ADAPTATION OPTIONS IN CANADIAN AGRICULTURE TO CLIMATE CHANGE

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Abstract

Adaptation in agriculture to climate change is important for impact and vulnerability assessment and for the development of climate change policy options. Although a wide variety of adaptation options has been proposed as having the potential to reduce vulnerability of agricultural systems to risks related to climate change, few have been subjected to analyses with respect to their likelihood of adoption, the conditions under which they would be adopted, and their overall suitability for implementation. Within the context of Canadian agriculture, this paper develops a typology of adaptation to systematically classify and characterize adaptation options to climate change. In particular, it differentiates adaptation options in agriculture according to the involvement of different agents (producers, industries, governments); the intent, timing and duration of employment of the adaptation; the form and type of the adaptive measure; and the relationship to processes already in place to cope with risks associated with climatic stresses. A synthesis of research on adaptation options in Canadian agriculture identifies four main categories: (i) technological developments, (ii) government programs and insurance, (iii) farm production practices, and (iv) farm financial management. In addition to these 'direct adaptations', there are options, particularly information provision, that may stimulate adaptation initiatives. The results reveal that most adaptation options are modifications to on-going farm practices and public policy decision-making processes with respect to a suite of changing climatic (including variability and extremes) and non-climatic conditions (political, economic and social). For progress on implementing adaptations to climate change in agriculture there is a need to better understand the relationship between potential adaptation options and existing farm-level and government decision-making processes and risk management frameworks.

Keywords adaptation, agriculture, Canada, climate change, policy, response options

1. INTRODUCTION

Adaptation is an important component of climate change impact and vulnerability assessment, and is one of the policy options in response to climate change impacts (Fankhauser, 1996; Smith and Lenhart, 1996; Smit et al., 1999). Indeed, the significant role of adaptation as a policy response by government has been recognized internationally. Article 4.1b of the United Nations Framework Convention on Climate Change (UNFCCC) (1992) states that parties are "committed to formulate and implement national and, where appropriate, regional programs containing measures to mitigate climate change and measures to facilitate adequate adaptation to climate change." The Kyoto Protocol (Article 10) further commits parties to promote and facilitate adaptation, and deploy adaptation technologies to address climate change (UNFCCC, 1998). Canada, like many other countries, recognizes adaptation as an important component of its climate change response strategy and is exploring adaptation options in several sectors.

Agriculture is inherently sensitive to climate conditions, and is among the most vulnerable sectors to the risks and impacts of global climate change (Parry and Carter, 1989; Reilly, 1995). Adaptation is certainly an important component of any policy response to climate change in this sector (Mizina et al., 1999; Reilly and Schimmelpfennig, 1999). Studies show that without adaptation, climate change is generally problematic for agricultural production and for agricultural economies and communities; but with adaptation, vulnerability can be reduced and there are numerous opportunities to be realized (Nordaus, 1991; Easterling et al., 1993; Rosenzwieg and Parry, 1994; Fankhauser, 1996; Smith, 1996; Mendelsohn, 1998; Wheaton and McIver,

1999). In Canadian agriculture, studies have identified climate change risks and have noted needs and opportunities for beneficial planned adaptations (Brklacich et al., 1997; Maxwell et al., 1997; Bryant et al., 2000). While adaptation in agriculture is often considered as a policy response of governments, it also involves decision-making by agri-business and producers at the farm-level (Smit, 1994; Benioff et al., 1996; Adger and Kelly, 1999). Adaptations in agriculture vary with respect to the climatic stimuli to which adjustments are made (i.e. various attributes of climate change, including variability and extreme events) and according to the differing farm types and locations, and the economic, political and institutional circumstances in which the climatic stimuli are experienced (Chiotti and Johnston, 1995; Tol et al., 1998; Smit et al., 1999; Bryant et al., 2000).

Many potential agricultural adaptation options have been suggested, representing measures or practices that might be adopted to alleviate expected adverse impacts. They encompass a wide range of forms (technical, financial, managerial), scales (global, regional, local) and participants (governments, industries, farmers) (Smithers and Smit, 1997). Most of these represent potential adaptation measures, rather than ones actually adopted. Climate change impact analyses often assume certain adaptations, although the adaptation process itself remains unclear (Chiotti and Johnston, 1995; Fankhauser and Tol, 1997; Tol et al., 1998; Smit et al., 1999). There is a need to understand what types and forms of adaptation are possible, feasible and likely; who would be involved in their implementation; and what is required to facilitate or encourage their development or adoption. A necessary step in addressing these concerns is the identification and

characterization of 'adaptation options' in agriculture (Brklacich et al., 1997; Bryant et al., 2000; Smit et al., 2000).

This paper represents a review of current knowledge about adaptation in agriculture from climate impact, adaptation and vulnerability studies, and from other research that addresses changes in agricultural production and economies. It also incorporates information and insights from stakeholders who make decisions in the agricultural sector, gained through workshops and other communications with representatives from the scientific communities, producer organizations, farm groups, government agencies, and individual producers.

The main purpose of this paper is to develop a typology to classify adaptation options in Canadian agriculture to climate change. Important attributes of climate change for adaptation in agriculture are identified, and insights about adaptive decision-making from several fields of scholarship are related to climate adaptation in agriculture. A critique of the main dimensions of adaptation provides the basis for the typology of adaptation options in Canadian agriculture. Agricultural adaptation types are differentiated primarily according to who is involved and what forms they take. The types are also considered according to how they are connected to processes already in place to cope with risks associated with climate and other conditions. The paper concludes with a discussion of the usefulness of the typology and provides suggestions regarding the role of adaptation options in on-going decision-making processes at the public and private levels.

