A Model of Diffusion of Genetically Modified Crop Technology in Concentrated Agricultural Processing Markets - The Case of Soybeans

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Abstract

In the paper, a dynamic model of diffusion of genetically modified crop technology is developed and simulated using the U.S. soybean market data. The model accounts for factors specific to agricultural markets, such as oligopsony power and strategic interaction among crop processors, growers' characteristics such as adoption behavior, and identity preservation requirements. Simulation results show how these factors affect the magnitude and distribution of the potential gains from genetically modified crops.

Keywords: biotechnology in agriculture, soybeans, innovation diffusion, oligopsony, genetically modified crop

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Introduction

Application of biotechnology in agriculture is expected to provide significant consumer and producer benefits, the magnitude and distribution of which depend critically on the structure of the markets via which the innovation effects are realized, as well as on the behavior of the market participants. In the paper, a dynamic model of diffusion of a supply-push genetically modified (GM) crop technology is developed and the model's simulation results are presented. For calibration purposes, the structure and database of the U.S. soybean complex are used.[1] The novelty of the model is in explicitly accounting for the possibility of oligopsony power and strategic interaction (otherwise called the 'buyer power') of the companies in the crop processing sector, the reality of which is a growing concern in many agricultural markets in the U.S. The model also incorporates such important determinants of the diffusion process as the crop growers' path dependent adoption behavior and other relevant characteristics, as well as the identity preservation and segregation requirements. As soybean market structure and the nature of GM soybeans are typical for many agricultural markets, our results are applicable to the analysis of diffusion of other GM crops.

The GM (Roundup Ready) soybeans have been designed to be resistant to glyphosate - a powerful herbicide that severely damages traditional (non-GM) soybeans. This improvement classifies GM soybeans as a supply-push, or process, innovation that saves on the growers' production and management costs.

In the last twenty years, the soybean processing industry, to which soybean growers sell most of their output, has become significantly more concentrated than most other U.S. food processing industries (Larson, 1998). At present, the four largest processing firms own about 80 percent of the industry's total capacity. There are also indications of an increasing real value of the soybean processing, or crush, margin as compared to the breakeven level in crushing (Shaub *et al*., 1988; *Soya and Oilseed Bluebook,* 2000). Soybean growers, however, are competitive. These stylized facts are indicative of the potential *oligopsony* market power that processing firms may be able to exercise in the purchase of soybeans.

In order to analyze how market power in processing may impact diffusion of a new technology such as GM soybeans, a vertical market structure is assumed where competitive growers sell soybeans to a concentrated processing sector that handles and processes soybeans

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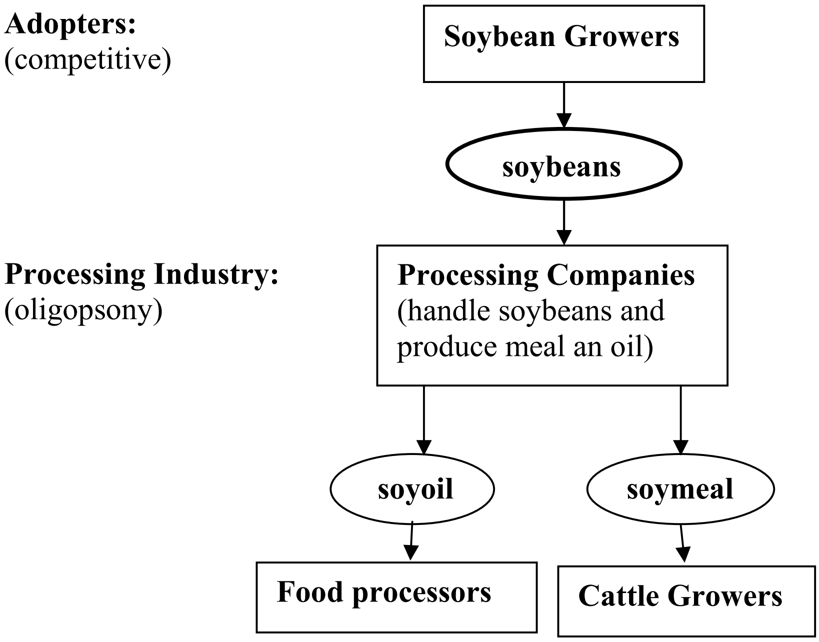
[1] The terms *GM soybeans* and *GM crop* are therefore used interchangeably throughout the paper.

