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A dynamic systems analysis of factors affecting success of identity-preserved products: the case of high-oleic soybeans

RESEARCH ARTICLE

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Abstract

The factors contributing to success of identity-preserved (IP) products are understood conceptually, but are rarely quantified. A combination of system dynamics modeling and group modeling building with value chain stakeholders provides a generalizable approach to quantify the relative importance of individual factors and identify information needed to assess market potential. The limited growth of IP high-oleic soybean oil (HOSO) provides a case example for application of these methods. The specific assumptions and results for HOSO will differ from other IP products, but some outcomes appear generalizable. First, the values of key drivers need to be documented over time, including the relative cost of the IP and the proportion of potential end users that are aware of the potential benefits. Because sustained cost advantages are a key driver of end-user switching behavior for HOSO, understanding the patterns for relative costs over time would be important to develop realistic estimates of sales growth. Similarly, our analyses suggest that assessment of end-user awareness is important, which may require use of alternative communication channels and monitoring efforts by key decision makers throughout the value chain, including product formulators and procurement staff.

Keywords: group model building, system dynamics modeling, identity preserved, high-oleic soybean
JEL code: Q33, Q16

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1. Introduction

Identity-preserved (IP)[1] oilseeds and grains have been around for more than two decades, with some success (e.g. canola in Canada; Smyth and Philips, 2001), but IP products have not always fulfilled their potential (Goldsmith and Bender, 2003; Tillie and Cerezo, 2015). Supply chain actors agree on many of the factors influencing interest in IP products. The potential benefits of IP vary by product and generally include price premiums for farmers and processors (Bard *et al.*, 2003), reduced costs or improved functionality for end users, and improved health outcomes for consumers (Baker and Smyth, 2012). Many researchers noted challenges to implementation of IP systems early on, especially the potential for higher costs (Brookes, 2002; Buckwell *et al.*, 2002; Kalaitzandonakes *et al.*, 2001; Maltsbarger and Kalaitzandonakes, 2000; Smyth and Phillips, 2001; Tillie and Cerezo, 2015) and the need for tracking processes (systems) to ensure identity preservation, mitigate risks and engender trust (Baker and Smyth, 2012; Barber *et al.* 2008; Hobbs *et al.*, 2001; Smyth and Phillips, 2001).

Extant literature also describes conditions likely to influence the success of IP products (although 'success' is not always clearly defined). These conditions include the need for a documentable value proposition for each of the actors in the supply chain: farmers, elevators, processors, and end users (Barber *et al.*, 2008; Bard *et al.*, 2003; Giannakas and Yiannaka, 2004; Kalaitzandonakes, 1998). Often, the value proposition is defined as the need for benefits of IP products to outweigh any additional costs for all value chain actors (Barber *et al.* 2008; Bender 2003). Retailers and consumers must accept IP products (Buckwell *et al.*, 2002; Giannakas and Yiannaka, 2004; Tillie and Cerezo, 2015), which may require the need to communicate benefits to these decision makers, especially if there is a price premium.

Although broad agreement exists about conditions that facilitate success of IP products in general, a number of substantive limitations arise when assessing the likelihood of success of a specific IP product. For example, much of the discussion is qualitative: we have limited systematic empirical evidence about what constitutes a 'sufficient' value proposition to induce participation by different supply chain actors or sufficient 'acceptance' by consumers or retailers. Goldsmith and Bender (2003) noted the limited quantitative evidence about the value proposition because most studies evaluate only static cost increases for IP products. The distribution of any increased costs and benefits also affects success of IP products. This distribution is influenced by multiple factors (e.g. bargaining position of supply chain actors; Buckwell *et al.,* 2002; Kalaitzandonakes, 1998) but has not been systematically explored. Other factors that are likely to be important such as supply chain coordination and intertemporal evolution of IP costs and benefits are only occasionally mentioned (e.g. Buckwell *et al.*, 2002; Goldsmith and Bender, 2003) and rarely evaluated empirically. Finally, although some studies (e.g. Cucugna and Goldsmith, 2018) describe the importance of interactions among different actors, few analyses integrate information and incentives throughout the entire IP product supply chain.

However, an analytical approach can be used to improve the quantitative assessment of the factors affecting the likelihood of success for a specific IP product, by combining techniques from system dynamics (SD) modeling (Sterman, 2000) with stakeholder engagement through a group model building process (GMB) (Rouwette and Vennix, 2009; Vennix, 1996). SD modeling allows explicit consideration of interactions among supply chain actors, the dynamics of costs and potential learning effects, and the impacts of time delays in the IP supply chain and their impacts on coordination. Engagement with stakeholders can provide insights about factors important success for a specific IP product, and more generally increase motivation for coordinated actions (Franco and Montibeller, 2010). More specifically, the two main objectives are:

1. To illustrate how a participatory GMB process can be used as a tool for assessment of IP product potential.
2. To assess the usefulness of the quantitative model developed via GMB to identify factors necessary for IP success, and to guide collection of relevant information to assess the probability of meeting industry growth expectations.

[1] Following Baker and Smyth (2012), we define IP as a system initiated by private firms in the grain and oilseed industry to secure premiums from domestic or international markets for a product trait or feature.

High-oleic soybeans (HOSs) are a relevant test case, having been identified as an IP product with high potential more than 20 years ago (Darroch *et al.*, 2002; Kalaitzandonakes, 1998;). HOS oil (HOSO) has a high oxidative stability (Napolitano *et al.*, 2018) compared to commodity grade soybean oil, which is valuable in frying applications. In 2018, the US Food and Drug Administration (FDA) concluded that 'consuming oleic acid in edible oils, such as olive oil, sunflower oil, or canola oil, may reduce the risk of coronary heart disease' (FDA, 2018), thus providing potential health benefits to consumers. This has generated considerable food industry interest in high-oleic oils more generally, including soybeans, canola and sunflower. Early projections indicated that HOS could contribute as much as 20% of US soybean production by 2005 (Bender, 2003). More generally, projections for HOSO demand have suggested rapid growth for nearly two decades, yet as of 2020 the market share of HOSO remains low (<1% of total soybean acres; Clayton, 2020). HOSO therefore provides an excellent test case to explore the factors that promote or hinder growth of IP products. We first describe the methods used for development of the SD model using GMB, then illustrate the application this simulation model to assess conditions (and interactions) likely to contribute to demand growth for HOSO. Although we report specific results for alternative scenarios to illustrate the importance of different factors, our objective in this paper is less to describe the specific steps or conditions required for the success of HOSO. This is in part because (as will be seen) the range of in outcomes can be wide due to uncertainty in data inputs and some elements of model structure.