2. CLIMATE STIMULI FOR ADAPTATION

In order to understand what adaptation options in Canadian agriculture are possible it is important to identify the climatic variables to which the adaptations relate, and to consider the role of non-climatic factors that influence the sensitivity of agriculture to climate change. This addresses the question: what is it that agriculture is adapting to? The applicability of adaptation options depends on the nature of the stimuli and associated vulnerability (Wheaton and McIver, 1999; Pittock and Jones, 2000; Smit et al., 2000).

Traditionally, the impacts of climate change on agriculture have been discussed with respect to current average (or 'normal') growing season conditions and possible future normal conditions (Brklacich and Smit, 1992; Baethgen and Magrin, 1995; Brklacich et al., 1997; Mizina et al., 1999). Conventional climate impact scenarios usually focus on the changes in average (mean) temperature and moisture. Some have also considered other climate characteristics such as the growing season length and the timing of frosts, and climate-related factors such as pests and diseases, invariably for an average year sometime in the future (Smit et al., 2000).

While most impact studies have considered changed average (mean) climate conditions, usually in a comparative static manner, analyses of agricultural vulnerability indicate that the key attributes of climate change are those related to climatic variability, including the frequency of non-normal conditions. Recent debates focussing on the relationship between climate change stimuli and adaptation in agriculture recognize that climate change includes not only long-term changes in mean conditions, but also a change in the year-to-year variation in growing season conditions, and the frequency and

magnitude of extreme weather events (Hulme et al., 1999; Wandel and Smit, 2000; IPCC, 2001). Understanding that climate change includes climatic variability and extreme events is important in analyses of adaptation. This is particularly so for agriculture, which is generally well adapted to mean or average conditions, but is susceptible to irregular or extreme conditions such as more frequent droughts and deviations from 'normal' growing season conditions (Reilly, 1995; Smit et al., 1996; Risbey et al., 1999). Vulnerability in agriculture can be directly attributed to the variability and extremes associated with climate change, which also contribute to the uncertainty surrounding adaptation (Chiotti and Johnston, 1995; Smithers and Smit, 1997; IPCC, 2001).

Despite the important influence of climate change, including variability and extremes, adaptation in agriculture does not function and evolve with respect to these climatic stimuli alone. Non-climatic forces such as economic conditions, politics, environment, society and technology, also have significant implications for agricultural decision-making (Bryant, 1994; Bryant et al., 2000). The effects of changing commodity prices, trade agreements, resource use rights, and government subsidies and support programs complicate the adaptation process (Brklacich et al., 2000). Adjustments in agriculture are made routinely in response to non-climatic conditions, especially the market, as much as to changing climate conditions. Non-climatic conditions may amplify or exacerbate climate-related risks, or they may dampen, counteract or overwhelm the climatic effects. Adaptive decisions in agriculture are made in light of the joint effects of climatic and non-climatic conditions.

3. EXPLORING ADAPTATION IN AGRICULTURE

Insights into adaptation in agriculture to climatic change, including variability and extremes, comes from a variety of research fields, which consider various scales (plant, plot, field, farm, region, sector, nation and international) and employ several different perspectives (Smithers and Smit, 1997; Bryant et al., 2000). Fields that provide insights into adaptations in agriculture include research on climate change impacts; natural hazards; agrarian political economy; innovation adoption; agricultural systems and farm decision-making; risk management; and agricultural vulnerability and adaptation. These bodies of scholarship can be summarized with respect to their main perspectives and approaches to adaptation apparent in each field, and how they contribute to our understanding of adaptation in agriculture.

3.1. Conventional Climatic Change Impact Assessment

With the potential to modify adverse effects of climate change, adaptation is important to climate change impact assessment (Reilly, 1995). Although agriculture is one of the most widely studied sectors with respect to the impacts of climate change (IPCC, 1996; 2001), adaptation in agriculture has still received little explicit consideration in impact assessment literature (Chiotti and Johnston, 1995). Conventional, scenario-based studies providing predictions of potential impacts in agriculture have addressed adaptation by making assumptions about human responses (Easterling et al., 1993; Rosenzwieg and Parry, 1994). Early (first-generation) impact assessment models provided estimates of the overall impacts or damages of climate change based on the assumption that no adaptations in agriculture would occur (Smit et al., 1989). Later (second-generation) impact assessment models arbitrarily assigned

adaptations to climate change, assuming adaptive responses on the part of agricultural producers with respect to changes in average temperature and moisture conditions (Mendelsohn et al., 1994; Smit et al., 1996). More recently, impact assessments have recognized the importance of farm-level decision-making in the adaptation process and have begun to focus on the role of human agency (Brklacich et al., 1997; Chiotti et al., 1997).

The earlier focus on the potential biophysical impacts of climate change scenarios on agricultural production (i.e. plant growth and crop yields) has shifted to include considerations of possible adaptations by producers (Bryant et al., 2000). However, there is still little analysis in the impact assessment literature of actual farm level decision-making in agriculture or of how such decisions relate to public policies.

3.2. Natural Hazards

Recognition that the pertinent features of climate change for most sectors are those associated with year-to-year variability and the frequency and magnitude of extreme climatic events has prompted consideration of adaptation in light of natural hazards (Smit et al, 1996). Natural hazards research is a long-established scholarly field that explores the interactions of humans and the environment by focussing on the impacts of and human responses to extreme events (Burton et al., 1993). Much attention has been directed to the identification and characterization of human adjustments to calamitous (extreme) events. Characteristics of the system being impacted and the perceptions of hazard risk by those impacted are noted as important in understanding human coping strategies and adjustments (Burton et al., 1993).

Climate change studies of agriculture address adaptation as an adjustment to the risks associated with changes in averages and, more recently, with recurring extreme events (Bryant et al., 2000). These analyses can be informed by natural hazards research, especially by raising the questions of how farmers perceive the risks associated with climate change (Brklacich et al., 1997; Chiotti et al., 1997), and by recognizing that adaptation is directly related to the perception of risks and involves conscious (planned) decision-making.

