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The Adoption and Diffusion of GM Crops in USA: A Real Option Approach

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Abstract

The paper aims at modelling adoption and diffusion decisions of farmers towards genetically modified crops under a real option framework. Modern GM crops help farmers to resolve two main sources of uncertainty: output uncertainty and input uncertainty. Those crops represent a revolutionary form of farming compared to the technology adoption studied in the literature in the late '70s-early '80s. The paper develops a theoretical model of adoption and diffusion of new GM crops under uncertainty and irreversibility. We test our theoretical predictions using data from 2000 to 2008 of a panel dataset constructed for 13 states of USA involved into the production of 4 different GM crop. These conclusions may appear to contradict the general perception of a delayed penetration for the GM crops, whose success seems to be retarded by lack of information, mistrust and an exaggerated perception of risks. GM crops tend to be invasive, in that their short term profitability is so high as compared with the investment needed, that once the hump of uncertainty is overcome, they operate a veritable takeover of agriculture

Keywords: Adoption, Diffusion, Uncertainty, Irreversibility, Real Option

Introduction

GM crop adoption has experienced unprecedented rate of growth over the past ten years. Worldwide, in 2008 there were 125 million of hectares of land under GM crop, with nearly 25 countries adopting this new kind of technology (James, 2008). The early adopters, namely the top 8 countries, growing more than 1millions of hectares of land are: USA, Argentina, Brazil, India, Canada, China, Paraguay, and South Africa. All together they represent 98% of the 125 millions of hectares of land under GMO, out of which, 57% is located in North America, 32% in Latin America, 6% in India, 3% and 1.5% in China and South Africa respectively. GM maize has been the major crop adopted by most of the countries. Since their introduction in 1996, GM crops exhibit a peculiar form of new technology, which could run counter the cases examined in earlier literature that has analyzed the adoption problem. The distinction between adoption and diffusion has emerged as a consequence of the problem of the sequential nature of farmers' decision. In the traditional approach, because the innovative technology was divisible (improved seed, fertilizer and herbicides), a farmer had to decide first how much land to cultivate under the new technology, and then decide the amount of fertilizers and pesticides to use. Farm level adoption was expressed as the degree of utilization of a new crop such as hybrid maize, and diffusion (or aggregate adoption) refers to extent of utilization of a technology (Rogers, 1962 and 1983; Just and Zilberman, 1983; Feder et al., 1985, Marra and Carlson, 1990).

The dichotomy between adoption and diffusion can be explained by two main reasons. Whether the farmers' decisions are sequential or simultaneous, the empirical evidence has indicated that a time gap existed between adoption and diffusion. If, at the early stage of their introduction, factors such as social, cultural, economic, technical and environmental (Jamison and Lau, 1982) explain low levels of adoption, it has also been observed that differences in access to and diffusion of information may be important determinants of adoption decisions (Longo, 1990; Aklilu, 1974; Ayana, 1985; Feder et al.1982). Social networks are also of fundamental importance in order to understand different degrees of adoption. In rural economies, farmers within a group tend to share information and learn new agriculture practices from each other

(Foster and Rosenzweig, 1995; Conley and Udry, 2000). The degree of adoption depends on the presence of "opinion leaders" in a community, who appear to be more exposed to sources of information, such as mass media or change agents (e.g., extension workers), with higher degree of education, and having more income and wealth (Chatman, 1987; Rogers, 1995, p. 92; Valente, 1996; Weimann, 1994). Diffusion depends on whether and how communication among farmers within the community occurs and, in particular, on whether there is homophily or heteropholy, namely whether individuals communicate more easily with those who are similar or different, respectively, from them. The empirical evidence is ambiguous, with some pointing towards a major flow of information from higher status rural groups to lower strata (Roling, Ascroft and Wa Chege, 1976; Van de Fliert, 1993), while for others, the results are not straightforward (Feder and Savastano, 2006).

The duality adoption/diffusion that has characterized the literature on new technology adoption during the 80es and 90es seems to be confounded when dealing with GM adoption. When farmers or countries have decided to adopt, they adopt and diffuse at an exponential rate. In this respect, the measure of diffusion in terms of the S-shape function is invalid. The statement that if large farmers adopt first, diffusion over a resource will occur more quickly; if small farmers adopt first, diffusion over the resource will occur more slowly fails to be endorsed by observations.

In this paper we look at the process of diffusion of GM crops, by focusing on two unconventional characteristics of the new varieties: their extremely high short run comparative advantage and the irreversibility of their adoption in the face of dynamic uncertainty both on the market for agricultural commodities on their long term sustainability. By looking both at theoretical arguments and empirical evidence, we claim that, because of these two characteristics, GM crops diffusion can be best explained in a real option framework, as a succession of reluctances and eager waves of adoption.

The paper is organized as follow: section 1 summarizes the literature on the adoption diffusion duality, section 2 depicts the theoretical model of adoption and diffusion decisions under uncertainty and irreversibility. Section 3 derives the conceptual framework underpinning the empirical work in the paper. This is followed by the description of the data source and the empirical results. The last section provides conclusions and policy implications.