via means of crushing them into soy-oil and soy-meal, which are subsequently sold to food manufacturers and the livestock sector:



The processing firms react to introduction of the GM soybeans that save on growers' costs by making their strategic output and pricing decisions subject to each other's responses, and to the adoption behavior and other characteristics of soybean growers.

We find that more competitive processing industry facilitates the diffusion of a GM crop, which benefits both growers and consumers. Finite adjustment speed of the GM crop supply, which is shown to reflect adoption behavior of the crop growers, impedes the diffusion process but benefits agricultural producers in the long run. Producer heterogeneity with respect to profitability of the GM soybeans is also an important determinant of the diffusion process, as it results in lower adoption levels and higher price of the GM crop. High levels of heterogeneity are also likely to speed up the diffusion process but, depending on the way heterogeneity is modeled and parameter values, do not necessarily increase the total surplus. High discount rates shorten the adoption period and increase the total surplus, together with GM soybean output and price.

I In section 1, we briefly discuss the mechanism of adoption of agricultural innovation by the growers and describe the dynamic model of GM soybeans adoption. Due to the space limitations, details of the model setup and calibration data are available from the authors upon request. In section 2, we discuss the simulation results.

1. The Mechanism of GM Technology Diffusion

In modeling the adoption behavior of soybean growers, the *probit* and *epidemic* approaches to innovation diffusion are appealed to, both of which have received a good deal of empirical support. The *probit* approach assumes potential adopters to be heterogeneous with respect to the relative profitability of the new technology (Stoneman, 1983). Adoptions occur at different times because the price of the innovation decreases exogenously due to accumulation of experience and supply growth. We modify this approach by assuming that the GM technology price remains constant but that the strategic behavior of processing firms in the soybean market causes *endogenous* GM crop price changes. Grower heterogeneity with respect to GM- soybean profitability occurs due to differing levels of weed infestation, levels of farm income, contractual relations with buyers or suppliers, and the possibility of cross-pollination of neighboring crops. With these specifications, the long-run supply of GM soybeans is more price inelastic than the supply of non-GM soybeans.

A drawback to the probit approach is that it ignores any uncertainty associated with the GM technologies, and thus makes no distinction between the short and long run demand for it. To account for this uncertainty, we also introduce the *epidemic* model of the growers' adoption behavior. The approach assumes uncertainty, or lack of information, about the profitability of a new technology on behalf of potential adopters, and thus emphasizes learning about it as the information becomes more widespread over time (Griliches, 1957; Mansfield, 1968). The proportion of non-users currently adopting the new technology is determined by the proportion of those who have already adopted it, the cornerstone of this reasoning being that delayed adoption reflects the uncertainty that firms attach to future profit streams which, in turn, depends on the speed of learning from existing users' experience.

The *epidemic* approach was initially applied to explaining adoption patterns of hybrid corn in the U.S. (Griliches). Subsequent research on adoption, however, has focused on a more general concept of the so-called effective information hypothesis under which adoption of new technology is determined by the quantity and quality of relevant information as perceived by the potential adopters (Fischer *et al*., 1996). Recently, Marra, Hubbel, and Carlson (2001) found that the most important factors in farmers' decisions to adopt Bt cotton were the on-farm experience and current county and state adoption and yield levels, which stresses the importance of information "nearness" and reduction of "noise".

Following the effective information hypothesis, GM soybean adoption decisions in the present model are influenced not only by current demand for GM soybeans, but also by private observations of recent profitability and adoption levels. This backward-looking behavior (delayed adoption effect) has important implications for the dynamics of the adoption process, particularly in the market for soybeans, as represents a constraint on the oligopsonists' intertemporal profit maximization behavior and creates additional incentives to expand GM soybean purchases.