3.3. Agrarian Political Economy

Research focussing on rural and agricultural change emphasizes the important role of institutions and other macro-level forces in the agri-food sector (Bryant and Johnston, 1992; Ilbery et al., 1997). Studies have addressed changes in agriculture, including adaptation as a decision-making process affected by political and economic variables (Blaikie and Brookfield, 1987). This literature recognizes that adaptation does not simply occur independently at the field or farm level, but it is a process greatly influenced by broader economic, political and social forces. In addition, policy initiatives by governments represent adaptations for the sector as a whole. The role of government policies, institutional arrangements, and macro-level social and economic conditions is increasingly recognized in adaptation studies (Smit, 1994; Chiotti and Johnston, 1995; Mizina et al., 1999).

3.4. Innovation Adoption

The adoption of technological innovations is one of the most frequently advocated strategies for adaptation in agriculture to climate change (Houghton et al., 1990; Rosenberg, 1992). Innovation adoption research provides insights into the decision-

making process by which adaptations are implemented by producers and diffused among farming communities (Jones, 1967). Studies within this field focus on the characteristics of producers that influence their decisions about adaptation measures. Factors such as decision-maker (producer) attitudes, values, motivations, and perceptions of risk and environmental conditions distinguish between producers who are 'innovators' and those who are 'laggards' with respect to the adoption of particular innovations (Rogers, 1983). Much attention also has been directed towards the attributes of specific innovations that lead to their adoption. Factors such as profitability, complexity and compatibility distinguish between innovations that are quickly up-taken and those that are not widely employed (Guerin and Guerin, 1994).

Innovation adoption research recognizes that adaptation is a multi-faceted decision-making process, and is a function of the personal and situational circumstances of the decision-maker and the characteristics of the innovation under consideration, and occurs within a context of changing economic, social, political and biophysical conditions (Rogers and Shoemaker, 1971; Ilbery, 1985; Chamala, 1987). This perspective informs an understanding of the processes by which adaptation options are implemented and their likelihood of adoption.

3.5. Agricultural Systems and Farm Decision-Making

Agricultural systems research has provided much useful information on the nature and dynamics of agricultural production systems and their responses to a myriad of climatic and non-climatic stimuli. It recognizes agriculture as a complex system, within which changes are driven by the joint effects of economic, environmental, political and social forces (Olmstead, 1970; Bryant and Johnston, 1992). This approach emphasizes

the interconnections among the various levels within the agriculture system (i.e. field, farm, community, region and nation) and can describe change at aggregate scales and individual farm scales (Cocklin et al., 1997). Models have been developed in this field to assess the economic impacts of climate-related changes in agriculture based on simulations at the regional (aggregate) scale (Klein et al., 1989) and estimates of changes in profitability at the farm-level (Arthur and Van Kooten, 1992). Studies have shown that decisions involving changes in agriculture are made at different levels that are inter-related, and as a result, patterns of agricultural activity, including adaptation, are the product of many individual decisions (i.e. by government, agri-business and individual producers) (Chiotti et al., 1997; Smithers and Smit, 1997).

Farm decision-making is seen as an on-going process, whereby producers are continually making short-term and long-term decisions to manage risks emanating from a variety of climatic and non-climatic sources (Ilbery, 1985). In this sense, adaptation is the result of individual decisions influenced by forces internal to the farm household (i.e. risk of income loss, environmental perception), and the external forces that affect the agricultural system at large (i.e. macro-economic policy, institutional frameworks) (Chiotti and Johnston, 1995).

3.6. Risk Management

Climate change, including variability and extremes, is a pervasive source of risk to agriculture. However, little attention has been directed towards farm-level risk management strategies in light of the uncertainty associated with the changing and variable climatic conditions (Smit et al., 2000). Risk management research recognizes that decisions in agriculture involve both risk assessment and specific actions taken to

reduce, hedge, transfer or mitigate risk (Wandel and Smit, 2000). Within this field, adaptation is often considered a response to financial risk in agriculture (whether the source is climatic or non-climatic) (Barry and Baker, 1984). Many studies have identified sources and types of farm-level risk due to climate change (Fleisher, 1990; Anderson, 1997; Turvey, 2001) and considered how these risks might be managed through adaptation (Easterling, 1996; Chiotti et al., 1997). This literature provides valuable insights into agricultural decision-making with respect to adaptation in light of the uncertainties associated with climate change, especially those resulting from increased variability and extremes.

3.7. Agricultural Vulnerability and Adaptation

The vulnerability approach to climate change recognizes that there are pertinent climatic attributes to which agricultural systems are sensitive, and that these attributes can be used as a platform for analyzing the impacts of climate change (Kates 1985; Carter et al. 1994). Vulnerability research identifies the climatic attributes relevant to specific agricultural systems (Parry, 1985; Swart and Vellinga, 1994), examines how these attributes are experienced through the variability and extremes associated with climate change (Burton, 1997), and considers adaptation strategies in light of these climatic stimuli and the other conditions that influence decision-making (Smit et al., 1996; Kelly and Adger, 2000). The vulnerability approach can identify differing sensitivities of specific agricultural systems, as a target for adaptation initiatives, and can indicate the types of adaptation that have been attempted with respect to climatic stimuli. This approach can provide insights into the conditions under which adaptive decision might be made.

The fields of literature summarized here inform adaptation research in four main ways: (1) Adaptations to climate change are common, and are likely to existing involve types of risk management and responses to perceived hazards (climatic variability and extreme events); (2) they manifest themselves at various scales including national public policy and individual farm decision-making; (3) they are driven by the joint effects of multiple forces (economic, environmental, political and social), not likely climate change alone; and (4) the forms they take and the likelihood of their adoption will vary according to the scale at which they occur and the particularities of their location. This provides an important backdrop for understanding the various dimensions of adaptation in agriculture.