1. Adoption and Diffusion

The decision to adopt a new technology has been widely documented in the literature. From a general point of view, a decision maker will invest in a new technology if this helps reducing the causes of uncertainty he has to face, and when the expected marginal benefits are larger than the costs he has to sustain. In this respect, modern GM crops help farmers to resolve two main sources of uncertainty: output uncertainty and input uncertainty. By delivering the promise to increase the yield and reduce the amount of pesticides used, those crops represent a revolutionary form of farming compared to the technology adoption studied in the literature in the late '70s-early '80s. In those years most studies focused on the benefits of introducing new technology such as hybrid maize into farming, where the main question was whether the higher fertilizer and pesticide requirement of the new crop was sufficiently offset by higher yields.

Since the pioneering works of Dillon (1971), and Anderson, Dillon and Hardaker (1977) a substantial body of the literature has tried to formalize and rationalize the decision-making process of farmers who face imperfect knowledge (when there is uncertainty) and when the outcomes of those decisions are uncertain (that is, the farmers faces risk). Despite the large number of studies on risk, uncertainty, and learning in the adoption of new technologies, there are two commonly observed theoretical and empirical regularities or "stylized facts" of new technology adoption: risk preferences would lead risk averse farmers to postpone the adoption decision, and the succession of early and late adopters would result in the S-shaped adoption/diffusion curve.

On the one hand, the adoption of a new technology can be conceived as resulting from a fine balancing act between its profitability and the farmer's attitude towards the risk associated to it.

An impressive empirical evidence, among the early literature of new technology adoption, has shown that farmers in developing countries are risk averse, and tend therefore to delay the decision to adopt a new technology (Moscardi and de Janvry, 1977; Dillon and Scandizzo, 1978; Binswanger, 1980, Antle, 1987). According to these studies, even a small uncertainty related to the increase in pesticides costs as well as the higher prices of the seeds, could make small and risk adverse farmers delaying the decision to adopt a new crop variety.

Farm size, and land endowment, is another important diversifying factor affecting the decision to adopt a new technology. In the empirical studies, a positive relation between adoption and farm size is often found when food security is not a binding constraint, or when there are fixed transaction and information acquisition costs associated with the new technologies, therefore preventing smaller farms to engage in innovation (Just et al., 1980; Feder and O'Mara, 1981; cited in Feder et al., 1985). Earlier studies (Schumpeter 1942; Cochrane 1958; Reimund, Martin and Moore, 1981) and later ones (Cohen and Klepper, 1996) have embraced the S-shape theory of the adoption/diffusion curve. Other studies, however, have pointed out to a negative relation between farm size and technology adoption, mostly due to farmers' risk aversion and their tendency to follow a technological ladder in adoption. Some studies claim that farmers follow a step-wise approach (first improved seed, and then fertilizers), (Byerlee and Hesse de Polanco, 1986; Norman et al, 1995; Kaliba and Featherstone, 1997; Kaliba et al., 2000), and that such an approach tends to delay technology adoption.

More than 50 years have elapsed since the first experiments and field trials of the hybrid maize (Shull 1909 – "inbred-hybrid maize", Jones 1916 – "double-cross hybrid") took to the replacement of the overall area planted under OPV maize "Open-pollinated variety" in late sixties. In particular, 30 years have elapsed from the emergence of the first hybrid seed companies (late twenties) to the development of the real hybrid seed industry. By 1960 hybrid maize completely replaced the area under OPV maize production in USA.

Although maize did not experience the so-called green-revolution of rice and wheat, dating from 1960 onward, improved crop varieties, such as hybrid maize, rice and wheat, started to be introduced in developing countries. The degree of adoption and dissemination of these modern technologies varied across and within countries, with differences due to size of the farm, risk attitudes, cash liquidity in order to buy fertilizers, geographical locations and so on.

In the USA, less than 15 years have elapsed since the first development of genetically modified *Roundup Ready* soybeans became commercially available, followed by *Roundup Ready* corn in 1998. By 2008, GM corn accounted for 85% of the 35.3 million hectare in the USA (James, 2008 – ISAAA), with roughly 78% constituted by hybrids with either double or triple stacked traits – and only 22% by hybrids with a single trait.

The speed of the adoption rate, as well as dissemination, has been multiplied by 3. It took only few years to bring GM crops to their complete maturity stage that is to the stage where GM crops are completely commercial, and are the predominant technology available to farmers.

Three main types of GM crops are today available: first, second and third generations. The major commercial GM crops are the first generation ones. These crops possess enhanced input traits modified for herbicide tolerance and insect resistance (James, 2003). Since their commercial introduction in 1996, they delivered the double promise of increasing agriculture yields and reducing farmers' operating costs, thereby fighting against the two main sources of uncertainty of agriculture operation. They thus appear to benefit farmers by lowering production costs, improving crop yields, and reducing the level of pesticides required for the control of insects, diseases, and weeds. Although their buoyancy in the first years of cultivation seems to be followed by a less spectacular performance in the later years, once adoption starts, the process of diffusion seems to proceed with an impetus unmatched by any previous experience with improved crop varieties. In particular, after an initial period of resistance, which seems to be based on uncertainty and risk aversion, their diffusion is not limited to replacement of previous crops of the same type, but it has the characteristic of a true takeover, using all potential land, including pastures and forests, that can be converted to their cultivation.

