institutional Political Social Technological
Scales of System Vulnerabilities and Responses	International National Agricultural sector Region Community, locality Farm, field, plant
Responses	Autonomous: crop choice, diversification, irrigation, crop insurance ... Public and Institutional Policy: infrastructure, information, research and development, taxes and subsidies

Finally, the framework represents an important contribution to the climatic change/agricultural impact debate because of its focus on the role of human agency, absent for so long in earlier research. Immediately, the complexities should warn us against simply extrapolating the results of biophysical modelling of climatic change, agroclimatic properties and crop yields, which characterized much of the earlier work in Canada on the impacts of climatic change on agriculture in Canada.

3. Research Methods for Adaptation-Related Issues

In this section, the principal methods used in research on adaptation to climatic change and variability in Canadian agriculture are commented on. What is most

evident is the rapid evolution of research methods. As the conceptual frameworks have evolved, new questions have been posed and a different range of research methods developed, including modifications of earlier ones.

Early on, the impacts of climatic change on agricultural systems were considered largely without recourse to the role of human agency in an adaptation process (e.g. Singh and Stewart, 1991; Brklacich and Smit, 1992). The approach was founded upon biophysical resource assessments, using climate-modelling procedures to assess changed agroclimatic properties under different climatic change scenarios. These changed agroclimatic properties were included in crop models to simulate yield changes. Implications regarding the agricultural production system would then be discussed in relation to changing relative yields for different crops in one or more agricultural regions. Little effort was made to assess such changes in relation to the economic, social and political characteristics of the production system. Furthermore, the farmer as decision-maker was not a factor in the analysis and interpretation, so the prospect of producers adapting to changes in climate was not explicitly considered.

This modelling effort involved what could be termed the 'simple impact approach' with an implicit assumption of a direct one way relationship between a specified climate and agricultural production. Given its central purpose, it did not investigate the large body of literature that emphasized the multi-dimensional nature of agricultural change in general.

Some of the resource assessment approaches did consider economic aspects by incorporating farm-level analyses based on micro-economic farm models (e.g. Arthur and Van Kooten, 1992; Brklacich and Smit, 1992). This form of analysis was similar to the U.S. MINK analysis (Rosenberg et al., 1993). Brklacich and Smit (1992), investigating the possible impacts of climatic change for the Ontario food production system, also expanded the climatic context for impacts estimation by incorporating variability in conditions into their model-based analysis of economic decision making and adaptation by the farm firm. Specifically, they introduced extreme conditions into their models as well as average ones, in an attempt to show the consequences of only adapting to mean conditions. However, these approaches are based on theoretical assumptions about farmer behaviour and aggregate supply and demand relationships.

From the late 1980s, the conceptual frameworks used in research on adaptation of agriculture to climatic change in Canada dealt with adaptation more explicitly and empirically. To start with, it was recognized that farmers might adopt a range of adaptive strategies, some cultural, some technological, either to cope with climatic change or to capitalize on new production opportunities (e.g. Rosenzweig and Parry, 1994). Thus, research began to explore actual adaptation behaviour. This led to studies of farmer decisions in light of variable conditions and the use of questionnaire surveys (Smit et al., 1996, 1997) and in-depth interviews and focus group encounters with farmers and other farm experts (e.g. Bryant et al., 1997; Brklacich et al., 1997; Chiotti et al., 1994, 1997). Thus, actual adaptation behaviour

has been addressed through several methodologies. Together, they have raised new research questions regarding how farmers perceive climatic change and variability, have identified those climatic properties that are of most importance to farmers in their decision-making, and have suggested the types of adaptive responses that can be anticipated.

An example of the type of methodology used is provided by Chiotti et al. (1997) in their work in Southern Alberta. In 1993, the researchers held a 'scoping' workshop with key stakeholders (representatives from government, an agricultural professional association and an irrigation project, and university and government researchers). Then, a list of some 50 farmers was drawn up for an area of three contiguous counties to represent the major farming systems present (dryland, irrigation and feedlot). From these, 38 interviews were conducted that focused on past experiences with climate, changes in farm practices and operations, and the climate and non-climate factors driving farm-level decision-making. These taped interviews were transcribed and subjected to a content analysis that informed the construction of a formal questionnaire. The latter was then sent to about 190 randomly selected farmers, yielding a response rate of approximately 25%. This analysis focussed on farmers' perceptions of climate risks, including climate change, relative to other forces prompting adaptations to practices.

