Simulating the Effects of Adoption of Genetically Modified Soybeans in the U.S.*

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Abstract:

The paper models the distributional effects of partial adoption of genetically modified soybeans under the assumptions of imperfectly competitive markets and identity preservation requirements. Our results show the welfare costs of market imperfections and improve understanding the diffusion of innovation in agriculture.

Keywords: genetically modified crops, agricultural innovations, soybeans, oligopsony

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Introduction

Introduction of genetically modified (GM) crops is the most important innovation in modern agriculture that promises more benefits than it has delivered. Biotechnology provides significant consumer and producer benefits, the magnitude and distribution of which depends critically on the structure of the markets via which the innovation effects are realized. While some agricultural markets are undoubtedly competitive, some are not. The object of our simulation is the U.S. soybean market in which growers sell most of their produce to the soybean processing and exporting industry (Larson, 1998). In the last twenty years, the industry has become significantly more concentrated than most other U.S. food processing industries. At present, four largest firms own about 80 percent of total capacity. The real value of the crush margin has increased from about $0.5 in the 1960s and 70s to almost $1.4 in the 1990s (*Soya and Oilseed Bluebook,* 2000), while the breakeven level in crushing was estimated to be only 15 cents in the 1980s (Shaub *et al*., 1988). These data suggest that there might exist an oligopsony in the U.S. soybean market. The other imperfectly competitive market in the chain is the GM soybean seed market, which is an institutionalized monopoly. The markets for soymeal and soyoil, however, are competitive (Deodhar and Sheldon, 1997).

In this paper, we develop a dynamic model of adoption of GM soybean technology under the assumption of imperfect competition in the soybean processing market. The model also accommodates identity preservation requirements that imply segregation of soybeans at all stages of production and distribution. The model is specified as a Nash oligoposony situation where players with market power (the processing companies) make their output and pricing decisions under certain incentive compatibility constraints and act strategically. Assumptions of the model are chosen to reflect the industry and market facts.

We use the model to evaluate market and distributional effects of partial adoption of GM soybeans in the United States. Our approach is innovative because, unlike other recent models of agricultural innovation (Buckwell, 1999; Moschini *et al.*, 2000), it assumes oligopsony in the soybean market and crop segregation. While specified for the soybean-processing complex, our model is also applicable to other GM crop markets and it improves understanding of the diffusion process of agricultural innovations.

In section 1, we discuss the mechanism of diffusion of agricultural innovation among the growers. In section 2, we review the literature on dynamic oligopoly and lay out the model of GM soybeans adoption. Calibration data are shown in section 3. In section 4, we present and discuss the simulation results. Section 5 concludes.

1. The Mechanism of Diffusion.

Diffusion of technological innovations can be considered a separate branch of economics. The literature on the subject is voluminous. Within the subject, the theories can be classified as:

- Intra-firm theories of diffusion: Stoneman (1983, 1987), Mansfield (1968);
- Intra-sectoral diffusion theories: David (1975), Grilliches (1957, 1980), Dixon (1980), Mansfield (1968);
- Game-theoretic approach: Reinganum (1981);
- Economy-wide diffusion: Schumpeter , Davies(1979).

In our opinion, the model that best suits adoption of innovation by agricultural producers is that of partial equilibrium, or probit model, according to the terminology used by Stoneman (1983) and David (1975). This approach states that the diffusion (i.e. adoptions scattered along time) arises from the unequal distribution of certain key characteristics of business entities or adopters that are decisive for adoption. Firms have the same information about the new technology (not necessarily complete), but not the same ability or potential profitability to use it at a given point of time. In a general case, it is the changes in profitability of the new technology, be it changes in the price of new inputs, new equipment, new product output, or a combination of them that are the engine of adoption. Firms are regarded as displaying the same rational behavior when faced with similar information, though submitted to different constraints as they do not share the same production conditions or are not positioned on the same markets. Davies (1979) has pointed out the major importance of firm size for introducing innovations. The most important feature of this approach is that the incentive from outside is the same for all firms, but the time of adoption differs because of the firms' heterogeneity.[1]

In the standard probit model of innovation behavior by firms, a firm *i* with a vector of characteristics z_i adopts the new technology at time *t* if and only if

$h(z_i)/r \geq p_t$, where, *h* is the difference in profitability of the innovated technology with respect to the existing technology, *r* is the discount rate; *h/r* is the present value of the gain brought by the use of the new technology, and p_t is the cost of acquisition of the new technology at time *t*.

[1] Actually, this model uses the same logic as basic microeconomic model of upward sloping supply (or downward sloping demand) – both derive the results from the heterogeneity of population.

Stoneman concludes that, as long as the price of the innovated technology p_t declines over time, the number of adopters increases. The implicit assumption of perfect competition and no strategic interaction among the adopters justifies the results.

The fall in price of the new equipment can stem from various sources in the industries of the innovation suppliers: learning by doing, incremental technical progress, and increasing returns to scale. This scheme of diffusion determines the number of firms using the new technology once $p(t)$ and the distribution law of the characteristics of the firms are known. If z_t is the characteristic of the marginal adopter at time t, $h(z_t) = rp_t$. If F is the cumulative distribution function of N firms constituting the industry with respect to z_t, then the number of users of the new technology is equal to $M_t = N(1 - F(z_t))$. If F has the normal distribution, the law of diffusion will be S-shaped. If F itself is a logistic distribution, as in the epidemiological models, it will be strictly a logistic curve. The diffusion rate, i.e. the penetration level M_t as a share of the whole population of firms, finally depends on the rate of evolution of price p for a given distribution of characteristic z.