2. Methods

We applied a quantitative SD model that was developed using a GMB process with key supply chain stakeholders to explore slower-than-expected growth in IP HOSO. GMB is a participatory approach for involving stakeholders in the process of developing, analyzing and using SD models (Hovmand *et al.*, 2012). GMB combines the use of system diagrams (Videira *et al.*, 2014) and computer simulation models (Andersen *et al.*, 2007) in group settings. In addition to developing a running simulation model, a GMB process provides three major benefits (Blackstock *et al.*, 2007): enhanced individual and social learning; mental model refinement and improved system understanding; commitment and trust (Figure 1). The process emphasizes stakeholder viewpoints about the linkages among supply chain organizations, and how these promote or limit the uptake of HOS varieties and use of HOSO. The GMB process consisted of two in-person workshops with 15 stakeholders to determine the linkages and decision rules that affect the potential for HOSO. Participants included soybean farmers (with and without experience in growing HOS varieties), seed companies that have produced seed for HOS varieties, and major oilseed processors that have organized HOS production programs. Although the workshops did not include representatives of food

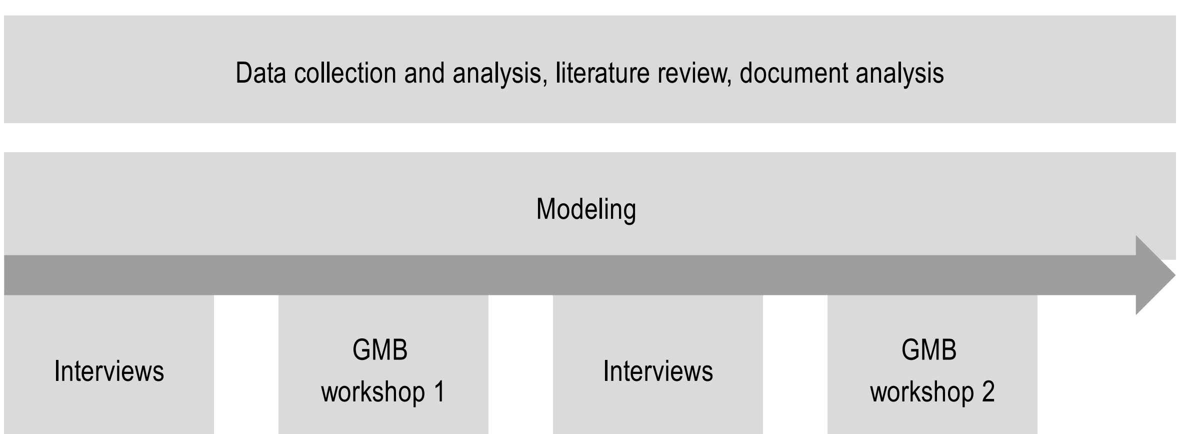

Figure 1. Overview of the group modeling building process.

processing companies or restaurant chains (i.e. buyers and end users of HOSO), selected companies were subsequently interviewed separately to ensure their perspective was represented.

The workshops were structured along 'scripts' for group model building (Table 1). Scripts are predefined sets of activities that have proven to be effective for facilitating group model building workshops based on the SD methodology (Hovmand *et al.*, 2012). The first workshop began with the facilitators presenting a 'reference mode' behavior over time that defined the issue to be addressed.[2] This 'reference mode' represented the actual slower-than-expected growth of HOSO adoption by end users (Figure 2) that contrasted with prior projections of rapid growth. Consistent with general GMB practice (Vennix, 1996), the purpose of the workshop was to engage stakeholder perspectives about why growth in HOSO end use (and the related goal of increased HOS acres planted by farmers) was much less rapid than predicted, and to develop an initial conceptual model of the systems linkages that could explain this phenomenon. The first workshop took place over two days in June 2019, and documented stakeholder perspectives on what motivates farmers, seed companies, oilseed processors and end users to switch from conventional to HOS or from other high oleic oils to high oleic soybean oil, and what constraints had affected growth. The initial conceptual model was developed, critiqued and modified with stakeholders during that workshop, and served as the basis for

Table 1. Activities and outcomes of the group modeling building workshops.

Workshop	Purpose	Activities and scripts	Outcomes
1	Development of an initial, conceptual model.	Presenting the reference mode.	Consensus over the reference mode of behavior.
		Graphs over time: engage participants in a group model building session in framing the problem, initiating mapping, eliciting variables, and gathering input in deciding the reference modes for the study.	Interim output: interesting, self-sustaining group discussion about variable clusters. Deliverable: candidate variables for the system dynamics model.
		Initiating and elaborating a 'stock and flow' model: get an initial idea of central concepts and their relationships at the beginning of a project.	Interim output/product: increased consensus on dynamic hypothesis. Deliverable: a possible structural explanation for observed behavior that can be used as a dynamic hypothesis on the basis of which formal modeling starts.
2	Model validation and refinement, scenario definition.	Presentation of proposed model structure based on workshop 1.	Stakeholders concluded that the model structure appropriately represented interactions discussed in the first workshop.
		Presentation of model initial quantitative results of scenarios.	Stakeholders discussed results of the scenarios and the underlying reasons for the observed behavior.
		Interactive modeling of additional scenarios.	Stakeholders suggested additional scenarios that were analyzed in real time.
		Discussion of model adequacy.	Stakeholders indicated the model was appropriately structured for its stated purpose.