Other research on adaptation to climatic change in Canadian agriculture has used similar research methodologies. Bryant et al. (1997) used the focus group approach with farmer groups in two major agricultural regions in Quebec, the south-west region of Quebec and the Quebec City region. Brklacich et al. (1997), working in Eastern Ontario, also used the focus group approach. The focus groups in both these research efforts incorporated presentations of the projected impacts of climate change (scenarios of annual average conditions) on the yields of dominant crops in the respective regions. This was intended to focus farmers' attention on climatic change and to identify possible adaptive responses. Brklacich et al.'s (1997) research was followed up by a formal interview survey with a sample of 30 randomly selected farmers in Renfrew County. Bryant et al.'s (1997) work was followed up more recently by a sample survey of 30 farmers in the Napierville region, part of the south-west region of Quebec where two of the initial focus groups had been held (Granjon, 1999), using a questionnaire adapted from the one used by Brklacich et al. (1997). In both Brklacich et al. (1997) and Granjon (1997), as part of the questionnaire, farmers were presented with scenarios relating to changes in average climatic conditions under a climatic change scenario and projected yields for selected crops grown in their agricultural region. The farmers then indicated what changes, if any, they would make in light of these conditions.

This approach based on climate change scenarios addresses farmers' perceptions of climate stimuli and throws light on possible adaptations by farmers. Yet the approach is limited in two respects. First, it is based upon hypothetical behaviour; what farmers expect they might do given a particular future average climate. Second, the research focuses on annual average conditions, which do not

represent the key vulnerabilities for most agriculturists for whom variations from averages are the more pertinent stresses. This importance of variabilities and extremes associated with climate change, not just annual mean conditions, is evident from the survey research described above and is increasingly reported elsewhere in the vulnerability and adaptation literature.

A complementary empirical approach records and analyses actual farmer decisions over a period of years during which growing season conditions vary; this variability reflects the uncertainty inherent in both current climate and climatic change. For example, for a sample of 120 farms in Southern Ontario, Smit et al. (1996) documented changes undertaken over a five year period, and identified those changes that were related to climatic stimuli. Given the frequency with which crop breeding is suggested or assumed as an adaptations in agriculture, Smit et al. (1997) documented farmers' use of crop varieties as a strategy to cope with variations in growing season conditions over a five-year period, in which both favourable and unfavourable conditions were experienced.

The challenges to agricultural adaptation research raised in these projects are daunting. Yet the studies have illustrated the existence of multiple sources of stress in the farmers' decision-making environments and the numerous constraints on farmers' employment on adaptations measures. Climatic change expressed solely in terms of annual average conditions is not considered to be problematic, and there is considerable scepticism in the farm community about climate change. Together, these suggest that significant anticipatory adaptations to climate change are unlikely in Canadian agriculture. However, the research has also shown the importance of temporal variations in climatic conditions; farmers are sensitive to anomalous conditions and do employ a suite of adaptations or coping strategies that have application to risks associated with climatic change.

4. Research Findings

First, some comments are offered on the research that has focused on biophysical modelling and crop yield impacts in Canadian agriculture. Then, we provide a commentary on the research dealing more explicitly with adaptation under two headings: a) the individual farm and community or locality level, and b) the broader agricultural system level. For each, the commentary is related to the components identified in the adaptation framework (Table 1).

4.1. THE BIOPHYSICAL MODELLING EXERCISES

While the research reported on here is not specifically about adaptation, it provides the context from which the current focus on adaptation in Canadian agriculture to

climatic change and variability has emerged. Where appropriate, we make some comments about assumptions used, and about the types of findings generated and their implications.