Many indicators of heterogeneity among firms have been used in empirical tests of this standard probit model, for example the mean wage rate as a proxy for the qualification of the labor force (David, 1969), the ratio of indirect to direct labor which measures both the ability to handle new equipment and the interest to invest in labor saving equipment (Antonelli and Tahar, 1990), and the level of growth of sales (Benvignati, 1982).

Considering diffusion of GM crops, in particular soybeans, the primary adopters are the agricultural producers as it is their profit function that is affected by the GM technology. The sources of farmers' heterogeneity relevant to the profitability of GM soybeans are as follows:

- The level of weed infestation. GM soybeans provide cost savings to the growers because of their resistance to glyphosate – a powerful herbicide. The more weed infestation an agricultural producer faces, the more cost benefits GM soybeans offer. Weed infestation is a more urgent issue in the southern soybean growing regions than in the Midwest and in the North. It is likely that GM soybean varieties are more profitable in the Southern growing regions.
- The level of farm income. There is some level of risk associated with GM crops. The sources of the risk are numerous, ranging from potential hazards GM crops impose on other crops to the public attitude towards GM foods. The incentive to adopt a GM crop is inversely related to its riskiness. When some risk is present (i.e., it is uncertain what the price will be, so that there is some expectation but relatively high variance), the farmers with higher income would react to the expected differences in profitability more readily than the farmers with low income.[2] Related producer characteristics are the stock of machinery, storage capacities, farm size, level of diversification of activities, and other factors that affect a farm's financial stability.
- Contractual relations with buyers or suppliers. If a farmer has entered a contract with a buyer or supplier (a seed company), she is more restricted in her production choices. Depending on the price she gets by the contract, she might be more or less willing to take the risk and plant GM crop.

[2] Theoretically, the utility function is always concave so that the level of risk aversion decreases with wealth.

A straightforward development of the standard probit model supposes that firms' decisions are not simply linked to the current prices, but also to some expectation concerning these prices in the future (Stoneman, 1987). Firms can effectively anticipate falls in prices if they presume some diffusion to take place. The behavioral equation is then modified to

$$h(z_i) \geq rp_t + (p_t - p_{t+1}^e), \qquad \text{or}$$

$$h(z_i) \geq (1+r)\,p_t - p_{t+1}^e.$$

In the case of agricultural producers facing the opportunity to plant GM crops, it is usually not the costs of the new technology that vary in time, but the growers' output prices. It is reasonable to assume that agricultural producers (soybean growers), unlike bigger business entities, are restricted in the ability to anticipate future prices. One of the more plausible assumptions is that of adaptive expectations. In particular, making next year's planting decisions and facing *the general* uncertainty about GM crops, the growers consider *both* the crop's profitability and this year's price change. It is also likely that agricultural producers generally do not have to commit to GM crops in the future once they've planted them. A producer will, therefore, plant GM crop if

$$w_t + \beta(w_t - w_{t-1}) \geq \bar{c}_i + c(z_i),$$

where w_t is the price of GM crop, $\bar{c}_i$ is the cost of growing traditional varieties, and $c(z_i)$ is the cost saving from GM technology. β is the weight attached to the significance of the adaptive expectation of the next year's price. $0<\beta<1$ and it must be negatively correlated with the uncertainty about GM crops. β can also be related to the growers' heterogeneity. For the purposes of the model, we assume β to be constant.

Transforming the inequality above gives us the condition for adoption by a grower with characteristic z_i:

$$w_t = \frac{1}{1+\beta}(\bar{c}_i + c(z_i)) + \frac{\beta}{1+\beta} w_{t-1}, \quad \text{or}$$

$$w_t = s(\bar{c}_i + c(z_i)) + (1-s)w_{t-1}, \qquad 0 < s < 1.$$

It is easy to show that, given GM soybeans provide some cost savings, the GM soybean inverse short-run supply function is

$$w_t = sw(Q_t) + (1-s)w_{t-1},$$

where $w(Q_t)$ is the long-run (time invariant) supply function that depends on the profitability of the GM crop and on the heterogeneity of the producers in the characteristics that affect the GM crop's profitability. Taking a linear approximation,

$$w_t = s(a + bQ_t) + (1-s)w_{t-1}.$$

It can be shown that, given GM soybeans provide some cost savings,

$b > b^N$ and $a < a^N$, where the superscripts N denote coefficients of the traditional (Non-GM) soybean supply function ${w^N}_t = a^N + b^N Q_t^N$ which is not dependent on expectations because the situation with the traditional crops is much more certain.

This reasoning is similar to the assumption of sticky prices: the process of diffusion is state dependent and the state is the price. The GM crop price is, in our opinion, the best candidate for the state variable, because it immediately affects the growers' planting decisions.

Now, the bulk of raw soybeans is purchased by the soybean processors or exporters represented by the same companies who are assumed to know the short and long-run supply functions. The buyers do not set prices but rather quantities.[3] There is voluminous literature on price discovery, particularly in agricultural markets. The general opinion is that the prices efficiently reflect the supply and demand conditions.

When the processing industry is an oligopsony, it is the behavior of the processing companies that, together with the supply conditions, determines the time path of the input prices and hence the paths and levels of GM soybean adoption. We thus model the diffusion process as a dynamic oligopoly game with the agricultural producers' adoption behavior described as above.