In the model, soybean processors are assumed to be risk-averse and to know the growers' adoption behavior. The goal of each processing firm is to maximize the present value of its crush margins on both non-GM and GM soybeans minus the costs of identity preservation (IP). The IP costs are modeled as a function of the proportion of GM soybean production and facility management efficiency. The adoption process starts at the moment of introduction of GM soybeans, after which processors play a dynamic oligopsony game by strategically setting the quantities of GM and non-GM soybeans purchased from the growers. The soybean futures market is not modeled explicitly; instead it is assumed that either processors have market power there or growers do not take full advantage of hedging.

The model is calibrated with data from agricultural statistical sources and previous research. Due to the complexity of the analytical solution of the model, sensitivity analysis is performed by numerical simulation of the model in the program MATLAB©. [1]

2. Simulation Results

Due to the impaired tractability of analytical comparative statics and dynamics analysis of the adoption process as specified in the solution to the model, we use numerical simulation to examine the model's behavior. In particular, we are interested in how the model's parameters affect the diffusion dynamics and equilibrium prices and outputs of GM and traditional soybeans, as well as the magnitude and distribution of gains realized due to the innovation adoption. The software used for the simulation is MATLAB. Below, we present results of sensitivity analysis with respect to the number of firms in the processing market, growers' adoption behavior, growers' heterogeneity with respect to profitability of GM soybeans, and the discount factor. Our results are by no means exhaustive, but we believe that the most important determinants of the diffusion process of biotechnological innovations have been considered.

<u>Number of processing firms in the raw soybean market</u>.

Interesting results are obtained by varying the number of soybean processing firms, which reflects the processor oligopsony power. A more competitive market leads to greater realization of the producer cost savings that GM soybeans offer, which implies a higher long run equilibrium share and price of GM soybeans with correspondingly lower share and price for non-GM soybeans. In compliance with the general results of the dynamic oligopoly theory with Nash-Cournot behavior, a more competitive processing sector in our model means that the processors garner a lower share of the cost savings from the GM technology, while grower and consumer surplus are larger. Market characteristics approach competitive levels as the number of firms increase.

Table 1: Stationary Equilibrium Price, Quantity, and Gross Processing Margins with Varying Number of Firms

Number of processing firms		**1**	**2**	**3**	**10**	**100**
GM soybean price	**($/ton)**	134	165	180	207	220
Traditional soybean price	**($/ton)**	144	114	102.4	74.7	65.4
GM soybean output	**(mill. tons)**	21	27.5	30	36	38
Traditional soybean output	**(mill. tons)**	22.5	16	13.5	7.5	5.5
Aggregate processing margin	**(mill. $)**	6375	5913	5465	4216	3401