4. CHARACTERISTICS OF ADAPTATIONS

There exist a large number and variety of measures or actions that could be undertaken in agriculture to adapt to climate change (Smit, 1993; Kelly and Granich, 1995; Reilly, 1995; Brklacich et al., 1997; Reilly and Schimmelpfennig, 1999). There also exist numerous characteristics by which adaptations can be understood and distinguished, and which serve as a bases for a typology of agricultural adaptations (Burton et al., 1993; Stakhiv, 1993; Carter et al., 1994; Bijlsma et al., 1996; Smithers and Smit, 1997). Among the distinguishing characteristics of adaptation are intent and purposefulness; timing and duration; scale and responsibility; and form.

4.1. Intent and Purposefulness

Intent and purposefulness differentiate between adaptations that are undertaken spontaneously as a regular part of on-going management (autonomous) from those that

are consciously and specifically planned in light of a climate-related risks (Carter et al., 1994; Bryant et al., 2000). Within socio-economic systems, public sector adaptations are usually conscious strategies, such as investment in government programs, but private sector and individual adaptations can be autonomous, planned or a combination of the two (Smit et al., 2000). For example, the development and employment of resource management innovations can be both part of the on-going management strategy of producers and a planned response by industry. Adaptation evaluation and prescription necessitates consideration of consciously planned responses to climate change (Mizina et al., 1999).

4.2. Timing and Duration

Timing of adaptation differentiates responses that are anticipatory (proactive), concurrent (during), or responsive (reactive). Duration of adaptation distinguishes responses according to the time frame over which they apply, such as tactical (shorter-term) versus strategic (longer-term) (Stakhiv, 1993; Smit et al., 1996). Autonomous adaptations, be they public or private, are usually concurrent or reactive and tactical in nature (Smit et al., 2000). Planned adaptations in agriculture to climate change are normally presented as addressing current and future climate-related risks, but they are also informed by past experiences with climatic conditions and variations.

4.3. Scale and Responsibility

Adaptations can be distinguished according to the scale at which they occur and who is responsible for their development and employment. Adaptation in agriculture to climate change occurs at a variety of spatial scales (i.e. plant, plot, field, farm, region and nation) (Smithers and Smit, 1997). At the same time, responsibility can be differentiated

among the various actors that undertake or facilitate adaptations in agriculture including individual producers (farmers), agri-business (private industries), and governments (public agencies) (Smit et al., 2000). However, most discussions of adaptation do not distinguish the roles of different decision-makers. For example, a commonly espoused adaptation in agriculture is the use of crop development for changed climatic conditions. Such an adaptation would likely involve government agencies (encouraging this focus in breeding research), corporations (development and marketing of new crop varieties), and also producers (selecting and growing new crops). Any realistic assessment of adaptation options needs to systematically consider the roles of the various stakeholders.

4.4. Form

Adaptation in agriculture occurs via a variety of processes and can take many different forms at any given scale or with respect to any given stakeholder. Distinctions among adaptations based on form have been suggested by Burton et al. (1993), Carter et al. (1994), and Smithers and Smit (1997). These studies consider adaptations with respect to, among other things, their administrative, financial, institutional, legal, managerial, organizational, political, practical, structural, and technological characteristics. For example, Bryant et al. (2000) identify farm-level forms of adaptation including modification of resource management, purchasing crop insurance, and diversification. They also identify different forms of policy level adaptations including aid for research and development, incentive strategies and infrastructure measures. Differentiating responses to climate change according to form provides a useful framework for understanding adaptation in agriculture.

5. TYPES OF ADAPTATION OPTIONS IN AGRICULTURE

This section represents a critical review of the diverse and disparate literature and experience to provide examples, descriptions and explanations of specific types of adaptation options in Canadian agriculture to climate change. It also incorporates information and insights from the various stakeholders who undertake decisions in the agriculture sector gained through workshops and other communication with representatives from the scientific community, producer organizations, farm groups and government agencies, and individual producers (see Acknowledgements).

This paper takes adaptation to refer to "adjustments in ecological-social-economic systems in response to actual or expected climatic stimuli, their effects or impacts" (Smit et al., 2000, p. 6). As a result, the types of adaptations included here are activities which represent changes in some attribute of the agricultural system (the agriculture sector or farms within it) directly related to reducing vulnerability to climate change.

It is common in reviews of adaptation options to include activities, especially the provision of information on climate change and potential impacts, that may prompt consideration of adaptations, but that, in themselves, are not direct changes in the agriculture sector or farms within it (Bryant et al., 2000). Certainly, the dissemination of information (on climate change, possible impacts and vulnerabilities, potential adaptation options, etc.) is something governments can do to promote adaptations, and it may be a necessary precursor to adoption of adaptation measures. This is especially important given insights from natural hazards and innovation adoption literature regarding the role of perception in the adaptation process. However, in this paper we consider information provision, dissemination and training as important parts of the means by which

adaptation might be encouraged rather than as specific agricultural adaptations in their own right.

Agricultural adaptation options are grouped according to four main categories that are not mutually exclusive: (1) technological developments, (2) government programs and insurance, (3) farm production practices, and (4) farm financial management. The typology is based on the scale at which adaptations are undertaken and the stakeholder involved. The first two categories are principally the responsibility of public agencies and agri-business, and adaptations included in these categories might be thought of as system-wide or macro-scale. Categories three and four involve farm-level decision-making by producers. Within each category specific examples are considered in light of the distinctions discussed earlier and farm decision-making in general. The main types of adaptations are summarized in Table 1 with examples in each category.

5.1. Technological Developments

Technological adaptations are developed through research programs undertaken or sponsored by federal and provincial governments, and through research and development programs of private sector industries. As summarized in Table 1, technological adaptation options have been proposed in *crop development* (to increase their tolerance); *weather and climate information systems* (to provide forecasts); and *resource management* (to deal with of climate-related risks).