2. A theoretical model for the rate of adoption and diffusion

Assume that the GM technology, as a new source of wealth for farmers, is exogenous and stochastic. Specifically, because of demand volatility, and the experimental nature of the crop, the opportunity to earn income Q from biotechnology innovation is assumed to be a random variable following a diffusive stochastic process of the Brownian motion variety:

$$dQ = \alpha Q dt + \sigma Q dz \qquad (1)$$

dz being a random variable with mean zero and variance equal dt. The units of measure of Q are in terms of yield equivalents (e.g. tons of produce per ha of land), and the parameters α and σ^2 represent respectively the drift or trend in income and the variance. Individuals (depicted by the subscript *i*) obtain income y_i assumed for simplicity to be proportional to price P multiplied by yield Q the area under GM crops N_i:

$$y_i = PN_iQ \qquad (2)$$

The individual obtains a share w_i of GM area (i.e. $N_i = w_i N$) and therefore can obtain $w_i AQ$ of innovative activity, where Q is the yield earned per unit of activity of the *i*th farm. Because of the fact that traditional technology may entail different levels of inputs depending on technological know how and risk aversion, individuals are heterogeneous in their ability to obtain an income x_i from the traditional crops, but not for the GM crop:

$$x_i = Pv_iG_i \quad ; \quad y_i = PQN_i \qquad (3)$$

where v_i is the yield of the traditional crop and $G_i = \omega_i G$ is the area of traditional crops and N_i the area of GM crop of the *i*th farm. Both yields are assumed to be independent of the farm size of operation. In each period, the farmer can sell or buy land services S_i at the price p, and this may include purchasing or selling land to other farmers as well as developing new farm land from alternative previous uses, such as forests and pastures. The price of land p thus summarizes average costs to bring additional land into farm production, including investment and opportunity costs from alternative uses according with a land supply function of a given elasticity. The land farmed by each farmer respects the constraint: $S_i = \omega_i G + w_i N$, where $\omega_i = \frac{G_i}{G}$ and $w_i = \frac{N_i}{N}$.

The *i*th farmer faces the dual problem to determine the size of his farm and to distribute his farm land between the two technologies by trying to maximize his extended net present value (ENPV) according with the expression:

$$\max_{w_i} ENPV_i = \frac{1}{\delta}[(P-c)v_i(S_i - w_i N) + (P-k)w_i NQ - pS_i] + w_i NI - B_i Q^{\beta_1} \qquad (4)$$

In (4), $\delta = \rho - \alpha$, while I represents the investment that is necessary to undertake in order to adopt the new technology. $B_i Q^{\beta_1}$ is the waiting option corresponding to the investment in the new technology according to the value matching condition:

$$B_i Q^{\beta_1} = \frac{1}{\delta}[(P-c)v_i(S_i - w_i N) + (P-k)w_i NQ - pS_i] - w_i NI \qquad (5)$$

Maximizing with respect to farm size brings the farmer to seek the equality between the net marginal product of land and land price. Thus, in the initial situation, with no GM adoption, the expected net present value (NPV) of the traditional technology can be expected to be greater than the opportunity cost of land, the difference reflecting rents from the fixity of land and other transaction costs.

From the point of view of the GM crop, however, we face a completely different situation for two major reasons. First, adoption requires an irreversible investment, both because of irrecoverable costs and because the new varieties tend to spread outward in ways that cannot be reversed (Beckman et al., 2006). Second, crop profitability is uncertain because of lack of sufficient information on performance and risks (yields follow a stochastic process). Maximizing expression (4) with respect to the farmer's share of the GM crop, therefore, under the stochastic constraint in (5), we find that the choice of the area under the GM crop that would maximize the extended net present value is:

$$w_i^* = \frac{\beta_1[(P-c)v_i - p]S_i}{N\beta_1[(P-c)v_i + I\delta] - N[(\beta_1 - 1)(P-k)Q]} \qquad (6)$$

This choice corresponds to what can be defined as "adoption", i.e. the level of technological development at which the *i*th farmer will decide to enter the new technology. Such a level will depend on his exposure and information to it, and can be quantified by his share w_i of the total GM area. As already noted, before the process of adoption starts, net margins per ha of the traditional technology can be expected to exceed the opportunity cost of land (i.e. either the cost of developing new land or of renting it). This means that the numerator in (6) will be positive. At the same time, the net present value (NPV) of the cash flow per ha expected from the traditional crops may be expected to exceed the NPV per ha of GM crops since this includes investment costs and expected yield from the stochastic process is still low and more uncertain. Here the drift of the stochastic process ruling the GM yield incorporates both the tendency of yield to grow with more experience in cultivation (at least from the first, buoyant years that characterize most GM crops) and consolidation of (not necessarily founded) farmers' expectations of higher and growing yields for the future. After a period of cautious experimentation, however, once the level of Q is reached for which adoption becomes convenient (i.e. expected NPV from the new technology exceeds the NPV for the old one even after adjusting for uncertainty and investment costs), the price of land p will be driven above marginal productivity per ha of the traditional crops. Both the numerator and the denominator of (6) will thus see their signs reversed and the substitution of the new for the old technology will become total when the following equality is reached:

$$\frac{\beta_1}{\beta_1 - 1}(p + \delta I) = (P - k)Q \qquad (6a)$$

At this point, all farms will also have totally adopted the new technology. Because GM yield continues to grow, however, expression (6a) denotes a movable bound, as the price of land will be continuing increase under the push of the new technology. Thus, the process of diffusion will not be complete until all available land has been drawn into the new technology and the price of land has risen to the point where no increase in expected GM yields will be capable to bring new land into culture.