2. The Model of Adoption

Existing dynamic oligopoly models typically accommodate some index of market power, which includes three leading market structures: perfect competition, non-cooperative Nash, and the cartel/monopoly behavior. The index is designed to describe rather than explain the market outcome - it is an assumption about how the firms react to each other's actions. Different indices can be consistent with the same equilibria (i.e., a non-cooperative equilibrium may be identical to the perfect competition or to a cartel solution). The index enters the model as a parameter, v that reflects the markup of price over marginal cost. In this approach, given the demand (for oligopoly) or supply

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[3] The two products in question (GM and traditional soybeans) are homogeneous, and there is little reason to believe that producers would completely specialize in either GM or traditional soybeans (the elevators and plants of every big producer are scattered around all soybean growing states). Thus, we choose quantities to rule out Bertrand behavior.

(oligopsony) equation for a homogeneous product, firm *i*'s marginal revenue curve is given by the degree of market power actually exercised. For oligopoly with *(n+1)* firms,

$$\frac{\partial R_{it}}{\partial q_{it}} = MR_{it}(q_{it}, v_i) = p_t + (1 + nv_i)\, p_t' q_{it} ,$$

$v=-1/n$ implies $MR=MC$, $v=1$ implies monopoly ($MR=p+p'Q=MC$), and $v=0$ implies Nash-Cournot. While in the empirical literature on *static* models, the parameter *v* often is interpreted as a constant conjectural variation, there is a more neutral interpretation of *v* as a gap between marginal cost and price. In dynamic models, the index is similarly defined (as an equilibrium price-cost markup), but it also depends on the shadow value of the state, which is endogenous. In our model, we assume Nash-Cournot behavior ($v = 0$), which is consistent with empirical findings about concentrated industries (Gollop and Roberts, 1979).

The two most common structures of dynamic oligopoly games are those of open loop and feedback. Under the **open-loop** structure, the agent's information set consists of calendar time and the state vector in the beginning of the game. The equilibrium is, a Nash equilibrium in open-loop strategies. Each firm chooses a sequence of controls (*a trajectory*), which are a function of time and initial state. In other words, each firm maximizes its stream of profits given the initial condition, the market power index *v*, and an assumed path of its rivals. Under the assumption of open-loop behavior, the steady states for the three leading market structures (competition, Nash-Cournot, and cartel) are usually equal to their static analogues.

Under the **feedback** structure, the agent's information set consists of calendar time and value of the *current* state vector. Strategies map the information set in actions in each period. This enables firms to respond to surprises that are caused by additive random shocks from nature. The equilibrium is a set of decision rules rather than a set of trajectories in the open-loop game. Players choose state-contingent policy rules, and the resulting equilibrium is sub-game perfect. The equilibria are typically not unique (*inter alia*), it can regress to punishment and trigger strategies) and there is no way to identify the underlying game by observing market outcomes.

In standard models (Fudenberg and Tirole, 1984, 1986), both open loop and feedback equilibria are obtained by the simultaneous solution to a number of dynamic programming equations (equal to the number of firms) representing the value of player i's profits as fuctions of lagged outputs.

For reasons of tractability, many theoretical and empirical dynamic models assume the use of open-loop strategies. There are cases where the open-loop models are the same as feedback models and it has been shown that the differences in comparative statics with respect to the steady states, as well as in comparative dynamics, are always cardinal and never ordinal (Karp and Perloff, 1993). In particular, feedback models always lead to more competitive behavior than the open-loop models. This is the result of a *preemptive incentive* that is absent in the open-loop equilibria (Tirole *et al*, 1986). This generalizes the comparative statics for the steady states in two models to entire equilibrium paths.

In this article, we solve our model as an open-loop game, which does not undermine the validity of the parameter sensitivity analysis.

To show the basic mechanism of the process let us, for a moment, abstract from the output demand cross-price elasticities. While little is known about the segregated demands for soybean outputs, it is reasonable to assume that the cross-price effects for the products of different "origin" are negligible. Also, the effects of the world demand for processing outputs are likely to be weaker than the domestic input supply effects, because introduction of GMOs in agriculture is a supply-push process.

Consider a monopolist's profit in the crushing industry:

$$\Pi = p^G(Q^G)Q^G + p^N(Q^N)Q^N - w^G(\underset{+}{Q^G}, \underset{-}{Q^N})Q^G - w^N(\underset{+}{Q^N}, \underset{-}{Q^G})Q^N,$$

the first-order derivative with respect to GM crops being:

$$\frac{\partial \Pi}{\partial Q^G} = \frac{\partial p^G}{\partial Q^G}Q^G + p^G - \underbrace{\frac{\partial w^G}{\partial Q^G}(Q^G, Q^N)Q^G}_{+} - \underbrace{w^G(Q^G, Q^N)}_{+} - \underbrace{\frac{\partial w^N}{\partial Q^G}(Q^G, Q^N)Q^N}_{-},$$

where superscripts *G* and *N* refer to the GM and traditional (non-GM) crops. *Q*'s denote quantities and *p*'s prices. This condition corresponds to static profit maximization problem, assuming that it is the goal of the corporation.

The last term in the first-order condition is the cross-price effect stemming from the fact that processing more GM output increases the price of GM crop and makes growers switch to GM crops thus reducing the price of traditional varieties.