4.1.1. Agroclimatic Properties

Much of the research on agroclimatic properties for Canadian agriculture under different climatic change scenarios has paralleled U.S. research (e.g. Easterling et al., 1992). Research on Canadian agriculture has focused mostly on Ontario (e.g. Viau and Mitic, 1992), Quebec (e.g. Singh and Stewart, 1991), the Canadian Prairies (e.g. Arthur, 1988a, 1988b; Arthur and Abizadeh, 1988) and the Northwest (e.g. Mills, 1994). Variations on different scenarios have been introduced as well as incorporating CO₂ fertilisation and its effects (e.g. El Mayaar et al., 1997; Singh et al., 1996; Singh et al., 1998).

Many modelling efforts have been region-specific using different models and assumptions; thus, inter-regional comparisons of results are difficult. Regional variations of potential agroclimatic properties are large under the different climate change scenarios; larger seasonal moisture deficits are anticipated in all regions, being particularly severe for Ontario. However, all the global climatic change scenarios and studies reviewed by Brklacich et al. (1998) suggest considerable warming for all Canadian regions. Using one agroclimatic indicator as an example, average frost-free seasons under these warmer conditions would be expected to be longer and warmer, and more conducive for commercial agriculture than the existing thermal regimes. For the principal agricultural regions in Ontario, the Prairies and Quebec, most estimates put the extension of the average frost-free period at three to five weeks; for the Atlantic region, the estimates are longer, from four to eight weeks, while for the Peace River region and other regions near the current agricultural margin, the estimates of the extension of the frost-free period are shorter, from about three to four weeks.

4.1.2. Crop Development and Yields

The impacts of changes in agroclimatic properties on crop development and yields have received a great deal of attention. This large body of research does not deal explicitly with adaptation issues. Nor does it address the important variable of the changing comparative advantage of different agricultural regions under climate change, a factor of considerable importance in agricultural trade and regional specialization, and adaptation at the macro scale. However, this research has provided insights into the extent to which potential adaptive responses (e.g. switching from spring-seeded to winter-seeded cereals, more irrigation) might offset the negative consequences of a climatic change. On the other hand, these crop modelling exercises have not been placed in the broader context of adaptive behaviours (Brklacich and Stewart, 1995; Savdie et al., 1991).

The research has dealt more extensively with grain crops compared to other

major crop groups such as oils seeds, forage and potatoes with Ontario, Quebec and the Prairies receiving the most attention. Generally, global climatic change scenarios are associated with an increase in the rate of development of grain crops, but in these three major agricultural regions, the net effect of several interacting agroclimatic variables, particularly moisture-related, would in general be to depress yields (e.g. Brklacich et al., 1998; Parry and Carter, 1989).

4.1.3. Land and Regional Production Potential

The impact of climatic change on agricultural land and production potential has not been a major focus of research on adaptation of Canadian agriculture to climatic change and variability. What research exists deals mostly with the Peace River region and Ontario. For Ontario, for example, Brklacich and Smit (1992) estimated that climatic change, even allowing for some adjustments in regional production patterns, could be associated with a decline of 6% of the agricultural production potential. Some research has investigated regions beyond the current arable lands. In the Prairies, for example, it was estimated that most of the land north of the current arable Prairie lands would remain only marginally suitable for farming, despite an increase in temperature under climate change scenarios (Arthur, 1998a, 1998b; Arthur and Abizadeh, 1988). Under one scenario, 3.1 million hectares of organic soil would become available to farming, but these would support only forage crops, and the opportunities would be insufficient to warrant commercial production.

4.2. THE INDIVIDUAL FARM AND COMMUNITY LEVEL

Agricultural adaptation is about decisions and changing conditions at farm and local levels. The focus of much research has been on farmer behaviour, actual farmer decisions and the factors that influence those decisions. At the farm and community level (aggregations of farmers operating in some form of localized social network), climatic stress indicators are interpreted and tactical and strategic decisions made that form the basis of regional adjustment patterns. Much research on adaptation in Canadian agriculture has focused at this scale in order to document, describe, characterize and explain the adaptive behaviour of farm decision-makers. As noted in section 3, most of the recent research has involved scoping exercises (e.g. focus groups with farmers) followed by interviews with farmers on a more systematic basis, in a specific region (e.g. Chiotti et al., 1997; Brklacich et al., 1997), although there has been some comparative work (e.g. Bryant et al., 1997).