To summarize: with zero adoption rate, the numerator of (6) will be greater or equal to zero (the net margins per ha of the traditional technology greater than the cost of land services). When the threshold of profitability of the new technology will be reached, however, the price of land will start being driven up by growing GM expected yields and soon the price of land will exceed the marginal product of the traditional crops. Land will be progressively shifted toward GM crops, but it will soon become a race between the accelerating price of land services and the increase in GM yields. The adoption process will be slowed down by uncertainty and accelerated by GM yield increases. While land prices are sufficiently low, however, the two technologies may coexist and in this case, the GM share will be higher the higher is GM yield Q and related net margins $P - k$, the lower the cost of land services (and other land augmenting inputs), and the lower the profitability of the traditional technology. In this intermediate stage, as can be seen by differentiating w.r.t. to β_1, the optimal share w_i increases with the value of this parameter[1] and thus decreases with uncertainty (since β_1 is negatively related to the variance of the stochastic process).

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[1] The derivative equals to: $\frac{dw_i}{d\beta_1} = [(P - c)v_i - p]S_i$ and is greater than zero if the traditional crop is grown on the *i*th farm.

To find the total number of ha N under the BT crop, we recall the condition $\sum w_i = 1$, where the sum is over all farms involved in the adoption process. Performing this sum in (6) and solving for N , we obtain:

$$\frac{N}{S} = \frac{(P-c)\bar{v}_s - p}{\dfrac{(P-c)\bar{v}_n - [\dfrac{(\beta_1 - 1)}{\beta_1}(P-k)Q - I\delta]}{}} \qquad (7)$$

where $\bar{v}_s = \sum \frac{S_i}{S} v_i$ and $\bar{v}_n = \sum w_i v_i$ denote the average yields of traditional crops respectively on total land and on the land devoted to the new technology.

Expression (7) shows how the diffusion mechanism differs from the adoption one. While the individual shares (i.e. the level of adoption) depend only on exogenous variables, some of which vary idiosyncratically across farmers (e.g. the distribution of farm size and the yield of the traditional crops), the total area under BT crops depends on adoption from a plurality of farmers and thus, endogenously, on the distribution of the individual farm areas between the new and the old technology. Note that $\frac{N}{S}$ is equal to 1 only when all farmers have adopted, but for less than full adoption, diffusion will be larger (i.e. $\frac{N}{S}$ closer to 1), the closer the NPV of the new technology will be to the aggregate opportunity cost for switching from the old to the new technology.

$$(P-k)Q = \frac{\beta_1}{\beta_1 - 1}[(P-c)(\bar{v}_n - \bar{v}_s) + p + I\delta] \qquad (7a)$$

The first term in square brackets in (7a) is negative if the farmers that adopt the new technology are, on average, less productive with the old one. This seems reasonable, under most circumstances, since the first adopters would be those that gain most, *coeteris paribus*. Thus, diffusion will be faster, the more diversified the farmers in their ability to increase incomes by using the old technology.

From (6) we can also derive the value for the equilibrium price p of land services by applying the constraint of the total land available $S = \sum S_i$. Assuming a constant elasticity supply function for land $S = S_0 p^{\eta}$, we find that at full adoption land will be drawn into cultivation at the average rate:

$$\frac{dS}{dt} = \eta\alpha(\beta_1 - 1)(P - k)Q \qquad (8)$$

where we have applied $EdQ = \alpha dt$ from the definition of the stochastic process in (1).

To summarize our analysis: for a given price of land, the adoption rate of the individual farmer will depend in principle on how profitable is the GM crop as compared to the traditional crops. For a sufficiently higher differential profitability, all farmland will be devoted to GM crop. The process of diffusion, however, will cause land price to rise, and new land will be drawn into cultivation. A race between the yield increases spurn by the new technology and land prices will ensue with uncertain results, since the apparent ever-increasing character of GM economic profitability will result into a progressive takeover of a whole variety of other land uses, including pastures and forests.

3. Some empirical evidence

By linearizing equation (6), we obtain the following estimable equation for the rate of adoption:

$$w_i = f(\underset{+}{N}, \underset{+}{S}, \underset{+}{P}, \underset{-}{p}, \underset{+}{c}, \underset{-}{k}, \underset{-}{\sigma^2}, R) + u_i \qquad (9)$$

where we have introduced a variable R to indicate, in addition to variance, the perceived level of risks that may affect the farmers' decisions. In (9) u_i is a well-behaved random disturbance and the symbols under the variables indicate the expected pattern of signs. While we do not have farm level data to estimate (9), we have data of adoption at the level of each US state for 5 years. We can thus re-write equation (9), denoting time with the subscript t as:

$$\psi_{jt} = \sum_{i=1}^{n_j} w_{it} = g(\underset{+}{N}, \underset{+}{S}, \underset{+}{P}, \underset{-}{p}, \underset{+}{c}, \underset{-}{k}, \underset{-}{\sigma^2}, R) + \sum_{1=1}^{n_j} u_{it} \qquad (10)$$

Because total land at the state level can be considered also a measure of diffusion of the new technology, by a simple transformation of (10), we can also specify a "diffusion" equation of the following form:

$$N_{jt} = \psi_{jt} N_t = N_t \sum_{i=1}^{n_j} w_{it} = h(\underset{+}{S}, \underset{+}{P}, \underset{-}{p}, \underset{+}{c}, \underset{-}{k}, \underset{-}{\sigma^2}, R) + V_{jt} \qquad (11)$$

where N_{jt} denotes the area under the GM crop considered in the *j*-th state in the *t*-th year and V_{jt} is again a well-behaved random disturbance.