The development of new crop varieties including types, cultivars and hybrids, has the potential to provide crop choices better suited to temperature, moisture and other conditions associated with climate change. This involves the development of plant varieties that are more tolerant to such climatic conditions as heat, drought, frost and

flooding through conventional breeding, cloning and genetic engineering (Joseph and Keddie, 1981; Major et al., 1991; Smithers and Blay-Palmer, 2001). This adaptation option can also include the development of food products that can be more easily transported and stored in response to changing climatic conditions (Smit, 1993). Although crop development is often proposed as an adaptation option, little attention in crop breeding has been directed towards increasing resilience to particular climatic conditions.

Most crop development, whatever its focus, is undertaken in light of prevailing climatic conditions, and there have been remarkable achievements in the development of crops suited to particular climatic norms (Duvick, 1992; Slater, 1994). There is little evidence that the crop development community (public and private) has targeted 'robustness' to climatic variations (also known as stability and resilience) in its programs (Smithers and Blay-Palmer, 2001). It has been suggested (Tollenaar et al., 1994; Tollenaar and Wu 1999), that in the case of corn, there has been improvement in this robustness, perhaps a serendipitous development related to the nature of breeding selection. On the other hand, van Herk (2001) noted that not only is climatic variability not a target for crop breeding (although it could be), but also that an anomalous climatic season is seen as an inconvenience in field testing, with its results discarded, rather than an opportunity to test for and retain the robustness features of the crop variety. Furthermore, there already exist a very wide range of crops and varieties, with differing climatic requirements, yet farmers still have to make management choices when selecting from among these.

Another type of technological advance is the development of information systems capable of forecasting weather and climate conditions associated with climate change. Weather predictions over days or weeks have relevance to the timing of operations such as planting, spraying or harvesting. Seasonal forecasts, such as estimates of the likelihood of conditions associated with El Niño - Southern Oscillation phenomena, have the potential to aid risk assessment and production decisions over several months. Information on longer-term climate change scenarios can inform farmer decision-making with respect to climatic variability and the probability of extreme events. In these ways, weather and climate information systems can facilitate farm-level adaptation. Farmers may use this information with respect to the timing of operations (i.e. planting and harvesting) (Carlson, 1989; Wilks, 1992), the choice of production activities (i.e. crop varieties) (Murphy, 1994), the type of production (i.e. irrigation or dry-land agriculture) (Reilly, 1995), and financial management activities (i.e. use of crop insurance and water rights) (Lou et al., 1994). While seasonal forecasts have the potential to aid production decisions (Murphy, 1994), studies of producer perceptions and decision-making show that their reliability would have to be greatly improved before they influence producer risk management choices (Brklacich et al., 1997).

The development of technological innovations in resource management also has the potential to address climate-related stimuli. Broad-scale water resource management innovations address the risk of water (moisture) deficiencies or surpluses associated with shifting precipitation patterns and the probability of more frequent floods and/or droughts. At a broad or regional scale these innovations include the development of irrigation systems, water transfers, water diversions, and desalinization technologies

(Smit, 1993; Easterling, 1996; de Loë et al., 1999). Farm-level resource management innovations have also been proposed. These adaptations include mechanical innovations such as the development of integrated drainage systems, land contouring, reservoirs and recharge areas, and alternative tillage systems (Rosenberg, 1981; Dumanski et al., 1986; Spaling, 1995; Easterling, 1996). Resource management innovations assume adequate supplies of water and are often constrained by prevailing economic and institutional arrangements. The lead responsibility for developing technological adaptations tends to be governments and agri-business; the employment or adoption of these technologies is a farm-level decision, often informed by government or industry programs.

5.2. Government Programs and Insurance

Government programs and insurance are institutional responses to the economic risks associated with climate change and have the potential to influence farm-level risk management strategies. These include government *agricultural subsidy and support* (to decrease the risk of climate-related income loss, and spread exposure to climate-related risks publicly); *private insurance* (to decrease the risk of climate-related income loss, and spread exposure to climate-related risks privately); and *resource management programs* (to influence resource management in light of changing climate conditions).

Agricultural subsidy and support programs involve modifications to and investment in both established and *ad hoc* federal and provincial programs. *Ad hoc* programs provide compensation for disaster-related income loss independent of the support provided by established crop insurance, income stabilization and farm production subsidy, support and incentive programs (Schmitz et al., 1994; Smit, 1994). All of these programs greatly influence farm-level production and management strategies by

transferring risk in agriculture. Modifications to the terms of reference for crop insurance or other farm production subsidies, supports and incentives have the potential to encourage or discourage changes in farm-level production and management by spreading exposure to climate-related risks (Ye and Yeh, 1995; Wang et al., 1998; Turvey, 2001). Changes to government investment in income stabilization and disaster relief have the potential to make more funds available to farmers to reduce the risk of income loss as a result of increased incidence, severity and duration of droughts, floods and other climate related-events (Romain and Calkins, 1996; Changnon et al., 1997; Love et al., 1997). The success of agricultural subsidy and support programs has been difficult to determine as government programs seldom address climate-related risks independently of other risks to agriculture (Van Kooten and Arthur, 1997).

The development of private insurance represents an adaptation to climate-related risks that is primarily the responsibility of the financial services sector, which is generally influenced by government programs. This involves the development of insurance schemes by private companies to address crop and property damage from such climate-related hazards as droughts, floods and other climate-related events. Although this type of adaptation has the potential to reduce vulnerability at the farm-level, its implementation is limited by the availability of existing government subsidized crop insurance and support programs to farmers (Boddis, 1994) and the increasing liabilities related to climate change experienced by the Canadian insurance industry (MacDonald, 2000).