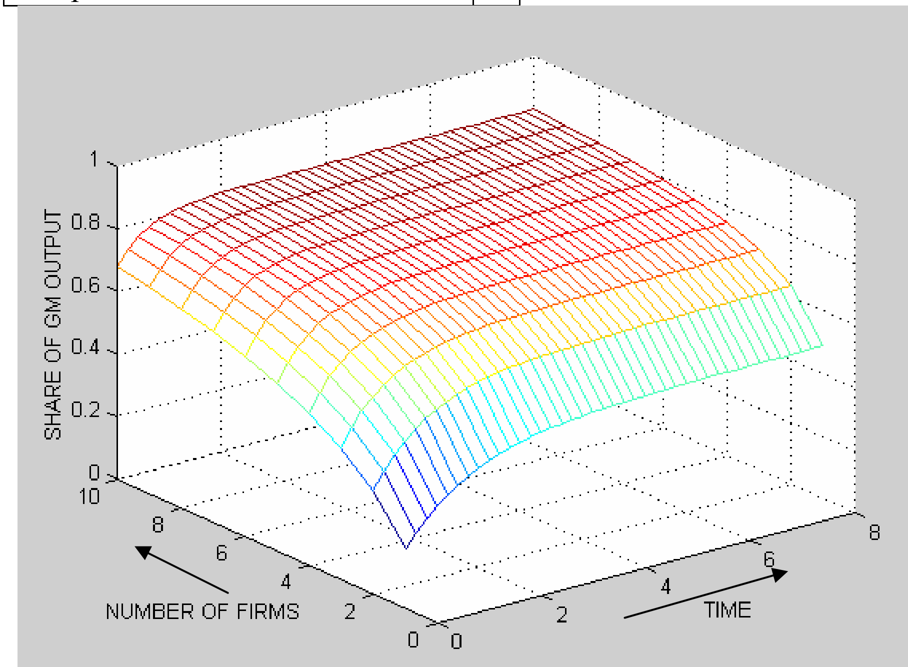
* s=0.5

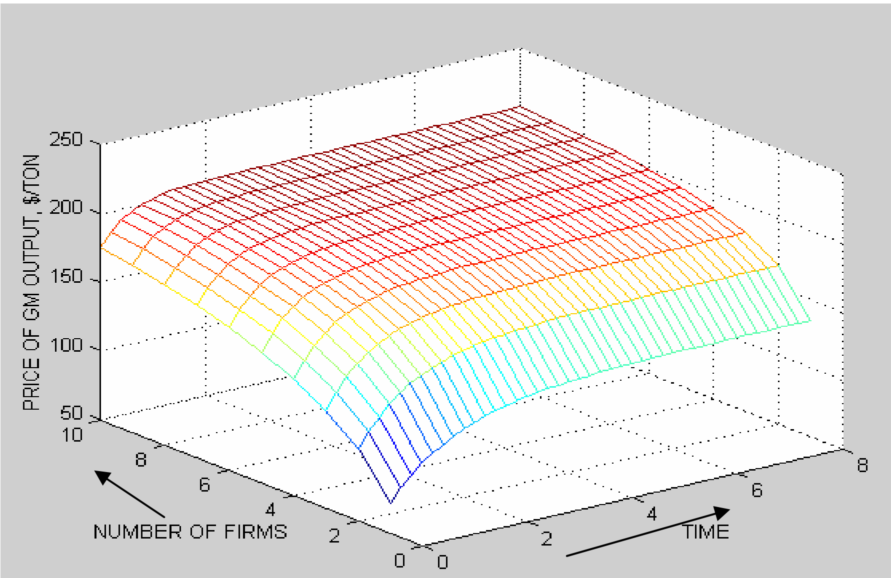
The number of processing firms also affects the dynamics of diffusion. The length of the adoption process, defined as the time it takes the variables to come arbitrarily close to their stationary values, is negatively correlated with the number of processors: in a more competitive market, the firms will expand their purchases of GM soybeans faster because of the pre-emptive incentive to seize market share before rival processors do it. With fewer processors, however, it is rational to first start buying only the cheapest GM soybeans from those growers who enjoy the highest cost savings from the new technology and then to gradually expand GM soybean purchases, keeping prices low because of the slow, or "retarded", GM soybean supply response. Table 2 and the diagrams below provide an illustration.

Table 2: Response of model to increasing number of processing firms

Share of GM soybeans	↑	Total surplus	↑
Share of non-GM soybeans	↓	Grower surplus	↑
Price of GM soybeans	↑	Consumer surplus	↑

Price of traditional soybeans	↓	Processor surplus	↓
Adoption time	↓		





In the feedback version of the model, the results discussed above would be similar, but with the stationary values reflecting more competitive behavior. The intuition behind this is that the GM soybean price being below its long-run value encourages the rivals' purchases of the GM crop transition to the new technology (which is identical to the argument that capacity building encourages investment in standard models). Under the feedback assumptions, there are stronger incentives to "invest" into GM soybeans now rather than later as a means of preempting the rivals' expansion into the GM market.

Growers' adoption behavior. As discussed in Section 2, the growers' adoption behavior is summarized by the parameter *s*, which is the speed of the GM soybean supply adjustment, reflecting producer perception of uncertainty about the crop, importance of past and current adoption levels for price expectation, and availability and speed of dissemination of information affecting planting decisions.