3.1. Data Source

We make use of a panel dataset built upon a set of different sources. Data for GM crop adoption are drawn from the USDA's National Agricultural Statistics Service (NASS) survey from 2000 to 2008 for 13 states of USA involved into the production of 4 different GM crops: Bt and Ht corn, all GE corn, and Ht soybean. Additional state level and aggregate data for the same period are drawn from the Economic Research Service (ERS) of the USDA. In particular, for each traditional crop we have state level information on total area harvested, price per unit of crop, whereas, at the USA level, our analysis include time series on index of fuel, herbicides, insecticides, and fertilizers. We complement our analysis with geographical dummies, and variables on yearly news about GM constructed using "Google News". Finally we have computed a time series variables on the number of GM permit approved by USDA's Animal and Plant Health Inspection Service (APHIS).

To analyze the effect of uncertainty on GM crop adoption and diffusion, we run two types of regression. : the first on the log difference of the area allocated to each GM crop and the total area in USA. This will test the adoption rate by each state. The second, on the adoption, namely amount of area allocated to each GM crop by state in every year.

We have two measures of uncertainty: one the one hand the variance of the area under each GM crop in USA over the period 1996 to 2008. Data at the state level are only available between 2000 and 2008, and computing state level variance would have reduced the length of the panel. For each year, starting from 2000, uncertainty proxy is computed as the variance of the residual of an OLS on time between t and t-t0. The second proxy of uncertainty is represented by the parameter $\frac{\beta_1}{\beta_1 - 1}$, applying specific values to rho minus delta, the percentage growth of farm revenue that the holder of the option is foregoing, in order to keep alive the option invest in GMO crops. According to Dixit and Pindyck, Beta is equal to

$$\beta_1 = \frac{1}{2} - \frac{(\rho - \delta)}{\sigma^2} + \sqrt{\left[\frac{(\rho - \delta)}{\sigma^2}\right]^2 + \frac{2\rho}{\sigma^2}} \, for \, \beta_1 > 1$$

3.2. Empirical Results

Tables 1- 4 present our results from the application of (11) and (10) to the database mentioned. While the results on the diffusion variable appear weak, those on the adoption variable (the share of land) are mostly significant and show all the expected signs.

Uncertainty over GM crop is more a matter of adoption rather than diffusion. As the figures of the pattern of GM crop development shows, once farmers adopt this new type of crop, the rate of diffusion is fast and the traditional S-shape curve of technology diffusion elapses.

The coefficient of the uncertainty proxies (variance and beta parameters) reflect the negative relationship between adoption and objective risk. In addition to that, to take into account the uncertainty associated with health risk of GMO, we have included a variable that summarizes the google page encompassing the following words "adoption + GM crop + health risk". As expected there is a negative relationship between adoption and the news, pointing towards an increasing reluctance of adopting before uncertainty is resolved. The coefficient of the remaining variables confirm the theoretical expectations of a supply function estimation. In particular, supply of GM crop increase land area under crop cultivation, with the price of the input trait of the GM crop, while it decreases with the price of any other input used.

Conclusions

Unlike other cultures and technologies, GM crops present distinctive characteristics in the adoption-diffusion stages. While adoption goes on by convincing farmers to experiment and substitute the new crops for the old ones, diffusion goes beyond full adoption on the part of all farmers. With the spread of the new crops to areas previously destined to other types of culture, and even to pasture and forests, diffusion tends to become a process of colonization, where potential land is progressively taken over by GM technology.

Both adoption and diffusion depend, for their deployment, on thresholds of perceived profitability and risks being crossed. These thresholds, in turn, depend on internal and external factor, such as experiments on and off farmers' own estates, information and prices. Diffusion, however, depends both on the crossing of the critical thresholds on the part of existing farmers for the same crops, and on its own thresholds to spread to other potential farming land. In the end, therefore, the two processes together are likely to show a much greater momentum of traditional innovative agricultural technologies.

These conclusions may appear to contradict the general perception of a delayed penetration for the GM crops, whose success seems to be retarded by lack of information, mistrust and an exaggerated perception of risks. As the experience in the US and in several other countries (e.g. Argentina and China) shows, GM crops tend to be invasive, in that their short term profitability is so high as compared with the investment needed, that once the hump of uncertainty is overcome, they operate a veritable takeover of agriculture. While adoption may still proceed slowly in several cases, and diffusion may thus be blocked by lack of information, administrative decisions or government interventions, the drive to extreme diffusion of GM's seems inevitable, given sufficient time. In fact, the only remedy for the loss of biodiversity implied by such a drive is in the diversification potential of the same GMs.