4.2.1. Farmer Perceptions: A Question of Information

Research on farmer perceptions and adaptations has highlighted the need to clarify the relationship between climatic change and climatic variability. For instance, Granjon (1999) found that while 70% of his 30 farmer respondents claimed to have observed 'climatic change' over the last 20 years, these 'changes' were for the most part related to specific events over a period of one or two years (e.g. two consecutive years of droughty conditions and the 1998 ice storm). Despite the ambiguities, focusing on actual experience with climatic variability does have considerable merit because climatic change will be experienced via on-going variability in climatic conditions (Smit et al., 1999).

One set of important farmer perceptions that emerge from this research (e.g. Bryant et al., 1997; Brklacich et al., 1997; Chiotti et al., 1997; Granjon, 1999) is that many farmers are sceptical about the reality of climatic change. They also express great uncertainty about the rate of change in conditions. In addition, perception of change and climatic events is no guarantee of farmers adapting to them. For instance, in Smit et al.'s (1996) study of 120 farmers in SW Ontario, it was found that while most farmers reported being significantly affected by variable climatic conditions over a 6-year period, only 1 in 5 made any conscious effort to adjust to climatic events. In Granjon's study (1999), while 70% of the farmer respondents said they had observed some form of climatic 'change' (mostly specific events), only 36% reported having made any adjustments subsequently. Finally, in Brklacich et al.'s (1997) study, while 27 out of 30 farmer respondents claimed to have observed climatic change over the previous 20 years, only 20% of these 27 respondents claimed to have made an explicit adaptation to the change. Clearly, no simple link exists between climatic stimuli and farmers' decision-making. Smit et al. (1996) show that adjustments to "economic" conditions are often adjustments to climatic conditions which are felt by the farmer in economic terms.

Furthermore, the emphasis on averages in many climatic models (e.g. in temperature, precipitation, growing season length) does not attract the attention of most farmers. Taken alone, information on changes in average conditions is not necessarily helpful in decision-making. Farmers are more sensitive to, and place more emphasis on variability in conditions such as precipitation intensity at critical periods of crop development and variation in local conditions (Smithers and Smit, 1997a; Bryant et al., 1997; Chiotti et al., 1997). Confronted with hypothetical climate scenarios in some of the research, farmers did suggest they would make changes, e.g. mostly in terms of changing the crop varieties planted; however, the suggested changes tended to be vague and non specific.

Obviously, this raises questions regarding the utility of some agroclimatic indicators commonly reported, and underscores the importance of efforts to introduce variability in conditions into vulnerability assessments (e.g. Brklacich and Smit, 1992; Smit et al., 1997). It is apparent that farmers do pay a great deal of attention to climatic conditions, but not necessarily the ones most commonly

supplied in climatic change scenarios. Uncertain variations from year to year are the risks that prompt adaptive behaviour. These conditions include rainfall intensity and duration, the incidence of early and late frosts, snow accumulation, high temperatures, and the intensity of droughty conditions at critical periods, or the frequency of droughts over several years.

Research on actual adaptive behaviour suggests that farmers are indeed sensitive to temporally variable climatic stimuli, making both tactical and strategic decisions. This was shown in by Smit et al.'s (1997) study of farmers' decisions regarding hybrid selection. Farmers' perceptions of conditions were strongly linked to their decisions, but these perceptions were greatly affected by recent - especially the previous year's - experience. Furthermore, the effects of and responses to climatic conditions are interdependent with other sources of change (Smit et al., 1996; Bryant et al., 1997). In Bryant et al.'s (1997) study, some dairy farmers in the Quebec City region acknowledged the importance of being aware of climatic variability, but were more concerned with the potential effects of the North American Free Trade Agreement on the Canadian supply management system for milk production. In support of this, Brklacich et al. (1997) suggested that the low rate of response by farmers' to perceived climatic change was related partly to the general variability in climatic conditions in any case and partly to the fact that weather and climate in relation to other factors in farm decision-making was declining in importance.