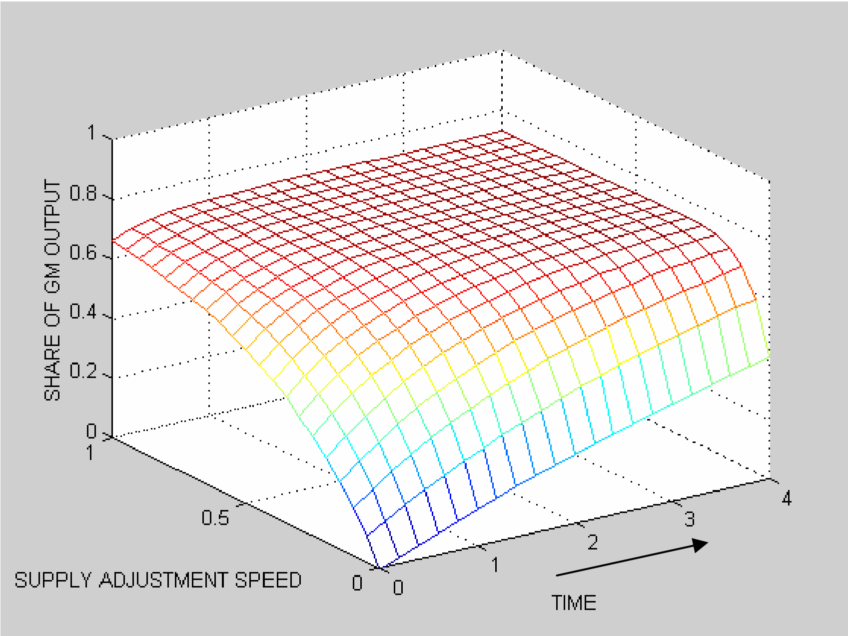
Simulation results indicate that slow supply adjustment leads to a higher long-run share and price of GM soybeans, but has the opposite effect on non-GM soybeans. Higher values of *s*, however, are also associated with serious delays in the adoption process, which makes the welfare effects ambiguous (see Tables 3 and 4).

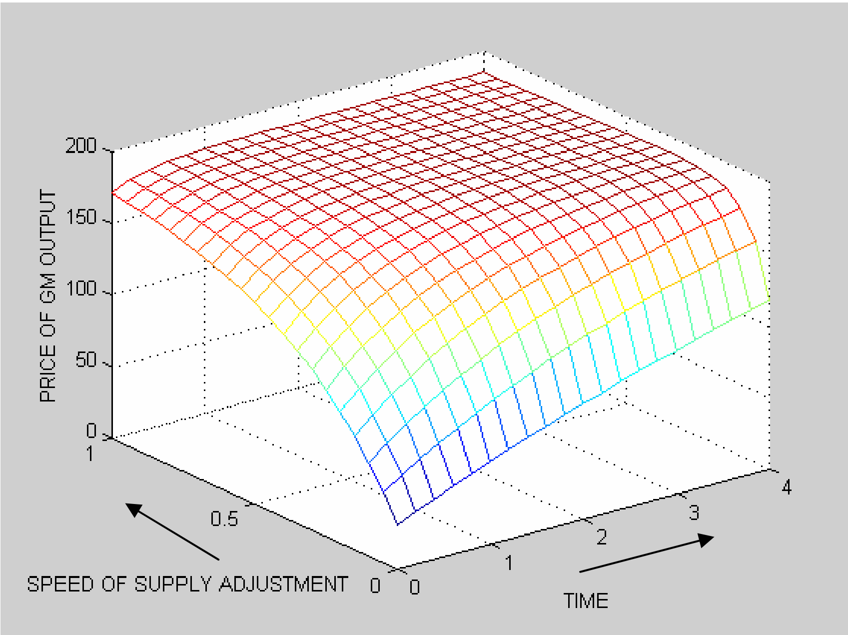
Table 3: Stationary Values (n=4)

S	**0.1**	**0.35**	**0.5**	**0.75**	**0.9**	**1**
GM soybean price (\$/ton)	207	191	188	186	186.5	185
Traditional soybean price (\$/ton)	74.7	88.5	90.8	93.1	94	95
GM soybean output (mill. tons)	36	33	32.5	32	31.8	31.6
Traditional soybean output (mill. tons)	7.5	10.5	11	11.5	11.7	11.9
Aggregate processing margin (mill. \$)	4225	5037	5226	5203	5230	5250