Table 1: Bt Corn Adoption and Diffusion

	(1) OLS on Log area Bt corn State i = **Diffusion**	(2) OLS on Log area Bt corn State i = **Diffusion**	(3) OLS on Log area Bt corn State i - Log total area Bt Corn in USA = **Adoption**	(4) OLS on Log area Bt corn State i - Log total area Bt Corn in USA = **Adoption**
Var log area Bt Corn USA (detrend)	-0.046		-0.481***	
	(0.83)		(8.68)	
(Beta/(Beta-1)) of Bt corn		4.640		48.638***
		(0.83)		(8.68)
Log share of farm in the state relative to USA	-0.128*	-0.128*	-0.128*	-0.128*
	(1.65)	(1.65)	(1.65)	(1.65)
Log Total area of corn Harvested	0.025***	0.025***	0.025***	0.025***
	(6.22)	(6.22)	(6.22)	(6.22)
Log Price per Unit	-0.016	-0.016	-0.016	-0.016
	(0.54)	(0.54)	(0.54)	(0.54)
Log nb Permit Approved	-0.037	-0.062	-0.025	-0.285***
	(0.64)	(0.75)	(0.43)	(3.45)
Log Index of Fertilizer Prices Paid	0.046	-0.016	-1.228***	-1.879***
	(0.34)	(0.10)	(9.14)	(12.25)
Log Index of Fuel Prices Paid	-0.017	-0.042	0.443***	0.177**
	(0.23)	(0.50)	(5.92)	(2.07)
Log Index of Herbicide Prices Paid	0.022	0.000	-0.170*	-0.405***
	(0.23)	(0.00)	(1.72)	(3.62)
Log Index of Insecticide Prices Paid	0.002	0.160	1.752***	3.399***
	(0.02)	(0.52)	(11.11)	(11.07)
Log Nb od pages on google news GM crops adoption	-0.005	-0.005	0.034***	0.034***
	(0.65)	(0.65)	(4.50)	(4.44)
Log Nb od pages on google news GM corn adoption health risk	0.002	0.000	-0.031***	-0.046***
	(0.43)	(0.03)	(8.06)	(11.23)
Dummy Northern Crescent Region	1.063	1.063	1.063	1.063
	(1.51)	(1.51)	(1.51)	(1.51)
Dummy Northern Great Plains region	-0.606	-0.606	-0.606	-0.606
	(0.59)	(0.59)	(0.59)	(0.59)
Dummy Prairie Gateway region	0.597	0.597	0.597	0.597
	(0.84)	(0.84)	(0.84)	(0.84)
Observations	117	117	117	117
Number of State nb	13	13	13	13
R-square within	0.32	0.32	0.99	0.99
R-square betwenn	0.87	0.87	0.87	0.87
R-square overall	0.32	0.32	0.99	0.99

Source: Authors' computation on NASS, ERS and APHIS Data

Absolute value of z statistics in parentheses

* significant at 10%; ** significant at 5%; *** significant at 1%

Table 2: Ht Corn Adoption and Diffusion

	(1) OLS on Log area Ht corn State i = **Diffusion**	(2) OLS on Log area Ht corn State i = **Diffusion**	(3) OLS on Log area Ht corn State i - Log total area Ht Corn in USA = **Adoption**	(4) OLS on Log area Ht corn State i - Log total area Ht Corn in USA = **Adoption**
Var log area Ht Corn USA (detrend)	-1.610		-7.479***	
	(1.22)		(5.66)	
(Beta/(Beta-1)) of Ht corn		2.342		10.877***
		(1.22)		(5.66)
Log share of farm in the state relative to USA	-0.086	-0.086	-0.086	-0.086
	(1.09)	(1.09)	(1.09)	(1.09)
Harvested	0.021***	0.021***	0.021***	0.021***
	(5.28)	(5.28)	(5.28)	(5.28)
Log Price per Unit	-0.020	-0.020	-0.020	-0.020
	(0.71)	(0.71)	(0.71)	(0.71)
Log nb Permit Approved	0.084	0.105	0.881***	0.979***
	(1.05)	(1.09)	(11.00)	(10.21)
Log Index of Fertilizer Prices Paid	0.140	0.074	-1.392***	-1.698***
	(1.02)	(0.59)	(10.16)	(13.47)
Log Index of Fuel Prices Paid	-0.080	-0.059	0.407***	0.504***
	(0.91)	(0.75)	(4.62)	(6.40)
Log Index of Herbicide Prices Paid	-0.073	-0.071	-0.539***	-0.532***
	(0.52)	(0.51)	(3.86)	(3.84)
Log Index of Insecticide Prices Paid	0.105	0.167	2.401***	2.692***
	(0.49)	(0.65)	(11.25)	(10.47)
Log Nb of pages on google news GM crops adoption	-0.001	0.004	0.101***	0.123***
	(0.09)	(0.46)	(14.87)	(13.81)
Log Nb of pages on google news GM corn adoption health risk	0.004	0.001	-0.037***	-0.047***
	(0.95)	(0.38)	(9.90)	(12.98)
Dummy Northern Crescent Region	1.202*	1.202*	1.202*	1.202*
	(1.68)	(1.68)	(1.68)	(1.68)
Dummy Northern Great Plains region	0.063	0.063	0.063	0.063
	(0.06)	(0.06)	(0.06)	(0.06)
Dummy Prairie Gateway region	0.724	0.724	0.724	0.724
	(1.00)	(1.00)	(1.00)	(1.00)
Observations	117	117	117	117
Number of State nb	13	13	13	13
R-square within	0.52	0.52	0.99	0.99
R-square betwenn	0.79	0.79	0.79	0.79
R-square overall	0.52	0.52	0.99	0.99