Let us now consider the possibilities that agricultural producers have of switching to/from other crops in response to the soybean price changes. If we treat the environment outside the soybean production as static, we should anticipate an increase in the area planted with soybeans in response to reduction in the production costs after introduction of GM varieties. But when we account for the fact that all the major soybean "competitor crops" to which the producers can switch are undergoing similar genetic modifications, together with the fact that the structures of markets for corn, rapeseed, canola, sunflower, and other crops are similar to that of soybeans[4], it seems more realistic to assume that no substantial increase in the soybean acreage will take place in response to the profitability changes. In our model, rather than assuming numerous substitution possibilities or considering soybean industry outside of the rest of the agriculture, we resort to simple but plausible assumption of constant area planted with soybeans. Because, according to most sources, GM soybeans do not exhibit higher yields, this implies that the total soybean output remains constant and time-invariant. Defining it as Q^T, we can write

$$Q^T = Q_t^N + Q_t^G$$

and, maximizing the above profit function with respect to Q^G gives us the condition:

$$\frac{\partial R}{\partial Q^G} = \frac{\partial p^G}{\partial Q^G} + p^G + \frac{\partial p^N}{\partial Q} Q^T - \frac{\partial p^N}{\partial Q} Q^G + p^N = \underbrace{\frac{\partial w^G}{\partial Q^G} Q^G + w^G (Q^G)}_{MC^G} - \underbrace{\frac{\partial w^N}{\partial (Q^T - Q^G)} - w^N (Q^T - Q^G)}_{cross\text{-}price\_effect} = MC,$$

which remains the same for each firm in an oligopsonistic processing industry.

Because we are interested in the diffusion of the GM technology, we consider the dynamic aspect of the profit maximization problem. If the processing industry consists of n identical firms, each of them maximizes the stream of profits:

$$J_i = \int_0^\infty e^{-rt} (p_t^N Q_{it}^N + p_t^G Q_{it}^G - w_t^G Q_{it}^G - w_t^N Q_{it}^N - c_{it}^{IP}) dt\ ,$$

where c^{IP} denotes the costs of identity preservation in presence of GM crops. The infinite horizon assumption is justified by the fact that it leads to maximizing the value of the firm at any point of time.

The maximization is subject to the equation for state-dependent GM input price

[4] Similar GM varieties are introduced, the structures of the seed and crop processing industries are the same, and the end uses of the processed products are similar, too.

$\dot{w}_t^{\,G} = s(w_t^G(Q^G{}_t) - w_t^{\,G})$ which is consistent with our reasoning about the diffusion models, the initial condition $w^G{}_0 = w_o^{\,N}$, and the transversality condition. The state is w_t^G, and firm i's control is Q_{it}^G, the output of traditional variety being determined by the constant planted area assumption condition. $w_t^G(Q_t^G)$ is the long-run supply equation and s is a function of all the exogenous factors influencing adoption behavior. s here denotes the speed with which the price converges to its level on the long-run supply equation.

While n defines the number of oligopsonistic firms with Nash-Cournot behavior, there may exist a competitive fringe consisting of smaller firms that are price takers and behave passively. Because the firms are identical, it can be shown that, provided the Hamiltonian for each firm is strictly concave in the control, the equilibrium at any point of time is symmetric (Fershtman and Kamien, 1987). Thus, the control of firm i is Q_t^{Gi} (Q_t^i to simplify the notation), and:

$$\sum_i Q_{it}^N = Q_t^T - \sum_i Q_{it}^{Gi} \text{ or } Q_{it}^N = Q_t^T / n - Q_{it}^G = Q_{it}^T - Q_{it}^G .$$

The assumption of constant proportions of traditional and GM soybeans for each firm is justified by the fact that each firm[5] in the soybean processing has plants and elevators in every soybean growing state and therefore complete specialization in GM or traditional varieties is unlikely. To make the notation less cluttered, we from now on drop the superscripts G from variables pertaining to GM soybeans.

Because we are looking for an analytical solution to a dynamic model, we are bound to specify the equation of motion in a linear form. We assume it is

$\dot{w}_t = s(a + bnQ_{it} - w_t)$, where $a+bQ_t$ is the long-run supply equation.

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[5] The firms, in this respect, should really be called companies.

The price of traditional soybeans, w_t^N, is similarly defined as

$$w_t^N = a^N + b^N Q_{it}^N = a^N + b^N (Q_i^T - Q_{it}),$$

where w_t^N is assumed not to depend on w_t because the cross-price effect is already captured by the effect Q_t has on Q_t^N.

The output demands are also assumed to be linear. The demands for GM and non-GM outputs are the weighted sums of meal and oil demands (the weights are technological coefficients of oil and meal production):

$$p_t^G = \alpha + \beta Q_t ,$$

$$p_t^N = \alpha^N + \beta^N Q_t^N = \alpha^N + \beta^N (Q^T - Q_t).$$

The gross revenue of firm *i* is then:

$$R_{it} = p^G Q_{it} + p^N (Q_{it}^T - Q_{it}).$$

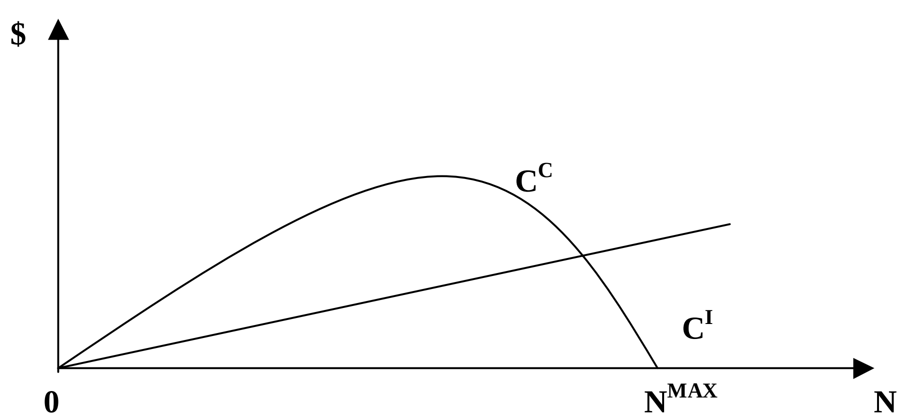
The costs are similarly defined. Because the soybean processing costs are arguably constant, their inclusion does not change the comparable results of the model. We thus include only the difference between the costs of processing GM and traditional soybeans, which is the costs of identity preservation (IP) that appear immediately after GM crops are introduced. Little is known about the IP costs, except that they are significant and are likely to be non-linear. The main argument is that, the more GMOs there are around, the more thorough the testing and other IP requirements are. The cost of identity preservation consists of the cost of checking the non-GM soybeans/meal for the presence of GMOs (inspection cost C^I) and the cost of cleaning the storage or processing facilities before using them for traditional (non-GM) varieties if GM soybeans have been stored or processed there before. The inspection cost is obviously linear in the quantity of the non-GM soybeans, but the cleaning cost is a non-linear function of the share of non-

GM produce in the total soybean output, typical elevator and crushing plant size, and of the efficiency of elevator/processing facilities management. Obviously, production management efforts are directed towards specializing production and storage facilities in either traditional or GM varieties. But, holding the plant size and the management efficiency constant, the costs of cleaning will depend on the frequency of a production facility's switching from GM to non-GM soybeans. Defining by N the number of shipments of non-GM soybeans to an elevator and/or processing facility, the cost of cleaning is:

$$C_{cleaning} = c^c \sum_{j=1}^{N} j \Pr(j, \frac{Q^N}{Q^{GM}}),$$

where c^c is the cost of cleaning a facility and $\Pr(j, Q^N/Q^{GM})$ is the probability that a shipment of non-GM soybeans is received j times *after* receiving shipment(s) of GM varieties. It can be shown that, with uniform distribution of arrivals of non-GM shipments, the cleaning cost function is an inverted parabola skewed to the right (see the figure below).

Figure 1. Costs of Identity Preservation



The most consistent way to specify the total costs of cleaning is as follows: $C^C = \mu\rho_t{}^N \rho_t{}^G Q_t^T$, where the ρ's are the shares of non-Gm and GM produce, respectively, and μ is a coefficient reflecting the real cost of a one-time cleaning, as well as the efficiency of logistics management. Using our notation, the total identity preservation costs of firm *i* are:

$$C_{it}{}^{IP} = C_{it}^I + C_{it}{}^C = c_{it}^I Q_{it}^N + \mu\rho_{it}{}^N \rho_{it}{}^G Q_{it}^T .$$

Subtracting the costs from the revenues, applying the symmetry, using the assumption of constant total output, and collecting terms yields the objective function of firm *i*:

$$\pi_{it} = Q_{it}\underbrace{(\alpha^G - \alpha^N + \beta^N Q_{it}^T + a^N + 2b^N Q_{it}^T - c^I + \mu)}_{K} - wQ_{it} - Q_{it}{}^2 \underbrace{(\beta^N + \beta^G + b^N - \mu / Q_{it}^T)}_{L/2} + \underbrace{Q_{it}^T(\alpha^N - a^N + (b^N - \beta^N)Q_{it}^T + c^I p^N - w_t^N)}_{M} .$$

By definition, the solution to the open-loop oligopsony game with Nash-Cournot behavior is determined by the simultaneous solution to *n* maximization problems:

$$\begin{aligned} &\underbrace{\max}_{Q_{it}} \int_0^\infty e^{-rt}(KQ_{it} - w_t Q_{it} - \frac{L}{2} Q_{it}{}^2 + M)dt \\ &\dot{w}_t = s(a + bQ_t - w_t) \\ &w_0 = w^N \end{aligned} .$$

The maximum principle gives us:

$$\begin{aligned} &H_Q^i = K - w_i - LQ_i + \lambda_i snb = 0 \\ &H_Q^i = -\dot{\lambda}_i e^{-rt} + \lambda_i re^{-rt} = -e^{-rt} Q_i - s\lambda_i e^{-rt} \end{aligned} .$$

Differentiating and substituting produces the following stationary values:

$$Q_i^* = \frac{(r+s)(K-a)}{(bn+L)(s+r)+sbn}, \quad \text{and}$$

$$w^* = \frac{(abn + aL)(s+r) + asbn + bn(K-a)(s+r)}{(bn+L)(s+r) + sbn},$$

with the steady state values of the traditional soybean quantities being determined by the model' specifications.

The optimization conditions can be differentiated with respect to time and rearranged to show that the equilibrium GM input price trajectory must satisfy the following second order linear differential equation:

$$\ddot{w} + A\dot{w} + Bw = F,$$

where

$$A = -r/L;$$
$$B = -s\frac{2sbn + rbn + L(s+r)}{L}; \qquad .$$
$$F = -\frac{sbnK(s+r) + as(sbn + L(s+r))}{L}$$

A particular solution to this equation is *F/B* which is exactly the stationary equilibrium price w^*. The roots of the characteristic equation associated with the homogeneous part of the equation above are both real (this is true since B is negative). If we take the stable solution and take the initial price $w_0 = w_0^N$, the following is the open-loop Nash equilibrium trajectory:

$$w_t = w^* + (w_0{}^N - w^*)e^{Dt},$$

where, $D = -1/2(A + \sqrt{A^2 - 4B}) < 0$.