Table 4: Model's sensitivity to producer uncertainty

Share of GM soybeans	↑	Total surplus	⇕
Share of non-GM soybeans	↓	Grower surplus	⇕
Price of GM soybeans	↑	Consumer surplus	⇕
Price of non-GM soybeans	↓	Processor surplus	↓
Adoption time	↑		





The lagged adoption behavior of the growers appears to be an imperfect substitute for their market, or bargaining, power vis-à-vis the crop processors. Uncertainty associated with future demand for GM crops and slow dissemination of relevant information prevents producers from reacting competitively, or quickly, enough to the incentives from the processors. In the post-adoption period, this is reflected by the fact that the steady state GM soybean output and price are higher with finite speed of supply adjustment. Simulation results suggest that, in the long run, the growers benefit from their GM adoption behavior. Depending on parameter values, slow GM soybean supply adjustment may or may not result in greater NPV of consumer and producer surplus.

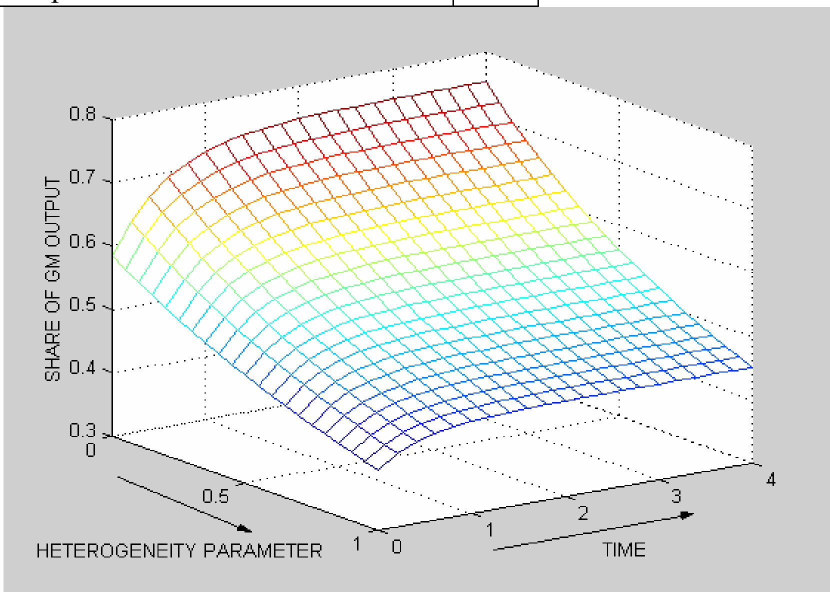
An important consideration is the significance of fast adoption from the perspective of the international competitiveness of the U.S. The reason is the international "spillovers" of agricultural innovations, in particular of biotechnologies. Biotechnology innovations may be adapted to different environments much faster than other agricultural innovations, for which location-specificity typically plays an important role (Moschini *et al.*, 2000). Besides, biotechnology innovations are generated within multinational firms that are ideally positioned for worldwide marketing. While the sales of new technologies to countries that export competitive products increase the profitability of a multinational, they also undermine the U.S. competitiveness in exports of the final product. In case of soybeans, higher GM technology adoption rates abroad increase cost efficiency of other major world soybean producers, undermining the U.S. competitiveness in the international soybean market.