[2] Although some GMB processes begin with a discussion to define the problem, in our case the problem was defined by the sponsoring organization and agreed to as appropriate by the GMB workshop participants.

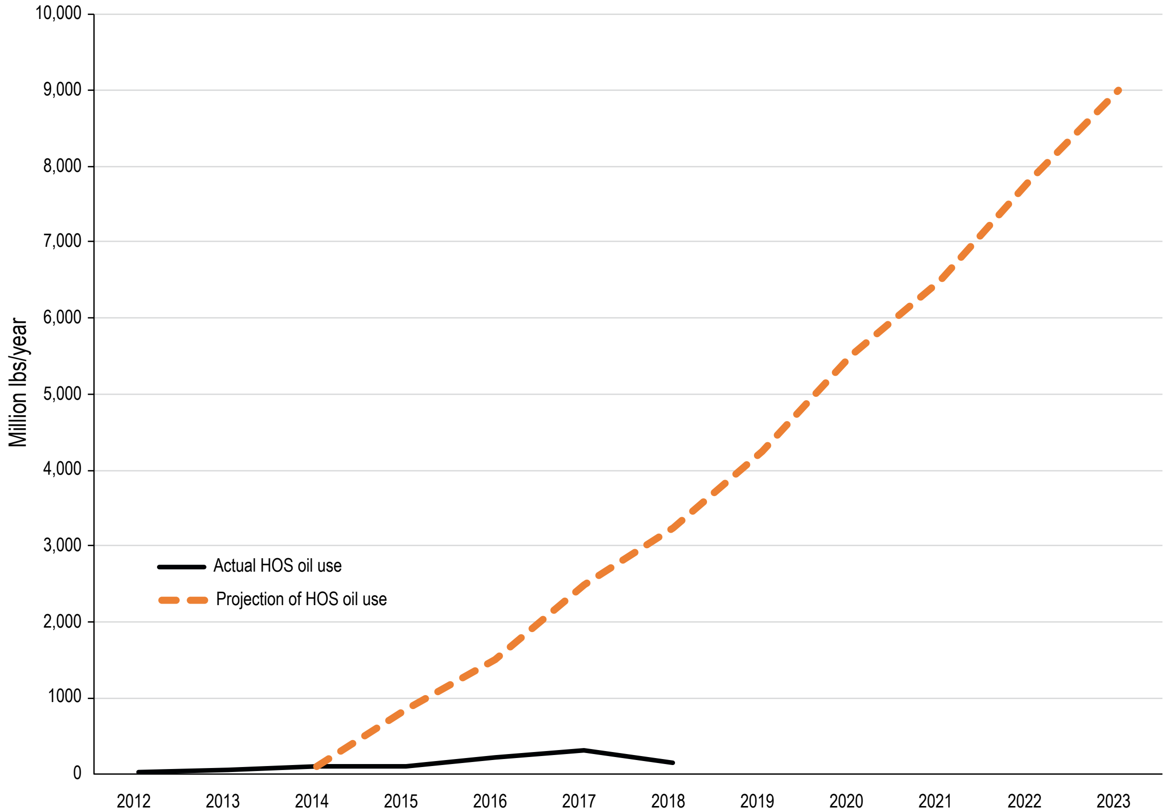

Figure 2. Reference mode diagram indicating difference between actual and projected high-oleic soybean oil (HOSO) use.

subsequent development of a quantitative model that incorporated core concepts from the conceptual model. A subset of those stakeholders reviewed the quantitative model and provided suggested modifications at a second in-person workshop in October 2019. Stakeholder comments and input from within the sponsoring organization informed the final quantitative model structure. Input from other key informants also guided specification of scenarios to evaluate the impacts of the factors stakeholders believed to be important for future HOS sales growth.

The quantitative SD model developed from the stakeholder conceptual model is designed to capture key linkages among HOS value chain stakeholder decisions and outcomes (Supplementary Figure S1B) and to represent the potential for coordination issues and other factors to impede growth of HOSO sales. Decisions by end users to purchase HOSO affect the decisions of processors to offer ‘programs’ of premiums to farmers to plant desired volumes of HOS varieties. Although end users do coordinate to some extent with processors, decisions about programs and premiums are sometimes made prior to contracted HOSO demand commitments. Seed companies need to make HOS seed production decisions well in advance of HOS planting decisions and those decisions are not typically well coordinated with processor production targets. Similar to previous studies of agricultural value chains (e.g. Berends *et al.*, 2021), the model emphasizes the importance of time delays and decision rules by stakeholders that can limit supply chain coordination and create disincentives to act, given that future decisions by others are uncertain. These coordination challenges constituted an initial hypothesis about causes for the observed limited growth in both HOS acres planted and HOSO usage by end users. However, the modeled linkages facilitate assessment of the effect of other factors affecting HOS growth, such as price premiums, costs, and end-user awareness and their interaction with value chain coordination. Stakeholder discussions and the resulting model also focus on the need for a value proposition for each of four stakeholder groups: farmers, seed companies, oilseed processors, and vegetable oil end users (often, restaurants or food processors).

The model is also designed to reproduce the 2018 observed values (310,000 acres planted and 155 million lbs HOS used) in 'dynamic equilibrium' with unchanged market or promotion conditions, then examines the impacts of changes to incentives for HOS production, processing and use. The model represents 240 months (10 years; monthly unit of observation) starting with observed data from 2018. It focuses only on the supply chain HOS varieties and does not include conventional soybeans. Four core linked modules include HO soybean production, seed supply, processing, and end use. A more detailed description of each module is provided in the supporting information.

3. Results

3.1 Stakeholder assessment of factors and modeling scenarios

The principal objective of the GMB process with stakeholders is to leverage their knowledge and expertise to examine quantitatively the factors that have constrained growth of HOSO below expectations and to identify potential actions to increase that growth. Based on the GMB discussions, stakeholders perceived that the value proposition, awareness of that value proposition by all actors, and supply chain coordination all have the potential to enable growth in HOSO demand. These informed the development of the scenarios analyzed, and farmer stakeholders provided input on scenario development through interactive analyses led by the modeling team.