As we pointed out earlier, the feedback equilibrium is similar to the open loop and the ordinal effects in the model are the same under both structures. For now, we omit the simulation with a feedback structure, but the discussion of the comparative dynamics below also pertains to a feedback setup under which, arguably, the oligopsonists behave more rationally.

3. Calibration

In order to show the dynamic properties of the process, we use annual data for calibration. The data are obtained from public sources (*Soya and Oilseed Bluebook*). Below are the values of the parameters defined in the previous section.

Soybean supply:

- Soybeans used for crushing prior to adoption: Q_0^N = 43.5 million metric tons (about 60% of the total soybean output)
- Traditional soybean price (also the starting value for GM price in the model): w_0^N = \$241 for a metric ton.
- Area planted: L = 28 million hectares
- Yield (same for both traditional and GM varieties): y = 2.62 MT/hectare
- Producer's cost saving from planting GM in comparison to the traditional variety: $\Delta\pi$ = \$20/hectare or \$7.63/MT (Moschini *et al*, 2000)
- elasticity of planting area with respect to price: φ = 1.2. This measure is rather arbitrary stemming from the fact that the existing soybean and oilseed models (FAPRI, SWOPSIM, and AGLINK) arguably underestimate soybean elasticities (Moschini *et al*, 2000) assigning them values ranging from .22 to .6.

The coefficients that emerge from these numbers are $b^N = \frac{\partial w^N}{\partial Q^N} = \frac{1}{\varphi}\frac{w^N}{Q^N} = 4.617$,

$a^N = w^N - b^N Q^N = 40$, and $a^G = a^N - \Delta\pi = 32.37$.

For the reasons discussed above, we assume b^G = 1.1 b^N =4.84.

According to various estimates, the inspection costs range from $0.18 to $0.54 a bushel (Lin, 2000). We assume c^I =$1.5/MT. μ is assumed to be equal to 30.

<u>Demand for crushing products</u>:

For clarity, we have assumed constant prices of outputs. This may be more realistic considering the competition that US crushers face in the world markets. But even if the industry is facing a residual demand in the output markets the effects of those demands must be weaker than those of the domestic soybean supplies.

- The transformation coefficients for meal and oil are: γ^M = 0.79 and γ^O = 0.21.
- The meal price is the average price in the 1990's: p_M = $219/MT. We assume that the price of meal from GM soybeans remains the same.
- The oil price is the average price in the 1990's: p_M = $590/MT. We assume that the prices after the introduction differ from this level by 5% for oil from traditional beans and –10% for oil from GM produce.

The output prices in our model are weighted meal and oil prices:

$p^G = \gamma^O p_O^G + \gamma^M p_M = 283$, and $p^N = \gamma^O p_O^N + \gamma^M p_M = 301$

4. Simulation Results

Because analytical derivatives of the steady states and particularly the trajectories with respect to the parameters are hardly tractable, we use numerical estimation results to examine the model's behavior. The software used for the simulation is MATLAB.

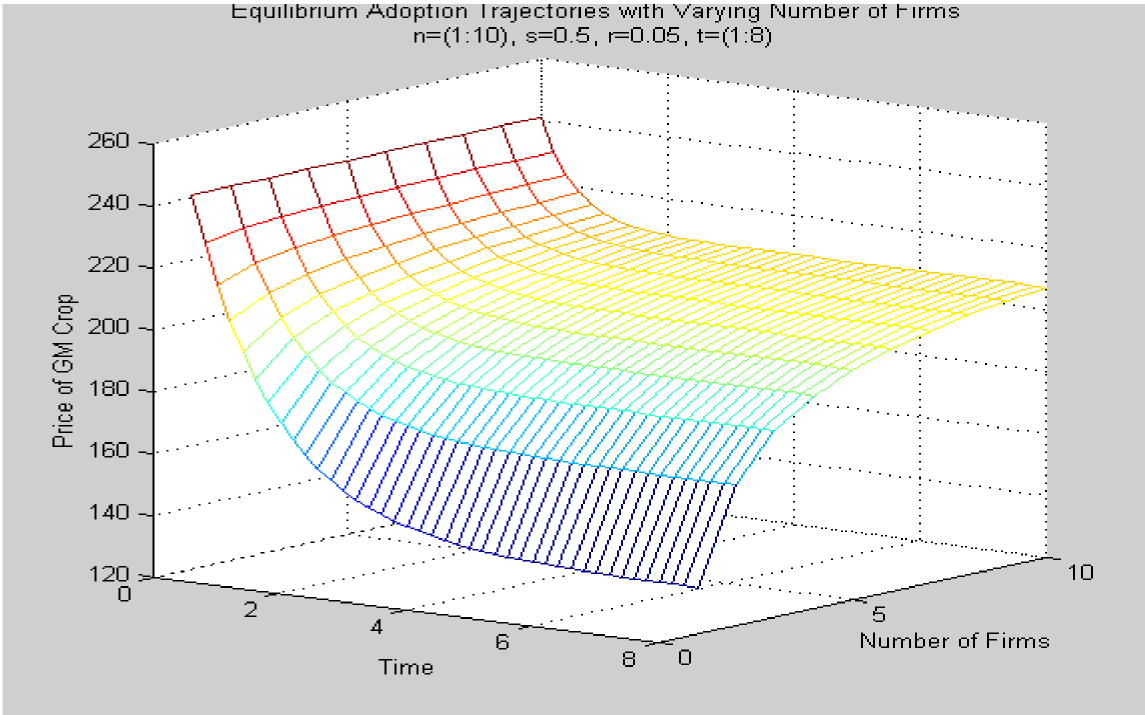
Of special interest is the model's responsiveness to changes in the number of firms in the market. Obviously, both the speed of convergence and the steady states depend on the competitiveness/market power in the processing industry. With the assumption of the Nash reasoning, both the equilibrium price and output increase together with the increase in the number of firms. The number of firms also influences the convergence speed. The table below illustrates:

Stationary Equilibrium Price, Quantity, and Aggregate Crushing Profits with Varying Number of Firms (s=0.5, output in millions of metric tons, profits in millions of dollars)

N	**1**	**2**	**3**	**10**	**100**
$\mathbf{w}^*$	134	165	180	207	220
$\mathbf{Q}^*$	21	27.5	30	36	38
Aggregate profits π^*	6375	5913	5465	4216	3401

It is easy to see that, in compliance with the dynamic oligopoly theory with Nash-Cournot behavior, the market characteristics approach competitive levels as the number of firms increase. Profits, however, decline at a lower rate.

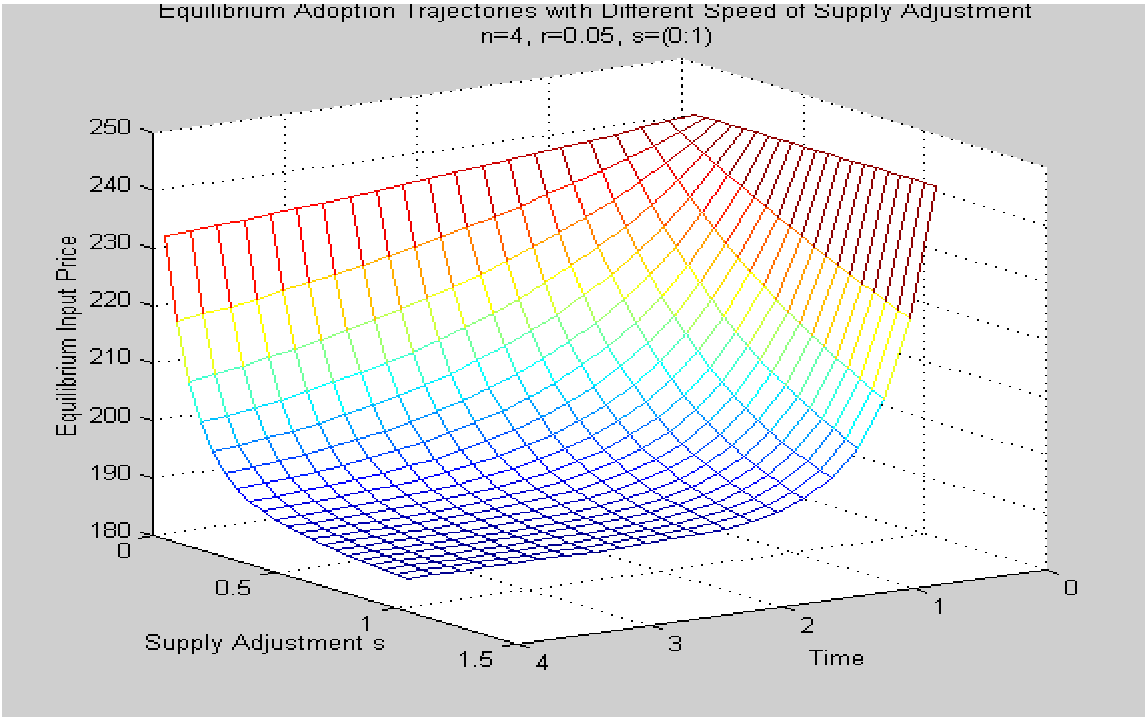
It is hard to compare the convergence periods analytically because the paths only asymptotically approach the steady states. Graphically, however, it can be shown that the time of convergence to the equilibrium adoption level decreases with the number of firms. A picture below illustrates:



The speed of supply adjustment, which in our model is caused by the uncertainty about GM crops future and producers' heterogeneity with respect to profitability of the GM technology, affects the steady state values of the price, quantity, and of course profits. With oligopsony, the higher the adjustment speed parameter *s*, the lower the steady state price and output, and the higher the profits. This trend is observed under different number of firms, and both when the starting price is *above* the long-run equilibrium price (as in our case) and when it is *below* it. With higher *s*, however, convergence is much faster which the figure below illustrates.

Stationary Values with Different Speed of Supply Adjustment (n=4, r=0.05)