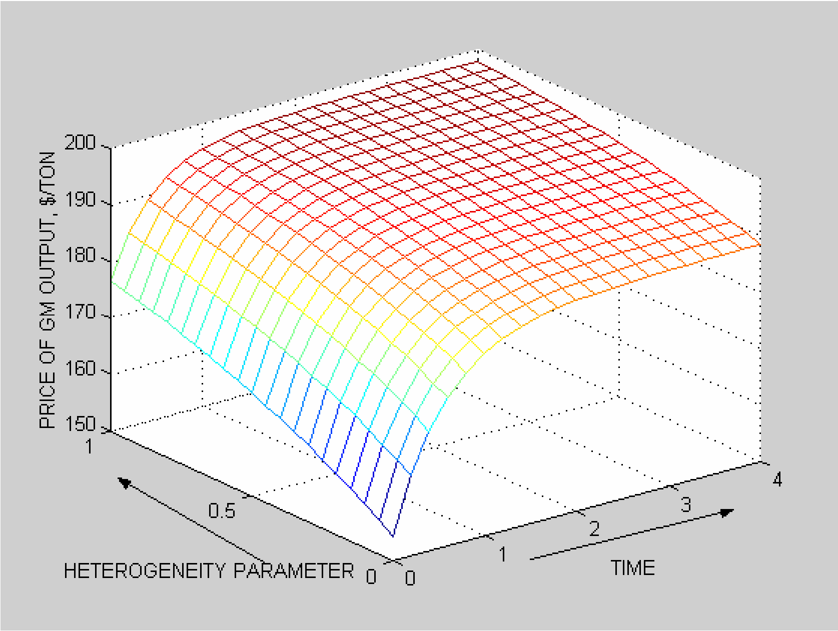
<u>Level of growers' heterogeneity with respect to cost savings from the GM crop</u>. The heterogeneity of the crop growers, modeled using the probit approach, is an important parameter in our results/construction as well.

The model suggests that, the more heterogeneous the growers are with respect to GM crop profitability (the bigger the difference between the elasticities of the GM and non-GM crop supply functions), the lower will be the equilibrium GM crop output and the higher its relative price, the lower the aggregate processor profits, and the faster the adoption process. Table 5 and the figures provide an illustration of these results.

Table 3: Model's sensitivity to increasing producer heterogeneity with respect to cost savings from GM soybeans

Share of GM soybeans	↓	Total surplus	⇳
Share of non-GM soybeans	↑	Total producer surplus	⇳
Price of GM soybeans	↑	Consumer surplus	↓
Price of non-GM soybeans	↓	Processor surplus	↓
Adoption time	↓		