Modeling analyzes the impacts of value proposition components to supply chain participants, as well as communication describing the cost and functionality benefits to end users. The impact of time delays and coordination issues on the potential for growth in HOSO are included, recognizing that in the near term it would be difficult to modify the nature of time delays and related coordination processes. As noted above, an initial 'Reference mode' scenario was consistent with limited growth in HOSO sales volumes over time (Table 2). This scenario was based on observed values in 2018 as well as information provided by stakeholders in the GMB workshops.

A second scenario evaluates the potential to replicate the projected growth in HOSO sales volume and HOS planted acres using annualized values of both variables from 2018 to 2027. The United Soybean Board (USB) receives annualized projections from various partners and adjusts these based on knowledge of potential agreements between end users and processors for future HOSO volumes.

Four additional scenarios evaluate the impacts of alternative assumptions on the degree to which the projected HOSO sales volumes would be achieved (Table 2). These scenarios modify the values changes in: (a) relative costs of HOSO; (b) level of communication efforts with end users; (c) required processor margins for HOSO; (d) premiums to farmers to grow HOS varieties; and (e) the price of conventional soybeans (specific assumptions for the six scenarios are shown in Table 2). The direction of impacts of most of these changes is known: reductions in the value of HOSO sales are expected from smaller cost advantages for HOSO, less intensive end-user communication efforts, higher processing margins, higher farmer premiums and higher conventional soybean prices. However, the extent to which each of these effects is empirically important and the potential for beneficial changes in one factor to offset others is not well known and drove development of the quantitative model.

Other scenarios assess the impacts of two key areas for which there was less consensus among participants in the GMB process: farmer response to HOS price premiums and economies of scale in processing and logistics for HOSO. There was considerable discussion in the GMB process about how the marketing provisions (i.e. 'buyer's call') and basis risk under HOS planting programs offered by processors were considered less desirable by soybean farmers and were a substantive impediment to increasing HOS acres planted by farmers.

Table 2. Scenarios analyzed and summary results.[1]

	Units	Reference mode	Replicate projections	Smaller cost advantage more communication	Higher processor margin	Higher conventional soybean price	Higher farm premium for HOS
Scenario assumptions							
Premium for HOS	$/bushel	0.50	0.50	0.50	0.50	0.50	1.00
Conventional soybean price	$/bushel	9.00	9.00	9.00	9.00	10.00	9.00
Processor markup required	% over cost	5.0%	5.0%	5.0%	10.0%	5.0%	5.0%
Cost advantage of HOSO	% difference	0%	10%	5%	10%	10%	10%
Communication efforts	Proportion	0.0	0.5	1.0	0.5	1.0	0.5
Outcomes							
Ending volume of HOS sales	mil lbs/year	155.0	1,359.2	1,137.0	891.6	774.6	1,167.8
Ending acres of HOS planted	acres/yr (×1000)	209.1	1,833.3	1,534.0	1,202.8	1000.0	1,575.5
Ending market share for HOSO	% market	5.6%	56.8%	41.4%	32.4%	28.2%	42.5%
Cumulative change in farmer margin	$ million	68.0	340.3	288.4	240.6	215.3	583.2
Change from reference mode							
Ending volume of HOS sales	mil lbs/year		1,204.2	982.0	736.6	619.6	1,012.8
Ending acres of HOS planted	acres/yr (×1000)		1,624.2	1,324.9	993.7	790.9	1,366.4
Ending market share for HOSO	% market		51.2%	35.8%	26.8%	22.6%	36.9%
Cumulative change in farmer margin	$ million		272.3	220.4	172.6	147.3	515.2
Change from replicate projections							
Ending volume of HOS sales	mil lbs/year			-222.2	-467.6	-584.6	-191.4
Ending acres of HOS planted	acres/yr (×1000)			-299.3	-630.5	-833.3	-257.8
Ending market share for HOSO	% market			-15.4%	-24.4%	-28.6%	-14.3%
Cumulative change in farmer margin	$ million			-51.9	-99.7	-125.0	242.9

[1] HOS(O) = high-oleic soybean (oil).

In addition, stakeholders expressed concerns about future yield lag as a result of lack of trait stacking[3] with the latest technology (e.g. herbicide resistance), and the impact of bundled input pricing (i.e. not just HOS seed but other inputs purchased as an input bundle from seed companies) on farmer incentives to plant HOS. Initially, these were incorporated separately into the model structure, but they proved difficult to quantify so only farmer willingness to plant based on price premiums was included (with the cost impacts implied by the nature of the response function). To assess the importance of assumptions about farmer response to price premiums for planting HOS, an alternative function was developed in which farmers were considerably less responsive (willing to plant) based on the same price premium (Figure 3).

Many previous analyses of IP (or niche) products have noted that the unit costs of processing and logistics can be considerably higher given the small volumes (Maltsbarger and Kalaitzandonakes, 2000; Smyth and Phillips, 2001). A number of GMB participants noted that changeover of processing and smaller-volume shipments increases costs. However, they did not provide quantitative estimates, and not all agreed it would be quantitatively important. Thus, our initial scenarios assume no economies of scale, that is, that small volumes of HOSO could be processed and transported at the same unit costs as larger volumes. To test the importance of this assumption, the cost functions for processing and logistics were adjusted to 2.5 times the minimum cost when volumes were very small. Additional details are provided in the Supplementary Materials.

