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Agricultural supply chain optimization and complexity: A comparison of analytic vs simulated solutions and policies

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ABSTRACT

With worldwide food security emerging as a major policy issue moving forward, the structure and optimization of key agricultural supply chains is of growing importance. In turn, while many working models of supply chain optimization have been developed to ensure analytic tractability, others are building more precise characterizations of a supply chain as a complex system that may not be amenable to analytic solution. This research examines an important agricultural supply chain from the perspective of developing effective solutions to complex internal optimization issues that could ultimately affect food security. To this end, the Canadian wheat handling system is a complex export oriented supply chain that is currently undergoing extensive changes with respect to quality control. We develop both analytic and simulation models of this supply chain with the ultimate goal of identifying effective wheat quality testing strategies in a complex operational and regulatory environment. While the analytic model is founded on limited assumptions about individual behavior, agent-based simulation allows us to model farmers and handlers as rational and learning individuals who make decisions based on their own experiences as well as the experiences of others around them. We then make explicit comparisons between solutions and policies generated using the simulation approach against those generated by the analytically tractable model of the wheat supply chain. While the two approaches generate somewhat different solutions, in many respects they lead to similar conclusions regarding the overall testing and quality control issue in wheat handling.

1. Introduction

Food safety has become an important focal point for both consumers and producers. Growing public anxiety about food safety has occurred mostly in response to major contamination issues in recent years. Recent examples include GM wheat contamination in the US, the 2013 meat adulteration scandal in Europe, the massive recall of Alberta beef products in 2012, the contamination of Canadian flax exports to Europe in 2009, and the highly publicized milk powder scandal in China in 2008. To this end, various policy responses and strategic industry initiatives have occurred in many countries (Hobbs et al., 2002). Competitiveness in international food production is becoming increasingly dependent on the safety and quality of food products, while effectively managing overall costs. This means industry participants need to work out effective management strategies and policies to maintain the integrity of their food supply chain.

In this paper, the issue of food supply chain integrity in this new marketing environment will be examined through consideration of an example from the Canadian grain industry. Policy changes regarding the control of grain quality and integrity are underway in the Canadian grain handling system, and these changes will generate novel risks that could potentially jeopardize grain handling integrity. Thus, there would appear to be a need for research designed to identify and validate novel reactive strategies designed to maintain sustainable and competitive grain supply chains.

Historically, Canada has had an enviable reputation for supplying wheat that uniformly and consistently meets international sales specifications. The key component of the quality control system for wheat in Canada has been the use of a simple identification system known as Kernel Visual Distinguishability (KVD) for wheat segregation. Under KVD requirements, each of the major classes of wheat grown in Canada was assigned a combination of seed-coat color and physical kernel configuration that renders them visually distinguishable from other classes, while the varieties within each class are visually similar. In simple terms, KVD allows a trained grader to distinguish the class of a registered variety of wheat solely by visual inspection.

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Despite its apparent advantages, there are significant costs also associated with the KVD system. Under KVD, if a new variety with superior characteristics does not meet the visual appearance standard, it cannot be registered, grown or sold by farmers. Such a KVD requirement puts a significant constraint on wheat breeders in developing new wheat varieties, and hindered their ability to quickly improve agronomic and quality characteristics (Canadian Grain Commission (CGC), 2005). In response to this impediment to innovation, the Canadian government announced that the KVD requirement for variety registration would be eliminated from all eight classes of wheat as of August 1, 2008. In its place, a declaration system was proposed for wheat segregation. The declaration system requires farmers to simply sign a declaration when they deliver wheat attesting to the eligibility of the wheat variety they are delivering into the handling system.

Movement away from KVD as a segregation tool has fundamentally altered the Canadian grain system and could have a significant effect on the Canadian wheat industry. Under the former KVD system, elevator operators could be reasonably confident that they could accurately identify the class of wheat delivered by a farmer to their facility merely by looking at samples from a truck or railcar. With a declaration system, varieties for new classes of wheat or new varieties in existing classes are likely to be similar in physical appearance to other already existing wheat varieties but could differ significantly in quality, e.g. the newly developed CDC Raptor variety designated as CWGP (feed class) looks fairly similar to the Carberry variety in CWRS (milling class). It is this possibility that provides an opportunity for misrepresentation of the variety by an individual farmer. If a variety is misrepresented as another physically similar to it, wheat handlers would not necessarily be able to distinguish the varieties from one another without actually performing testing on a sample. In turn, undetected mixing or contamination will reduce the performance of the wheat for the downstream users.