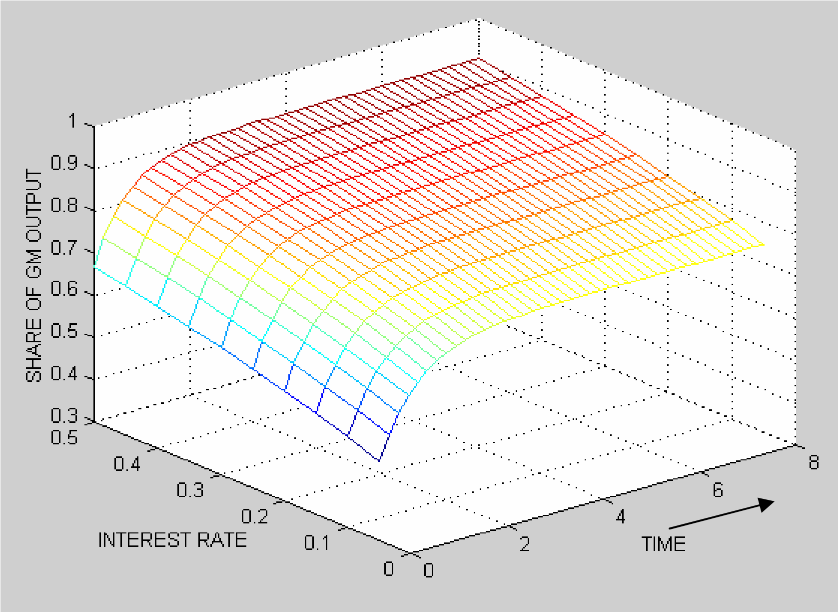


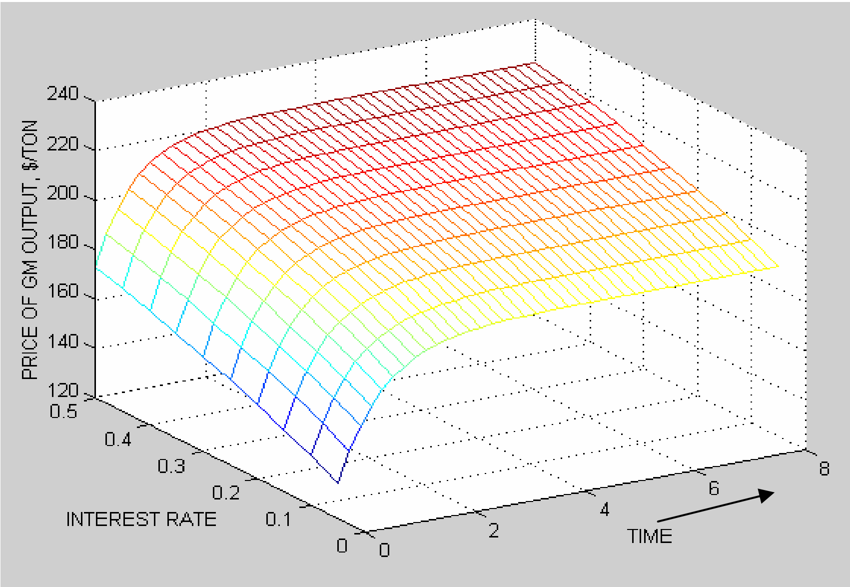
While the welfare implications of adopters' heterogeneity are parameter sensitive and therefore ambiguous, it is clear that the way a biotech innovation improves a crop affects the dynamics and equilibrium levels of, and hence the gains from, the diffusion process. According to our results, heterogeneity of potential adopters with respect to a particular innovation is an important economic consideration at the stage of innovation design.

<u>Discount rate</u>. Different values of the discount rate (*r*) also affect both the speed of convergence and the stationary values. In compliance with the general dynamic oligopoly theory, the simulation results show that the higher the discount rate, the shorter the diffusion period, and the higher the steady state GM output and price. The welfare effects, however, are ambiguous and parameter sensitive.

Table 3: Model's sensitivity to increase in discount rate *r*

Share of GM soybeans	↑	Total surplus	⇕
Share of non-GM soybeans	↓	Total producer surplus	⇕
Price of GM soybeans	↑	Consumer surplus	⇕
Price of non-GM soybeans	↓	Processor surplus	⇕
Adoption time	↑		


SHARE OF GM OUTPUT
1
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.5
0.4
0.3
0.2
0.1
0
INTEREST RATE
0
2
4
6
8
TIME


PRICE OF GM OUTPUT, $/TON
240
220
200
180
160
140
120
0.5
0.4
0.3
0.2
0.1
0
INTEREST RATE
0
2
4
6
8
TIME

5. Conclusions

In the paper, a model of adoption and diffusion of a genetically modified (GM) crop technology has been developed. The model is specified as a dynamic Nash oligopsony game, in which oligopsonistic crop processing companies make their strategic production decisions taking into account adoption behavior of the crop growers, the GM crop characteristics, and identity preservation requirements. While the model is solved analytically, numerical simulation of GM soybean diffusion in the U.S. is used for sensitivity analysis.

The simulation results show that competition in agricultural markets facilitates the process of a supply-push biotechnological innovation and increases adoption levels. On the other hand, oligopsonistic behavior of crop processors slows the diffusion process, while maintaining higher levels of traditional soybean production.

Slow speed of GM crop supply adjustment, which is shown to reflect adoption behavior of the crop growers, impedes the diffusion process but benefits agricultural producers in the long run. Welfare results, however, are ambiguous as they are parameter sensitive. Slow diffusion may also hurt the U.S. international competitiveness.

Higher producer heterogeneity with respect to profitability of the innovation results in lower equilibrium adoption levels and higher price of the GM crop. Higher levels of producer heterogeneity also speed up the diffusion process but, depending on the way heterogeneity is modeled, do not necessarily increase the surplus. It is certain that heterogeneity of potential adopters with respect to profitability of a particular innovation should be an important economic consideration at the stage of innovation design.

Higher discount rates shorten the adoption period and increase equilibrium GM soybean output and price, as well as the total surplus.

Endnotes

Details of the diffusion model setup and data used for calibration are available from the authors on request.

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