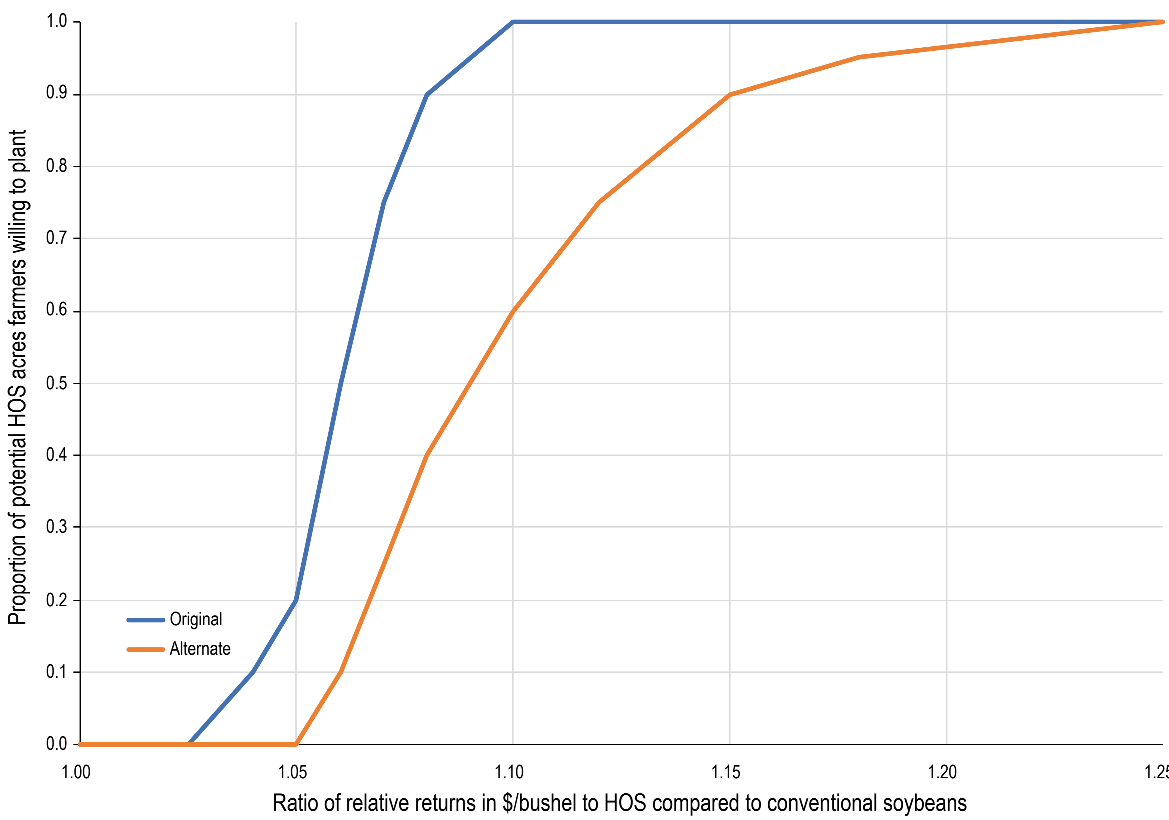

Figure 3. Comparison of original and alternate farmer interest functions for production of high-oleic soybean (HOS) acres.

[3] A combination of multiple genetic improvements, or traits, in a particular variety of a crop.

3.2 Modeling results

The main objective is to assess the usefulness of the quantitative model developed via GMB to identify factors necessary for IP success. This involves considering two related questions. First, are there conditions under which the pattern of projected growth in HOSO sales can be matched, and if so, what are those conditions? Second, what are the impacts of changes on the growth of HOSO sales?

To address the first question, we examine conditions that would make the projected increase in HOSO (Figure 2) possible by evaluating the impact of changes in the relative prices of HOSO (based on input from stakeholders about current and expected market conditions) and ramped up communication efforts with end users beginning in 2020. Under the 'Replicate projections' scenario, these changes would result in 1,500 million lbs by 2025 (Figure 4). The model predicts that under these conditions, the value proposition for HOS is sufficiently attractive to farmers, oilseed processors and end users to support sustained growth in this IP product. Moreover, supply chain coordination challenges due to delays in production of HOS seed would not markedly reduce the growth potential. There is only one planting season (2022) where HOS availability would be less than desired, with a shortfall of about 90,000 acres (14%) in seed availability. The growth in HOSO sales and increased plantings would generate nearly $370 million more in gross revenues for farmers planting HOS during 2020 to 2027 compared to HOSO sales under the reference mode (Table 2). However, the annualized rate of sales decreases from the projected values after month 105, due to limited availability of HOS oil. This shortfall occurs because HOS planting decisions are assumed not to account for the adjustments in desired inventory coverage as demand increases.

Based on the previous scenarios, reaching the projected values of HOSO growth requires sustained cost advantages. When the cost advantage is smaller but communication with end users is increased (scenario 'Smaller cost advantage more communication', Table 2), annualized HOSO sales at the end of the simulation total about $1,140 million, or about 75% of the projected values. If the cost advantage is eliminated in the