Source: Authors' computation on NASS, ERS and APHIS Data
Absolute value of z statistics in parentheses
* significant at 10%; ** significant at 5%; *** significant at 1%

Table 3: All GE Corn

	(1) OLS on Log area all GE corn State i = **Diffusion**	(2) OLS on Log area all GE corn State i = **Diffusion**	(3) OLS on Log area all GE corn State i - Log total area all GE Corn in USA = **Adoption**
Var log area Bt and Ht Corn USA (detrend)	-0.114		-401.264***
	(0.89)		(3.60)
(Beta/(Beta-1)) of all GE corn		2.360	
		(0.89)	
Log share of farm in the state relative to USA	-0.015	-0.015	141.611***
	(0.14)	(0.14)	(4.11)
Log area Harvested	0.026***	0.026***	-6.023***
	(5.28)	(5.28)	(3.41)
Log Price per Unit	-0.029	-0.029	-250.558***
	(0.91)	(0.91)	(38.46)
Log nb Permit Approved	-0.051	-0.064	-330.352***
	(0.90)	(0.95)	(9.01)
Log Index of Fertilizer Prices Paid	0.129	0.078	
	(0.88)	(0.51)	
Log Index of Fuel Prices Paid	-0.050	-0.066	-459.855***
	(0.61)	(0.78)	(27.53)
Log Index of Herbicide Prices Paid	0.036	0.020	1,348.944***
	(0.33)	(0.17)	(15.91)
Log Index of Insecticide Prices Paid	-0.057	0.063	-204.158*
	(0.34)	(0.24)	(1.87)
Log Nb of pages on google news GM crops adoption	-0.009	-0.008	-5.498**
	(1.08)	(1.04)	(2.08)
Log Nb of pages on google news GM corn adoption health risk	0.004	0.003	-3.099***
	(0.92)	(0.61)	(7.74)
Dummy Northern Crescent Region	1.145	1.145	-958.918***
	(1.28)	(1.28)	(3.33)
Dummy Northern Great Plains region	0.365	0.365	-1,378.572***
	(0.24)	(0.24)	(2.78)
Dummy Prairie Gateway region	0.377	0.377	811.690***
	(0.44)	(0.44)	(2.95)
Observations	117	117	117
Number of State nb	13	13	13
R-square within	0.47	0.47	1.00
R-square betwenn	0.76	0.76	0.06
R-square overall	0.47	0.47	1.00

Source: Authors' computation on NASS, ERS and APHIS Data

Absolute value of z statistics in parentheses

* significant at 10%; ** significant at 5%; *** significant at 1%

Table 4: Ht Soybean Adoption and Diffusion

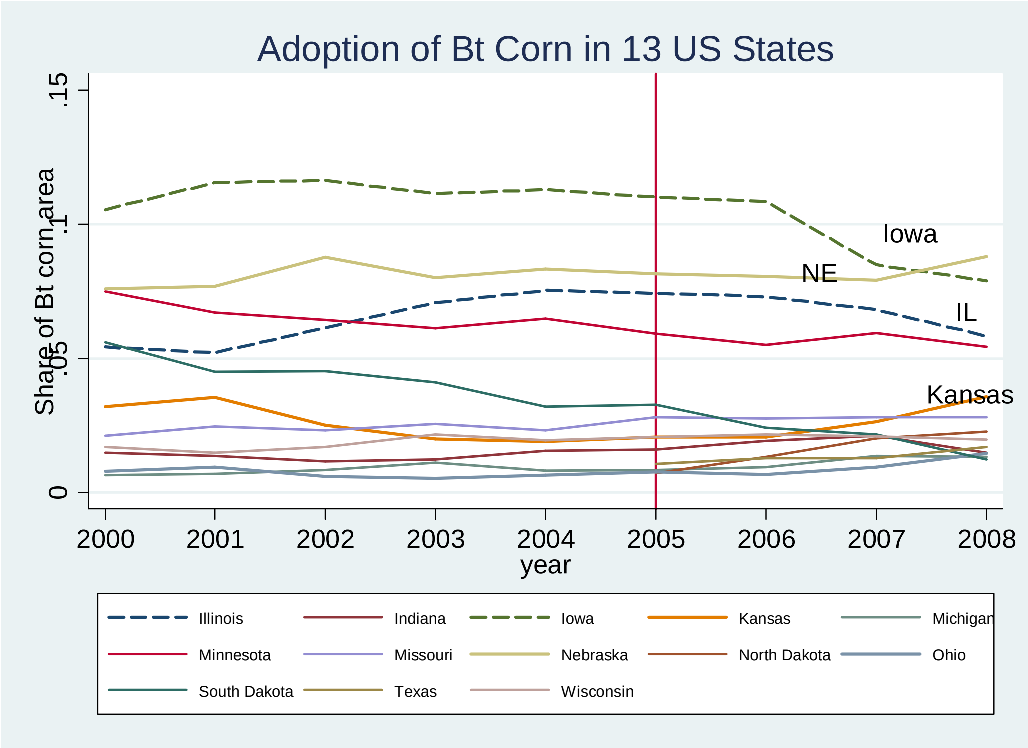
	(1) OLS on Log area Ht Soybean State i = **Diffusion**	(2) OLS on Log area Ht Soybean State i = **Diffusion**	(3) OLS on Log area Ht Soybean State i - Log total area Ht Soybean in USA = **Adoption**	(4) OLS on Log area Ht Soybean State i - Log total area Ht Soybean in USA = **Adoption**
Var log area Ht Soybean USA (detrend)	-0.026**		-208.307	
	(2.39)		(1.33)	
(Beta/(Beta-1)) of Ht soybean		0.653**		
		(2.39)		
Log share of farm in the state relative to USA	-0.001	-0.001	0.455	-0.145
	(0.44)	(0.44)	(0.03)	(0.02)
Log area Harvested	0.012***	0.012***	-0.543	0.121
	(19.15)	(19.15)	(0.14)	(0.05)
Log Price per Unit	0.000	0.000	0.912	4.479
	(0.11)	(0.11)	(0.15)	(1.18)
Log nb Permit Approved	-0.001	0.001	-185.511***	-12.080
	(0.18)	(0.30)	(3.26)	(0.69)
Log Index of Fertilizer Prices Paid	0.001	-0.007	195.955***	312.617***
	(0.25)	(1.55)	(4.05)	(10.17)
Log Index of Fuel Prices Paid	-0.004	-0.006**	-186.266***	-39.953**
	(1.60)	(2.00)	(4.89)	(1.99)
Log Index of Herbicide Prices Paid	-0.004	-0.008		-935.842***
	(0.51)	(0.87)		(12.41)
Log Index of Insecticide Prices Paid	0.011	0.030	-390.843***	328.499***
	(0.88)	(1.56)	(3.97)	(4.60)
Log Nb of pages on google news GM crops adoption	-0.000	0.000**	-28.675***	-34.260***
	(0.26)	(2.32)	(8.23)	(19.48)
Log Nb of pages on google news GM corn adoption health risk	-0.000	-0.000*	10.072***	16.957***
	(0.19)	(1.84)	(6.85)	(17.01)
Dummy Northern Crescent Region	0.030	0.030	-24.502	11.439
	(0.32)	(0.32)	(0.04)	(0.03)
Dummy Northern Great Plains region	0.078	0.078	-26.467	33.233
	(0.81)	(0.81)	(0.05)	(0.09)
Dummy Prairie Gateway region	0.198**	0.198**	-44.646	25.330
	(2.16)	(2.16)	(0.08)	(0.07)
Observations	117	117	117	117
Number of State nb	13	13	13	13
R-square within	0.85	0.85	0.73	0.89
R-square between	0.98	0.98	0.53	0.49