4.2.2. Farmer Perceptions of Adaptive Capacity

Farmers' concerns regarding climatic change and variability are also likely influenced by their perceptions of their own adaptive capacity. Bryant et al. (1997) found that farmers in Quebec expressed a high level of confidence with their ability to respond to climatic variability and hence, from their point of view, to climatic change. The changes in annual average conditions described by climate scientists are not considered problematic by farmers coping with interannual variations that exceed the predicted changes in mean conditions. Farmers also have confidence in their technological and management tool-kit.

Because of experience with previous climatic variability, some farmers believe the tools necessary to cope with climatic change are available (Bryant et al., 1997). Furthermore, they perceive this tool-kit will continue to expand. A large list of farm-level adaptations has indeed been identified (e.g. Smit, 1993). These strategies fall into the general category of autonomous strategies planned and implemented at the farm level, and include tillage practices, irrigation, drainage, hybrid selection, crop diversification, and participation in crop insurance. The range of tools is indeed large. However, farmers' confidence in this expanding tool-bag may be somewhat misplaced; choices still have to be made and in the face of year-to-year uncertainties, and it is not evident that the technological fix will resolve the issue for farmers (Smit et al., 1997; Johnston and Chiotti, 1998). Certainly, the frequent

and widespread crop losses and economic hardship associated with other-than-normal climatic conditions, and the ongoing need for public relief and compensation (e.g. Smit, 1994) suggest that the agricultural sector is not as well adapted to temporal variations and uncertainties in climate as is often claimed.

4.2.3. Community and Locality

Generally, research on adaptation in Canadian agriculture has focused on specific regions. However, the mechanisms by which human agency effects can be modified by local and regional circumstances has not been developed very explicitly, except as a general frame of reference for interpretation and in relation to farmers' perceptions of climatic change (e.g. Smit and Brklacich, 1992). Nonetheless, there is increasing reference to the presumed importance of specific sets of local/regional circumstances. This is most obvious in how farmers perceive the risks associated with climatic change and variability. In some regions (e.g. southern Alberta) with particular types of climatic vulnerability regarding water availability, farmers have expressed a keen interest in how climatic change would affect them because of the inter-regional dependencies in water management (Chiotti et al., 1997).

Furthermore, Bryant et al. (1997) suggest there is potential for variation in community adaptive capacity related to dominant economic structures, local culture and institutional frameworks. However, there is little systematic comparative work on this. Currently, it is more appropriate to express the locality relationship as a hypothesis: that there is significant geographic differentiation between regions and communities in relation to vulnerability to stress, and in relation to the capacities of farmers and communities to develop effective adaptation strategies.

4.2.4. Farm and Farmer Characteristics Related to Adaptive Capacity and Propensity

Much of what we know about this research question in the adaptation process derives from the vast body of research on the dynamics of agricultural development and the diffusion of agricultural practices. Farmer and farm family characteristics, e.g. education levels and participation in various information networks, and farm characteristics, e.g. farm size, the farm's financial health and crop structure, are potential factors affecting the ability and propensity of farmers to adopt certain strategies. In addition, characteristics of the strategies can also be important, e.g. cost of the strategy and anticipated effects.

Some farm characteristics that appear important are really characteristics that reflect the agricultural sector within which the farm functions. Hence, dairy farms operating under a supply management system may exhibit a lower propensity to engage in strategic changes generally because of the greater levels of certainty associated with product marketing (Bryant et al., 1997). Smit et al. (1996) found

that farm characteristics did not differentiate significantly between farms' adaptability, but their propensity to adapt was influenced by farmers' perceptions of climatic risks. Smit et al. (1997) show that farmers differ in their willingness to take risks via their choice of crops, and suggest that the availability of subsidized crop insurance influences the adoption of other strategies to manage climate-related risks. Again, it must be stressed that this research is in its early stages, and systematic empirical evidence of the links between farmers' perceptions of climatic change and variability, farmer and farm characteristics, and of the appropriateness of different tactics and strategies is only now being tackled.