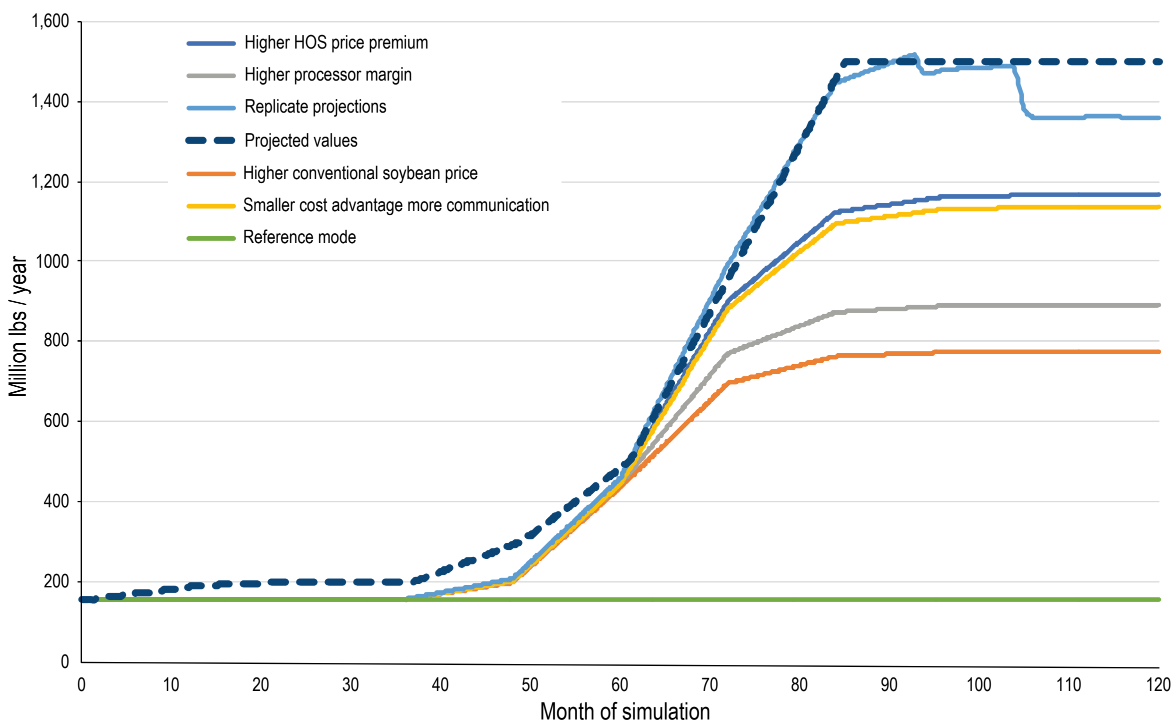

Figure 4. Annualized high-oleic soybean oil (HOSO) sales volumes under different modeled scenarios.

future, the model predicts that some market share would be lost back to other HO alternatives. The extent to which this would occur is uncertain, but simulations with a return to the original values after three years (scenario details not shown in Table 2) suggest that annualized HOSO sales could decrease after 2025 and ending values in 2027 would be only about 50% of the projected values. Thus, a consistent cost advantage for HOSO seems necessary for sustained improvement in market share.

However, other factors can also affect the growth of HOSO sales. In the GMB sessions, processors consistently stressed that they would commit processing capacity to HOSO only if the likely volume of purchases by end users at sales prices allowed them to meet margin goals relative to other uses of that capacity. That is, if alternative uses of the processing capacity provided greater margins, there would be a disincentive to process HOSO even if there was demand from end users. The impact on HOSO sales of increased margin goals for oilseed processors with a required margin of 10%, rather than the 5% assumed in the previous scenarios, was assessed and annualized HOSO sales in 2027 are reduced compared to projected values by about 40% ($608 million). This reduction in sales occurs because the higher margin goal would increase the cost to end users, reducing their demand for HOSO. The future margin requirement for processors is difficult to predict, because it depends on developments in multiple commodity markets, but is an important determinant of future HOSO sales volumes.

Finally, we examine the impacts of farmer incentives to produce HOS varieties through both modifications to the price premium and to the conventional soybean price. Premiums for HOS are intended to compensate farmers for additional constraints in marketing and to account for any current or future yield difference with conventional soybean production, especially given limited trait stacking in HOS. Increases in the former would be associated with increased interest on the part of farmers (but also marginally increased costs for end users) and increases in the latter with decreased producer interest in planting HOS given additional challenges at the farm level of producing and marketing HOS. In the scenario 'Higher HOS farm premium', a premium value of $1.00/bushel is assumed, which increases costs to end users and reduces the ending annualized HOSO sales by about 22% ($332 million) compared to projections. In essence, a $1.00/bushel premium would create incentives for farmers to want to plant many more acres of HOS than would be required to meet the demand of end users. Despite the reduced annualized volume of HOSO sales and fewer acres planted compared to a scenario with a lower premium value, the higher premium would increase cumulative farmer revenue gains by $248 million compared to the 'Replicate projections' scenario.

Soybean price were assumed to rise from the average value of $9.00/bushel to $10.00/bushel during 2020 to 2027, which has substantive impact on farmer interest in planting HOS varieties, reducing the acres that farmers would be willing to plant by nearly 50%.[4] However, the larger impact is on reduced demand. With higher conventional soybean prices and HOSO priced at the conventional price plus the premium, the cost to end users is increased and the relative cost advantage of HOSO is markedly reduced for the same assumed increase ($0.10/lb) in the cost of HOSO alternatives. Annualized HOSO sales under the 'Higher conventional soybean price' scenario are simulated to be 50% lower (about $725 million lower) than the projected values.[5]

The key takeaway is that the main factor determining HOS growth is relative cost compared to alternatives to supply the HO market, albeit also affected by end user awareness through communication efforts. Relative cost is affected by changes in cost of alternatives, premiums paid to HOS farmers, processor margin goals and conventional soybean prices. However, changes in relative costs can be difficult to assess given the proprietary nature of some data and its interaction with functionality (i.e. unit cost of product versus cost-in-use or value added). It is notable but not surprising that previous studies of IP markets have focused attention on factors other than cost, and that projections for growth have not specifically linked future sales

[4] This reduction is driven by the reduction in the additional (proportional) value of the price premium for HOS (5.3% of the conventional price for $9.00/bushel soybeans, but 4.7% of the conventional price for $10/bushel soybeans) based on a response function developed with farmer GMB workshop participants.

[5] This scenario does not consider potential changes in the cost of alternatives to HOSO that could occur simultaneously.

volumes to sustained cost advantages. Even using our simplified coordination mechanisms among supply chain participants, delays in the signals regarding growing demand for HOSO did not constitute a substantive constraint for growth of HOSO. Nonetheless, additional awareness of these delays is important to ensure ongoing effective coordination in IP systems like HOS.