Resource management programs involve the development of federal and provincial policies and programs that encourage or discourage changes in land use, water

use and management practices. This type of adaptation includes the development of land use regulations (Chiotti and Johnston, 1995), water use permits (Easterling, 1996) and 'best management' practices (Agriculture and Agri-Food Canada, 1995). Resource management programs also have the potential to address broad-scale changes such as northward shifts in pest infestations (Smit, 1993) and boreal forest patterns (Van Kooten, 1995). Implementation of these programs will require an assessment of existing institutional and economic arrangements and could require changes to existing legislation (Chiotti et al., 1997; de Loë et al., 1999). These policy instruments of governments represent adaptations at an aggregate scale and also influence farm-level adaptation decision-making.

5.3. Farm Production Practices

Farm production practices involve changes by producers in their farm operational practices, which may be stimulated or informed by government and industry programs. Farm production adaptations include farm-level decisions with respect to *farm production*, *land use*, *land topography*, *irrigation*, and the *timing of operations* (Table 1).

Changing farm production activities has the potential to reduce exposure to climate-related risks and increase the flexibility of farm production to changing climatic conditions. Production adaptations could include the diversification of crop and livestock varieties, and changes to the intensity of production. Altering crop and livestock varieties, including the substitution of plant types, cultivars and hybrids, and animal breeds designed for higher drought or heat tolerance, has the potential to increase farm efficiency in light of changing temperature and moisture stresses (Smit et al., 1996; Chiotti et al., 1997). Altering the intensity of chemical (i.e. fertilizers and pesticides),

capital and labour inputs has the potential to reduce the risks in farm production in light of climate change (Brklacich et al., 1997; Brklacich et al., 2000; Hucq et al., 2000). Decisions about changes in farm production practices are unlikely to be made in light of climate change risks separately from the risks associated with other economic, technological, social and political forces.

Changing land use practices involve altering the location of crop and livestock production. Rotating or shifting production between crops and livestock, and shifting production away from marginal areas has the potential to reduce soil erosion and improve moisture and nutrient retention. (Delcourt and Van Kooten, 1995) The conservation of moisture and nutrients in light of more frequent droughts can also be improved through the use of alternative fallow and tillage practices (Chiotti et al., 1997; Hucq et al., 2000).

Changing land topography involves land contouring and terracing, and the construction of diversions, reservoirs, and water storage and recharge areas (Smit, 1993; Easterling, 1996). This type of adaptation reduces farm production vulnerability by decreasing runoff and erosion, improves the retention of moisture and nutrients, and improves water uptake (de Loë et al., 1999).

Implementing irrigation practices involves the introduction or the enhancement of specific water management innovations including centre pivot irrigation, dormant season irrigation, drip irrigation, gravity irrigation, pipe irrigation and sprinkler irrigation (Smit, 1993). Irrigation practices also involve changing the scheduling of existing systems (Chiotti and Johnston, 1995). This type of adaptation will increase moisture retention in light of decreasing precipitation and increasing evaporation, and more frequent droughts. Irrigation practices could improve farm productivity and enable diversification of

production in light of climate-related changes (i.e. switching to crops that would otherwise not thrive in dryland agriculture) (Brklacich et al., 1997; Klassen and Gilpen, 1998).

Changing the timing of operations involves production decisions, such as planting, spraying and harvesting, to take advantage of the changing duration of growing seasons and associated changes in temperature and moisture. This type of adaptation includes the scheduling of crop and livestock production activities such as chemical inputs (Chiotti and Johnston, 1995), grazing (Chiotti et al., 1997), irrigation (de Loë et al., 1999), harvesting, mulches, planting, seeding, and tillage (Smit, 1993). Changing the timing of these farm practices has the potential to maximize farm productivity during the growing season and to reduce losses associated with heat stresses and moisture deficiencies.

5.4. Farm Financial Management

Farm financial adaptation options are farm-level responses based on the use of farm income strategies (both government supported and private) to reduce the risk of climate-related income loss. As a result, government agricultural support and incentive programs often influence farm financial management decisions. Farm financial adaptations involve farm-level decisions with respect to *crop insurance*, *crop shares and futures*, *income stabilization programs*, and *household income* (Table 1).

Crop insurance reduces income loss as a result of reduced crop yields from droughts, floods and other climate-related events, and in the case of subsidized programs (as in Canada) this spreads exposure to climate-related risks publicly (Smit, 1993; de Loë et al., 1999). Purchasing insurance entails financial decision-making aimed at stabilizing

income from crop production in light of climate change risks. This type of adaptation includes participation in established federal and provincial subsidized crop insurance programs (Turvey, 2001).

Investment in crop shares and futures has also been proposed to spread exposure to climate-related risks and reduce vulnerability to income loss (Mahul and Vermersch, 2000). This adaptation option involves the use of securities, shares and other financial options developed by government and industry, including banks, as an alternative financial management strategy to crop insurance (Turvey and Baker, 1990; McCulloch et al., 1994; Chiotti et al., 1997).

Participation in income stabilization programs also has the potential to spread exposure to risk borne by farmers and reduce their vulnerability to climate change. Many farmers already participate in established federal and provincial income stabilization programs, such as the Dairy Subsidization Program, Agricultural Income Disaster Assistance (AIDA) and the Net Income Stabilization Account (NISA) (Agriculture and Agri-Food Canada, 2001). Although the use of income stabilization programs is recognized as a potential climatic adaptation (Schweger and Hooey, 1991), it is unlikely to be considered independently of other political and economic influences.

Household income strategies have long been important adaptation options in Canadian agriculture. Such financial decisions may also represent a means of dealing with economic losses or risks associated with climate change. Diversification of income sources including off-farm employment and pluriactivity, has been identified as an adaptation option with the potential to reduce vulnerability to climate-related income loss (Brklacich et al., 1997; Smithers and Smit, 1997; de Loë et al., 1999). As with many

adaptations, diversification of household incomes is unlikely to be undertaken directly in response to climatic perturbations alone (Bradshaw et al., 2001).