4.2.5. Multiple Sources of Stress

Recent research into farm-level adaptation in Canadian agriculture has identified the importance of the multiple sources of stress faced by farmers (Brklacich et al., 1998; Bryant et al., 1997; Chiotti et al., 1997). Smithers and Smit (1997b) provide evidence that economic conditions (commodity prices) were powerful forces in the Kent-Essex area in explaining changes in cropping patterns, but climatic conditions, crop breeding and the growth in crop insurance were also influential. Farmers readily identify major sources of stress, some of which vary regionally. However, as Smit et al. (1996) point out, while most observers agree there are several external forces of change, it is probably unrealistic to isolate the different forces; rather, it is important to identify the nature of the intervening effects of the different forces. For example, the expansion of soybean production in Ontario is related to a complex mix of changes in plant breeding, production technologies, crop prices, enterprise compatibility, public programs, and a recognition of climatic risks.

4.3. THE AGGREGATE AGRICULTURAL SYSTEM

Adaptations in an agricultural system can be considered at the level of the farm firm or at more aggregate scales. Aggregate empirical analyses seek to identify evidence of changes in regional agricultural systems to climatic stresses. Modelling analyses based on climate change scenarios scale up estimates from the field and farm levels to assess impacts at a regional scale. From the point of view of adaptation, spatial scale is fundamental; for example, a failure at the farm scale via bankruptcy, or forced sale (maladaptation?), could be reflected as a macro-scale adaptation in the system via a reduction in the number of farms and a change in the size and enterprise mix of farms. Similarly, the existence of significant public subsidies and compensations associated with climatic variations may be considered necessary because of ineffective adaptive risk management at the farm scale. But such public programs can also be viewed as adaptations at the broad scale of the agricultural sector; and this system-wide adaptation is factored into the risk

management decisions of individual producers.

4.3.1. Economic and Regional Implications

Several studies have estimated the implications for regional economies and farm structure of climatic change based initially on climate scenarios and crop yield models. In the case of the Prairie region, the information from these crop models is fed into normative models of representative farms (in which adaptation is included via assumptions relating to full information, crop substitutions and profit maximization), which are then aggregated and connected to input-output models of the regional agricultural economy (e.g. Arthur, 1990; Arthur and van Kooten, 1992). These studies indicate that adaptation can greatly reduce adverse effects and realise opportunities associated with climate change. For example, assuming a known climate and complete adaptability in crop substitution, new crops and new areas, crop revenues in Manitoba were estimated at almost double current levels (Arthur and Van Kooten, 1992). However, the Prairie agricultural economy seems much less adaptable when variability about average conditions is considered (Arthur and Van Kooten, 1992; Wheaton, 1990; Wheaton et al., 1992). Scenario-based farm economic models were also developed for Ontario, assuming knowledge of changed conditions, but superimposing somewhat extreme wet and dry years (Brklacich and Smit, 1992). This study showed that when perfect adaptability was assumed, incomes could be increased with climate change but decreased in particularly dry years. By aggregating production constraints and opportunities over the province of Ontario, Smit and Brklacich (1992) show that without adaptation significant economic losses could be expected; and with adaptations involving system-wide crop choice, losses would be negligible (or become gains) under average conditions, but there would be greater risks associated with dry years. These studies show that the impacts of climatic change on agriculture are very sensitive to the variability issue and depend fundamentally on the nature of adaptations likely to occur. However, these studies tend to assume adaptive behaviour rather than analyze adaptive behaviour directly

4.3.2. Public and Institutional Strategies

The notion that certain institutional and public policy contexts can influence the propensity of the agricultural system to adapt to changing circumstances is a long-standing one. Crop insurance programs have been introduced to reduce risks associated with climatic variability. Smithers and Smit (1997b) provide evidence that crop insurance plays a mediating role between climatic variation and crop selection. The presence of crop insurance – itself an important adaptive strategy to deal with temporal variations in climate – tended to reduce the sensitivity of producers to unfavourable years and thereby reduce their propensity to adjust crop choice in response to growing season conditions.