3.3 The impact of the producer response function to high-oleic soybean premiums

An alternative assumption about the response function of farmers to HOS premiums results in markedly reduced use of HOSO (Figure 5 and Table 3), primarily due to much-reduced willingness of farmers to grow the HOS required. At a price premium of $0.50/bushel, the new function indicates a willingness to grow only about 280,000 acres of HOS, compared with 1.8 million acres under the alternative function. This markedly constrains growth in HOS given the limited product availability relative to desired quantities. Although the desired market share is still above 50%, sales increase only slowly (in part drawing upon existing inventory coverage) and then stagnate at only about 200 million lbs per year – above the 'reference mode' value of 155 million lbs per year, but nowhere near the expected potential of 1,500 million lbs per year. However, with a premium of $0.70/bushel, the maximum possible HOSO sales are achieved, about 1,400 million lbs per year – much closer to expected potential.[6] Thus, clear understanding of the relationship between premiums and perceived disincentives for planting HOS (and IP products more generally) is important to ensuring that premium structures align with potential industry growth.

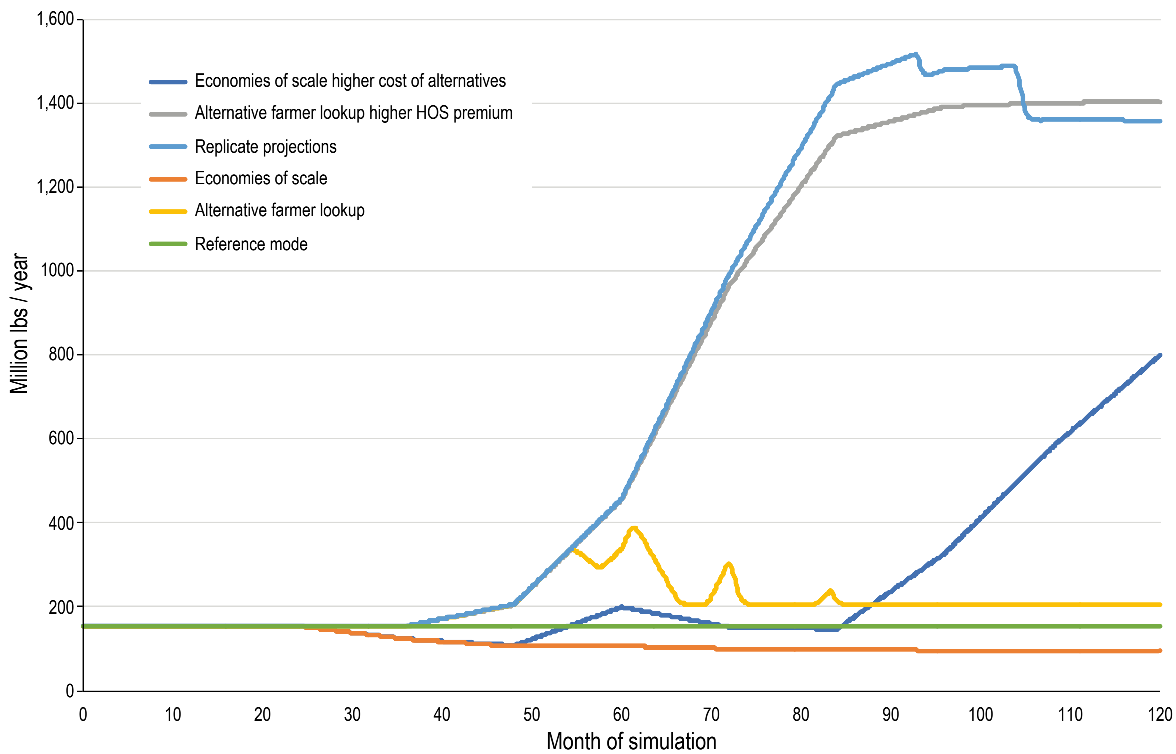

Figure 5. Annualized high-oleic soybean oil (HOSO) sales volumes under different modeled scenarios.

[6] A premium greater than $0.70/bushel has a decreasing effect on demand due to lower cost competitiveness.

Table 3. Additional scenarios analyzed and summary results.[1]

Scenario	**Units**	**Reference mode**	**Replicate projections**	**Alternative farmer interest**	**Alternative farmer interest with higher premium**	**Economies of scale**	**Economies of scale higher cost of alternatives**
Scenario assumptions							
Premium for HOS	$/bushel	0.50	0.50	0.50	0.70	0.50	0.50
Conventional soybean price	$/bushel	9.00	9.00	9.00	9.00	9.00	9.00
Processor markup required	% over cost	5.0%	5.0%	5.0%	5%	5.0%	5.0%
Cost advantage of HOSO	% difference	0%	10%	10%	10%	10%	20%
Communication efforts	proportion	0.0	0.5	0.5	0.5	0.5	0.5
Volume HOSO processed for full economies	mil lbs/mo	0.10	0.10	0.10	0.10	20.00	20.00
Outcomes							
Ending volume of HOS sales	mil lbs/year	155.0	1,358.8	205.8	1,403.7	97.0	801.2
Ending acres of HOS planted	acres/yr (×1000)	209.1	1,833.3	277.8	1,833.3	130.8	1,833.3
Desired ending market share for HOSO	% market	5.6%	56.8%	51.1%	56.8%	3.5%	73.4%
Cumulative change in farmer margin	$ million	68.0	340.3	91.1	469.0	49.6	125.9
Change from reference mode							
Ending volume of HOS sales	mil lbs/year		1,203.8	50.8	1,248.7	-58.0	646.2
Ending acres of HOS planted	acres/yr (×1000)		1,624.2	68.7	1,624.2	-78.3	1,624.2
Desired ending market share for HOSO	% market		51.2%	45.5%	51.2%	-2.1%	67.8%
Cumulative change in farmer margin	$ million		272.3	23.1	401.0	-18.4	57.9
Change from replicate projections							
Ending volume of HOS sales	mil lbs/year			-1,153.0	44.9	-1,261.8	-557.6
Ending acres of HOS planted	acres/yr (×1000)			-1,555.5	0.0	-1,702.5	0.0
Desired ending market share for HOSO	% market			-5.7%	0.0%	-53.3%	16.6%
Cumulative change in farmer margin	$ million			-249.1	128.7	-290.7	-214.3

[1] HOS(O) = high-oleic soybean (oil).