Alternatively, while there exists technology allowing identification of visually indistinguishable wheat varieties with sufficient precision, unfortunately at present, this technology requires a laboratory setting, so it is relatively slow to perform as well as more costly compared to the former KVD system (CGC, 2009). Under a declaration system, performing this kind of testing for every truckload of grain delivered will necessarily involve high costs. Given testing and segregation costs as well as risks of error, there is a fundamental tradeoff confronting handlers.

Officers and experts at the CGC and Canadian Wheat Board (CWB) are aware that commingling among visually indistinguishable varieties can unexpectedly occur any time and that future quality threats could be sudden and serious (Vanneste, 2012; Steinke, 2011). These individuals have also indicated that novel wheat handling strategies will be needed to maintain wheat uniformity and consistency while keeping monitoring costs down. In light of this, there are important operational choices for handlers concerning wheat testing within the current supply chain, such as the choice of testing location, and how intensively to perform such a test. Knowing this, the distribution of testing on wheat deliveries as well as maintaining responsiveness to information dissemination and feedback among farmers will likely become a strategic emphasis for wheat handlers. At present, the consequences of these changes are poorly understood within the Canadian handling system.

There are some prior studies examining the costs of wheat handling under different handling strategies, each using different modeling methods (Furtan et al., 2003; Wilson and Dahl, 2002, 2006). However, each study abstracts away from the inherent information feedback within the wheat supply chain, and thus they deviate from representative experimental conditions that ought to be used for evaluating the costs and risks of wheat handling under the new declaration system. With all changes in the grain system, we will need to identify a set of supply chain management solutions.

The primary objective of this study will be to identify a set of varietal testing strategies that help minimize the handling cost of the wheat supply chain under the new declaration system. In our assessment, the analysis of these strategies requires a combination of analytic and computational tools (Hommes, 2006). We start by establishing an analytic model to incorporate economic incentives inherent in the supply chain system, so as to identify testing strategies that optimize handling costs. Then we extend the static analytic framework in a dynamic sense through an agent-based simulation of the issue. Examining both the static and dynamic aspects of problems can help better identify strategic issues facing the system, as well as help us understand the costs associated with these strategic alternatives.

2. A stylized supply chain system and behavioral assumptions

First, to develop appropriate analytic and agent-based models, the wheat handling procedures involved in this study and assumptions concerning agents' behaviors must be carefully defined.

2.1. Modeling a basic grain handling supply chain

Essentially, the grain handling system modeled here starts with the farmer and ends with the terminal grain elevator. At the beginning, farmers load and haul truckloads of wheat to a primary elevator. When wheat is delivered to the primary elevator, several actions on the part of the handler or blender can be taken. These are (1) handlers load wheat from farm trucks; (2) handlers may test the truck samples; (3) any delivered wheat is stored in the elevator; (4) elevator samples may be tested before loading onto a rail car; (5) wheat is loaded on railcars for shipment to the terminal or port elevator; (6) the wheat in the rail cars may also be sampled, and finally (7) rail cars can be tested after leaving the elevator, but before loading at the port terminal elevator. Given this, any wheat segregation issues arising under the declaration system that might occur beyond the terminal elevator are outside the scope of this analysis. Based on logistics considerations and the prior research on this topic (Furtan et al., 2003; Wilson and Dahl, 2002, 2006), we assume that there are three possible test points which are indicated in actions (2), (4) and (7) respectively and represented as test points 1, 2 and 3 (Fig. 1). In addition, there are two points where a traceability mechanism can best serve to identify the sources of contamination: (1) contamination detected at test point 2 (traceability 1); (2) contaminations are detected at test point 3 (traceability 2) (Fig. 1). The economic argument for adopting traceability mechanism is that it allows the traceback of affect products in the event of a contamination problem so as to minimize social costs and facilitate the allocation of liability (Hobbs, 2004).

2.2. Behavioral assumptions

We rely upon a set of simplifying assumptions about appropriate behavioral rules to render the study tractable. By putting some sensible simplifications on the problems, we were able to create a set of relatively easily analyzed, yet interesting, models of social agents and their behavior, so as to illustrate a style of modeling in this area and its potential for providing new sights. In this case, these assumptions are

1. A farmer's wheat deliveries are consistent throughout a year, and they are either eligible CWRS or non-CWRS (CWRS is the