6. ADAPTATION PROCESSES

The typology illustrates the myriad of agricultural adaptation options available to governments, industries and individual farmers. There are many different kinds of adaptations with the potential to reduce vulnerability of agricultural systems to climate change risks. The development of technological, public policy and farm management options are commonly noted as having the potential to moderate a problematic climate change effect or to realize an expected opportunity, and the abundance and variety of potential adaptation options contributes to the view that the agricultural sector is very adaptable. Yet the process of adaptation in agriculture itself is rarely examined. There has been very little research on the likelihood that such adaptation measures would actually be adopted, or on the conditions under which such adaptations might be employed in the agri-food sector. Our limited knowledge in this area (corroborated by findings from research on innovation adoption, agricultural risk management, and agricultural systems and decision-making) indicates among other things that (1) there are distinctive (although inter-related) roles in adaptation for individual farm operators, agri-business (industry), and governments; that (2) decisions to adopt or modify measures or practices are rarely made relative to one risk alone, but in light of the mix of conditions and risks (climate, trade, prices, social norms, etc.) that influence decision-making; and that (3) decisions to adopt or modify measures or practices are usually made not in a 'once-off' manner, but in a dynamic, on-going 'trial-by-error' process.

Adaptation in agriculture involves various 'stakeholders' with different, yet often inter-related points of view. In order to evaluate and promote practically the adoption of adaptations such as the development of new crops or irrigation, it is necessary to recognize which players are involved and what their roles are with respect to adaptation. As illustrated in the typology, significant distinctions exist between adaptation options that are employed by private decision-makers, including industry and individual producers (farmers), and public decision-makers (government and public agencies). However, private and public adaptation options are not necessarily independent of each another, and often have inter-related roles in the adaptation process.

Many public programs and policies such as the development of crop varieties, resource management innovations and crop insurance are designed to directly influence individual behaviour with respect to adaptation. Indeed, the sharing of costs and benefits between government, industry and farmers is a key concern in understanding adaptation in agriculture, and informs an understanding of the likelihood of adaptation options actually being implemented. This is essential for efforts to promote adaptation to climate in the agricultural sector. If governments seek ways to encourage adaptation (to reduce losses or realize opportunities), they need to be aware of how government initiatives with respect to climate adaptation relate to producer decisions. For example, there is increasing interest in evaluating the relative merit of alternative adaptation options, so that the better ones might be encouraged (Smith and Lenhart, 1996; Klein and Tol, 1997; Mizina et al., 1999). Such evaluations are conventionally based on such criteria as effectiveness, economic efficiency, implementability, flexibility and so on. Both the evaluation criteria themselves and the performance on criteria may differ greatly

depending upon whether the evaluation was taken from the point of view of a government or a producer.

Understanding the relationships between adaptation options and the existing processes in place to deal with climate-related risks is a key component of any evaluation of adaptation options and of analyses of the likelihood of adaptation options actually being implemented in Canadian agriculture. Ultimately, adaptations in agriculture occur via decisions of producers (to employ a technology, to choose a crop, to change a practice, to alter timing, to modify inputs, to buy insurance, to enroll in a stabilization program, etc.). These decisions are made in the context of prevailing economic conditions, institutional and regulatory arrangements, and of existing technology, policy and financial systems, and social norms (Bryant et al., 2000). Adaptation processes are articulated through the institutional and regulatory mechanisms of prevailing agricultural, economic, financial, management, political and technological systems (Bryant, 1994). The mechanisms through which adaptation occurs are widespread and include public research and extension programs, resource management legislation and regulations, agricultural support programs, and economic policies (Titus, 1990; Carter, 1996; Smith, 1996). Adaptation options in agriculture are adopted relative to these mechanisms, which have the potential to modify the significance of climate-related stresses experienced in agriculture and are important constraints in the farm decision-making process.

The connections between adaptation options and existing adaptation processes and mechanisms involve primarily relationships between farm production practices and financial management, and public sector decision-making processes. For example, the adoption of irrigation as a farm production adaptation may be constrained by the

existence of water management regulations such as the legislation of water use rights (de Loë et al., 1999). Government research and extension programs promoting resource management innovations may also influence the adoption of farm production practice options through education and incentives (Hucq et al., 2000). In terms of farm financial management, agricultural support programs and macro-economic policies often influence the adoption of adaptation options (Lewandrowski and Brazee, 1993). For example, a survey of Ontario soybean producers showed that use of crop insurance varies not only with the conditions and level of subsidy in the program, but also with the other risk management strategies employed (Smithers, 1998).

Most adaptation options are not discrete technical measures likely to be undertaken specifically with respect to climate change. Rather, they are modifications to on-going farm practices and existing public policies and programs that relate not only to climatic conditions but also to other political, economic and social conditions. Agricultural decision-making with respect to adaptation to climate change is not likely to be considered as separate from other agricultural decisions. Nor is agricultural adaptation likely to be considered as independent of non-climatic stimuli (such as economic conditions, institutional arrangements, social norms and politics). At both the producer (farm) level and the public (government) level, decisions are made continuously, in an on-going, 'incremental' fashion, in light of multiple stimuli and conditions.

For example, a decision to diversify farm production or household income is not considered with respect to climate risks alone. Market risks, personal preferences, and capital and labour costs associated with changing production or enterprises are likely to overshadow the climatic stimuli for adaptation. Similarly, government decisions

regarding irrigation, crop insurance, subsidy and support programs, and resource management are made with respect to various economic, social, environmental and political conditions of which climatic conditions may play a very small role.

In identifying and evaluating which adaptations are attractive (and therefore likely to be adopted), consideration must be given to how they relate to on-going decision making processes, constraints, stimuli and decision criteria. Although the typology provides various examples of these relationships, further consideration of the connection between adaptation processes and mechanisms is necessary to usefully evaluate options, to fully address the likelihood that adaptation options will be implemented, and to identify the conditions and constraints under which they might be employed.