3.4 The impact of economies of scale

Assumptions about the volumes required to achieve economies of scale in HOSO processing and logistics and the nature of nonlinear change in costs are important determinants of HOSO sales. Current annual sales of HOSO of 155 million lbs imply an average volume processed of about 13 million lbs/month. Given the assumed nonlinear characteristics of the processing and logistics costs, if a volume of even 20 million lbs per month is required to achieve the minimum cost, unit costs would be increased by roughly 50% and the assumed cost advantage of HOSO is offset by increased costs. As a result, HOSO demand stagnates (Table 3, Figure 5). An assumed cost advantage of 20% given assumed economies of scale is sufficient to induce growth but it occurs more slowly (Table 3, Figure 5), reaching only a bit more than half of the projected 1,500 million lbs per year by the end of simulation.

4. Conclusions, implications and limitations

The GMB process with stakeholders resulted in a quantitative, model-based exploration and assessment of factors affecting the success of IP HOS. Some of these factors have been focal points for previous but primarily conceptual analysis, such as the value proposition and end user and consumer acceptance. This stakeholder group added other key factors influencing HOS success, including the coordination challenges given time delays between seed production, HOS production, and end-user demand, that IP price premium is best evaluated relative to the evolving price for the non-IP products, and the importance of communication strategies and channels to make IP product buyers more aware of the value proposition.

Our analytical approach shows how to frame and model quantitatively the impact of these different factors on potential growth of IP products. It also clarifies the information needs for assessment of potential for IP sales growth and allows quantitative assessment of alternative assumptions about future market conditions or incentives for supply chain actors. Moreover, this process promoted an improved understanding by the participating supply chain actors of the conditions necessary for sustained growth, including the nature of the value proposition required for their consistent involvement. This unexpected benefit helped to align supply chain actor expectations about future growth potential and temper expectations for rapid growth. These more realistic expectations of HOS sales growth improved the perception of HOS potential because they provided an alternative to a focus on the gap between previous (optimistic) projections and relatively stagnant sales growth through 2020. Our approach also permits different supply chain actors to assess the potential return on investment (ROI) from HOS under alternative assumptions and the likelihood that organizational ROI targets can be met. At a relatively low cost, this approach can add substantive value to the assessment of the challenges and opportunities for IP product development and launch.

The specific assumptions and thus results may differ for other IP products. In that sense, our analyses align with 'exploratory modeling', the use of a series of experiments to explore the implications of varying assumption and hypotheses (Bankes, 1993). Our model suggests a plausible explanation that can guide the identification of new data sources and similar examples, but also provides an improved basis for decision making about potential growth of HOS. However, certain outcomes of our approach appear generalizable to other IP crops. First, it is relevant to document over time values of key drivers, such as relative costs of the IP compared to alternatives and the proportion of end users that are aware of benefits. Because sustained cost advantages (in use) are a key driver of end-user switching behavior, understanding the patterns for relative costs over time would be crucial to generate a realistic pattern of IP sales growth. Similarly, our analyses suggest that assessment of end-user awareness is important, which may require alternative communication channels and monitoring effort among key decision makers (both product formulators and procurement staff).

Our process also emphasizes the important role of coordination among supply chain actors, particularly given that demand for the product (HOSO) is not realized until much later than the decisions necessary to ensure that demand can be met. The time delays between production decision for HOS by seed companies, planting decisions by farmers and realized HOS demand can constitute a considerable challenge to growth.

Our analyses suggest that this dynamic can be overcome as an IP market matures and demand becomes more stable (predictable). That said, under the current configuration of the supply chain, improved coordination can be difficult to achieve given the dynamic nature of the value proposition for key supply chain actors, such as the ROI goal for oilseed processors and the functionality and cost-in-use goals of end users.

4.1 Limitations and future research

Our process emphasizes the need for a clearly defined and quantified value proposition for all supply chain stakeholders and, perhaps more importantly, the need to understand how variation in the value proposition is likely to affect the behavior of supply chain actors. Key information needs that require further research are:

To represent farmer decisions, a quantitative understanding of the impacts of more constrained IP marketing arrangements, risks and future yield impacts of IP varieties, and their impact on the relationship between price premiums and farmer's willingness to plant required acres.

To represent processor decisions, a quantitative understanding of the margin goals and economies of scale in IP processing and logistics.

To represent end users, the combination of functionality and cost goals necessary to capture market share, and a better quantified understanding of the existing levels of awareness and the ability of communication and marketing efforts to modify them.

Our analysis also does not represent factors that could be important for the success of other IP products. First, we focus on food uses for HOSO rather than other potential markets such as industrial use in the paving industry. The value proposition will likely differ even among food users, and additional supply chain actors could further complicate supply chain coordination issues. Secondly, given the large fixed costs of HOS seed variety development and bundled input packages, we assumed that seed production would meet seed company ROI goals and thus do not represent this component explicitly. We do not explicitly represent any functionality differences (as a component of end user cost advantages) or the costs and complexities of farm level management of IP. We also do not include the costs or specific approaches required for efforts to increase awareness by end users. More generally, data on cost advantages of HOSO and functionality and more granular assessment of the benefits to end user or margin goals for processors is difficult to assess, and thus the functions linking cost and demand are approximations. However, this approach allows quantitative analysis of the impacts alternative assumptions and assessment by GMB process participants about the reasonableness (likelihood) of those assumptions being accurate.

Supplementary material

Supplementary material can be found online at https://doi.org/10.22434/IFAMR2021.0132

Figure S1A. Initial systems diagram.
Figure S1B. Systems diagram for the quantitative model.
Figure S2. Core elements of farm-level model structure.
Figure S3. Core elements of the seed production model structure.
Figure S4. Core elements of the processor costing model structure.
Figure S5. Core elements of the processor inventory management model structure.
Figure S6. Core elements of the end user awareness model structure.
Figure S7. Nonlinear relationship between the ratio of revenues net of selected costs for HOS to conventional soybean varieties.
Table S1. Components of the evaluation process for the HOS model.
Table S2. Summary of selected sensitivity analyses.

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Conflict of interest

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