Climate-related public payments to agricultural producers in Canada are large and continuing – as they are in many countries, notably in Europe, USA and Japan. For the two decades 1972 to 1992, Canadian federal government payments directly related to climate (e.g. drought assistance, crop loss compensation, crop insurance) are estimated at \$5 billion (Smit, 1994). These payments illustrate the degree to which agricultural is sensitive to variability in climatic conditions. They modify the effects at the farm level and thus influence individual adaptive behaviour. They also represent a societal-scale adaptation to climatic variations; and there is some question about the sustainability of such programs, particularly if climatic change brings increases in the frequency and/or magnitude of some extremes.

Institutional and public policy initiatives can contribute in other ways to the adaptive capacity of the agricultural system. Strategies designed to enhance the capacity of the system to undertake appropriate autonomous change can include incentives, education and information communication, and providing aid to research and development to develop appropriate technologies for different regions and sectors. At a more collective level, among the various strategies that can be employed, public intervention can provide aid for infrastructural development, can encourage agricultural associations to introduce educational programs and information sessions for their members on climatic change and variability, and undertake or encourage research and development, particularly on strategies to manage risks associated with a variable and changing climate.

5. Conclusions

Research on adaptation in Canadian agriculture to climatic change and variability has been characterized by several thrusts. First, the conceptualization of agricultural adaptation has focused increasingly on human agency, both farmer decision-making and public policies. This has included the recognition of a range of external forces of change in attempts to estimate the consequences for farmers of climatic change, the identification of key indicators of interest to farmers, and the consideration of actual processes of adaptation. Second, the research has recognized the importance for agriculture of the variability of climate, not just annual average conditions. The research has evolved beyond a focus on comparative static considerations of climate scenarios, to examinations of agricultural sensitivities and thresholds to temporal variations in climatic conditions. Third, research that has explicitly tackled adaptation has used a variety of social science research methods to identify pertinent stimuli and likely responses. Several research projects have used the output from climate change/crop modelling analyses as a basis for seeking farmer perceptions and potential adaptations to climatic changes. Others have systematically documented strategies employed in agriculture to cope with temporal variations in climatic conditions,

providing insights into responses that might be expected to climatic change conditions. In all these areas, the research is converging with research in related fields, dealing with risk assessment and management, human perception and behaviour in light of environmental hazards.

However, significant challenges remain. Whereas much work on climate change relates to average conditions, the adaptation research to date in agriculture indicates that it is not average conditions that are critical to the farmer, or to governments who share the burden of climate-related losses. Rather, it is the inter-annual and intra-annual variations, and not just in temperature or precipitation but also in specific sets of agroclimatic conditions, which are currently not easily extracted from climate models. A useful approach to the change-variability issue is to identify critical climatic thresholds from analyses of the sensitivity of agricultural systems (e.g. a frequency of drought beyond 2 years in 5). This threshold information would then be used by both those developing adaptation options and those in the climate research community who can estimate the probabilities of such thresholds being reached with climatic change.

Another challenge relates to the factors that affect the propensity to adapt and the adaptive capacity of agricultural systems – economic, political, socio-cultural, technological, and informational. Clearly any attempt to estimate likely future adaptation cannot ignore the role of these factors that serve to constrain or enhance the adoption of adaptive strategies.

There is considerable debate – in both the scholarly and public policy communities – about the adaptive capacity of Canadian agriculture to risks associated with climatic change, and hence about the need for planned public initiatives to promote adaptation. There is no simple answer, but some evidence suggests that several institutional and policy measures have contributed to reducing the propensity of the Canadian agricultural system to adapt via other means to changing climate conditions. If this is so, then it becomes even more urgent to engage in an evaluation of different adaptation strategies, both autonomous and those involving public and institutional measures, to assess their appropriateness and effectiveness.

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