7. CONCLUSION

This paper focuses explicitly on adaptation options in Canadian agriculture to deal directly with the risks related to climate change, including climatic variations and extremes. There is an immense variety of potential adaptation options available, grouped here into four main categories. *Technological developments* involve the development of crops, weather and climate information systems and resource management innovations, including irrigation, by government and industry, to be subsequently adopted by producers. *Government programs and insurance* involve federal and provincial agricultural subsidy and support programs (including crop insurance, established income stabilization and *ad hoc* compensation), federal and provincial resource management programs, and development of private insurance by the financial services sector. *Farm production practices* involve decision-making by producers and include diversification and intensification of crop and livestock production (including crop substitution),

changing land use and topography, irrigation, and timing of operations. The final category, *farm financial management*, also involves decision-making by producers and includes the use of crop insurance, investment in crop shares and futures, participation in income stabilization programs, and diversification of household income. While this typology provides the structure for differentiating options available in Canadian agriculture, the types remain rather generic. Obviously, for specific farm systems, regions and producers particular forms of adaptation measures would need to be tailored to local conditions and decision-making processes.

Adaptation in Canadian agriculture involves various stakeholders, who have different, but often inter-related roles. Governments (and other public agencies), private industries and corporations, and individual producers (farmers) all have a place in the adaptation process. Governments and industries need to be aware of how public initiatives (such as increased investment in income stabilization or crop insurance) and private initiatives (such as the development of new crops or crop insurance) relate to producer decisions. Agricultural adaptation options at all levels are part of a larger process, within which decisions are made continuously, in an on-going, 'incremental' fashion, in light of multiple (climatic and non-climatic) stimuli and conditions. Producers, in particular, would consider climate change, if at all, as part of their on-going management decision-making.

For climate change impact assessment and/or vulnerability assessment in agriculture to be practical there is a need to incorporate well-founded estimates of the *likely* employment of adaptation options. This requires an understanding of the processes of decision-making in agriculture; the ways in which potential climate change adaptation

options fit into the real risk management decision-making frameworks of governments, industries and producers; and the constraints and stimuli for adoption with respect to adaptation scenarios. At the same time, any effort to promote and encourage the implementation of adaptation options in Canadian agriculture should include an *evaluation* of options available. This necessitates the recognition of the stakeholder(s) involved in a particular adaptation option, and of how an adaptation relates to broader adaptation decision-making processes.

It is also becoming clear that the development of specific adaptation 'product choices' or 'policy prescriptions' (i.e. 'direct' adaptation measures) may not be the most useful or practical means of promoting adaptation to climate change in agriculture, or in any sector. The IPCC (Smit et al., 2001) has recognized the practical limitations to identifying and evaluating particular adaptation measures, given their huge variety, their peculiarities in particular applications, and the importance of fitting climate adaptation into on-going decision processes. The IPCC has suggested that a useful alternative to dealing with particular 'adaptations' is to work to enhance 'adaptive capacity', that is, the broader ability of a system (in this case, agricultural producers, regions or sectors) to cope with climate-related risks and opportunities. Not only does this allow for local and individual assessment of options, and the incorporation of adaptation into existing risk management processes, but it also recognizes the distinct roles of the public and private sectors. Consistent with the promotion of adaptive capacity is the dissemination of information on climate change risks and vulnerabilities, and on the broad types of adaptations that stakeholders might consider.

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TABLE (1) Main Types and Selected Examples of Adaptation Options in Canadian Agriculture

TECHNOLOGICAL DEVELOPMENTS

Crop Development

- Develop new crop varieties, including hybrids, to increase the tolerance and suitability of plants to temperature, moisture and other relevant climatic conditions.

Weather and Climate Information Systems

- Develop early warning systems that provide daily weather predictions and seasonal forecasts.

Resource Management Innovations

- Develop water management innovations, including irrigation, to address the risk of moisture deficiencies and increasing frequency of droughts.
- Develop farm-level resource management innovations to address the risk associated with changing temperature, moisture and other relevant climatic conditions.

GOVERNMENT PROGRAMS AND INSURANCE

Agricultural Subsidy and Support Programs

- Modify crop insurance programs to influence farm-level risk management strategies with respect to climate-related loss of crop yields.
- Change investment in established income stabilization programs to influence farm-level risk management strategies with respect to climate-related income loss.
- Modify subsidy, support and incentive programs to influence farm-level production practices and financial management.
- Change *ad hoc* compensation and assistance programs to share publicly the risk of farm-level income loss associated with disasters and extreme events.

Private Insurance

- Develop private insurance to reduce climate-related risks to farm-level production, infrastructure and income.

Resource Management Programs

- Develop and implement policies and programs to influence farm-level land and water resource use and management practices in light of changing climate conditions.

FARM PRODUCTION PRACTICES

Farm Production

- Diversify crop types and varieties, including crop substitution, to address the environmental variations and economic risks associated with climate change.
- Diversify livestock types and varieties to address the environmental variations and economic risks associated with climate change.
- Change the intensification of production to address the environmental variations and economic risks associated with climate change.

Land Use

- Change the location of crop and livestock production to address the environmental variations and economic risks associated with climate change.
- Use alternative fallow and tillage practices to address climate change-related moisture and nutrient deficiencies.

Land Topography

- Change land topography to address the moisture deficiencies associated with climate change and reduce the risk of farm land degradation.

Irrigation

- Implement irrigation practices to address the moisture deficiencies associated with climate change and reduce the risk of income loss due to recurring drought.

Timing of Operations

- Change timing of farm operations to address the changing duration of growing seasons and associated changes in temperature and moisture.

FARM FINANCIAL MANAGEMENT

Crop Insurance

- Purchase crop insurance to reduce the risks of climate-related income loss.

Crop Shares and Futures

- Invest in crop shares and futures to reduce the risks of climate-related income loss.

Income Stabilization Programs

- Participate in income stabilization programs to reduce the risk of income loss due to changing climate conditions and variability.

Household Income

- Diversify source of household income in order to address the risk of climate-related income loss.