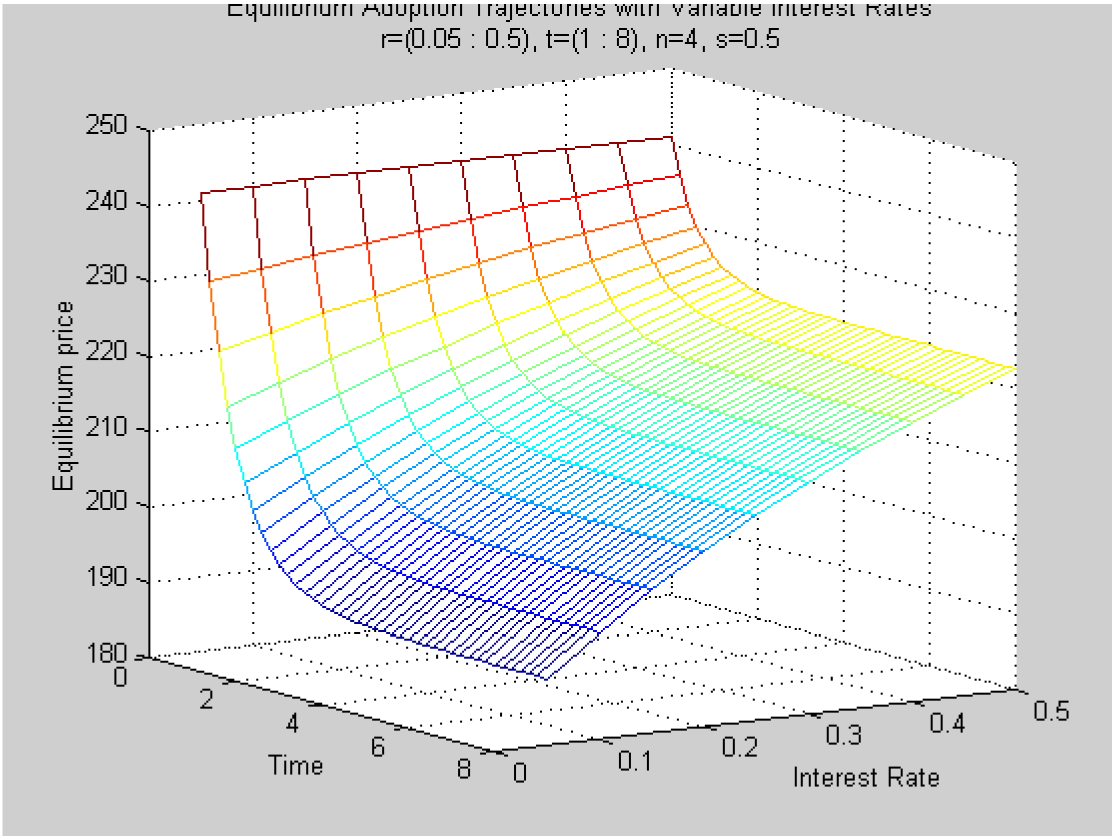
S	0.1	0.35	0.5	0.75	0.9	1
$\mathbf{w}^*$	207	191	188	186	186.5	185
$\mathbf{Q}^*$	36	33	32.5	32	31.8	31.7
π^*	4225	5037	5226	5203	5.23	5.25



Delayed/lagged growers' responses (which are analogous to sticky prices) appear to be an imperfect analogue to "market power" of agricultural producers. In our model, uncertainty about the future and additional heterogeneity caused by the GM technology prevents producers from reacting perfectly competitively. Instead, they exhibit lagged responses to the incentives from the processors (one may say they stick to what they have). And, in the post-adoption period, this is also reflected in the fact that the steady state price is higher than in the case when they are perfectly responsive. It is easy to see that lower prices (lower output) of GM crops reduce the net surplus from the innovation. In particular, agricultural producers benefit from higher GMO output (the more GM crop is grown, the more costs savings are realized). Our simulation results suggest that, when there is uncertainty about GM crops safety and profitability, the growers benefit both in the long and short run. The aggregate surplus over the period of adoption, however, may not be higher because it takes much longer to converge to equilibrium. At this stage, it is ambiguous whether output/price stickiness related to uncertainty and/or imperfect expectations is a good or a bad thing, given there's market power in the processing. Obviously, *less* market power in processing increases both the price and output and also speeds up the transition. And, if we consider GM crops to be something undesirable but unavoidable and care about the producers, we should favor a combination of market power and the uncertain image of GM foods.

From the perspective of the international competitiveness of the U.S., faster adoption seems more desirable. The reason is international "spillovers" of agricultural innovations, in particular biotechnologies. Biotechnology innovations may be adapted to different environments faster than traditional agronomic innovations, for which location-specificity typically plays an important role (Moschini *et al.*, 2000). Also, biotechnology innovations are typically produced by the multinational firms, which are ideally positioned for worldwide marketing. Sales of the latest technology by US multinationals to countries that export competitive products increases profitability for these firms, but undermines US competitiveness in exports of final product. In case of soybeans, higher GM technology adoption rates abroad increase cost efficiency of the other major world soybean producers, undermining US position in the international soybean market.

Different interest rates also affect both the speed of convergence and the steady state. The higher the interest rate, the shorter the adoption period is and the higher the steady state output and price.



Though we do not solve the feedback form of the model, which assumes slightly more realistic firm behavior, theoretically the sensitivity analysis results discussed above will be the same, but the steady state values will reflect more competitive behavior. The intuition behind this is that the price being higher than its long-run value discourages the rivals' transition to the new technology under the feedback assumptions (which is identical to the argument that capacity discourages investment in standard models). Therefore, firms have a greater incentive to lose money buying GM produce at a higher price and processing it as a means of preempting their rivals' expansion into the GM market, and so they "invest" into GM soybeans now. The incentive is absent from the open-loop equilibrium.

5. Conclusions

In this paper, we developed a dynamic model of adoption of GM soybean technology under the assumption of imperfect competition in the soybean processing market. The model is specified as a Nash oligoposony situation, where players with market power make their output decisions facing a probit structure of adoption by the growers and identity preservation requirements

The simulation results show that market power slows the adoption process, but maintains higher level of traditional soybean production. On the other hand, uncertainty associated with GM crops and conservative behavior of the growers benefits agricultural producers and increases the total surplus in the long run. However the adoption period is much longer in this situation, which may undermine the US international competitiveness.

Suggestions for further research include using numerical methods to provide more adequate functional forms and game structures to improve the explanatory power of the model and exploring the model's sensitivity to other parameters. The model can also be applied to other oligopsonistic markets in agriculture.

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