R-square overall	0.85	0.85	0.73	0.89

Source: Authors' computation on NASS, ERS and APHIS Data

Absolute value of z statistics in parentheses

* significant at 10%; ** significant at 5%; *** significant at 1%



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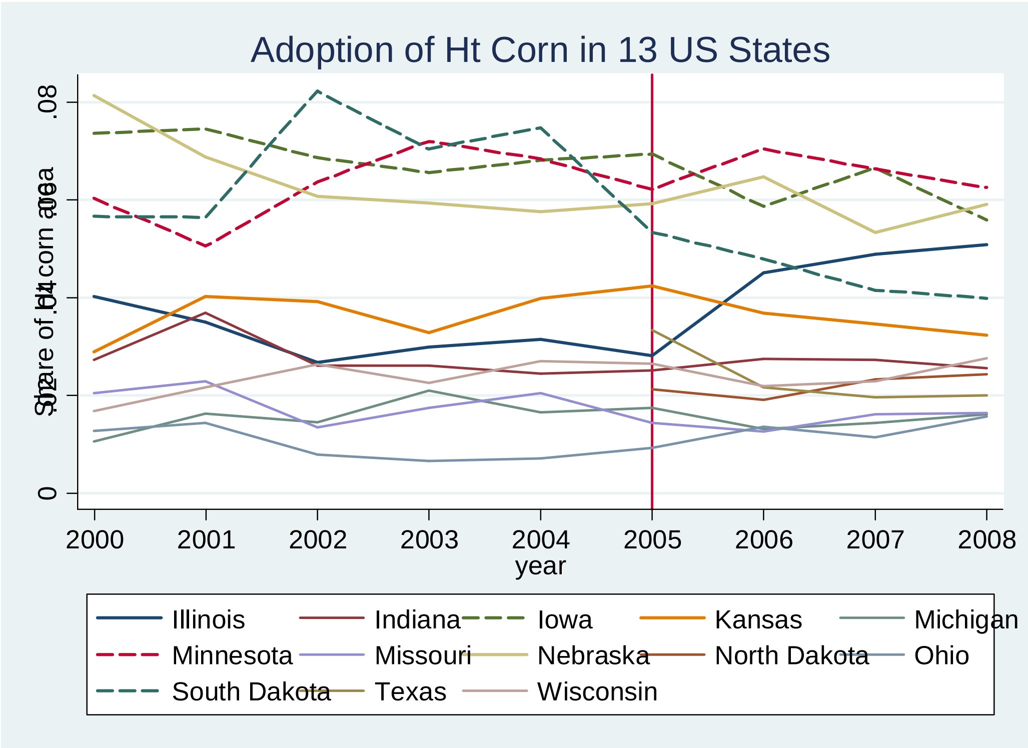

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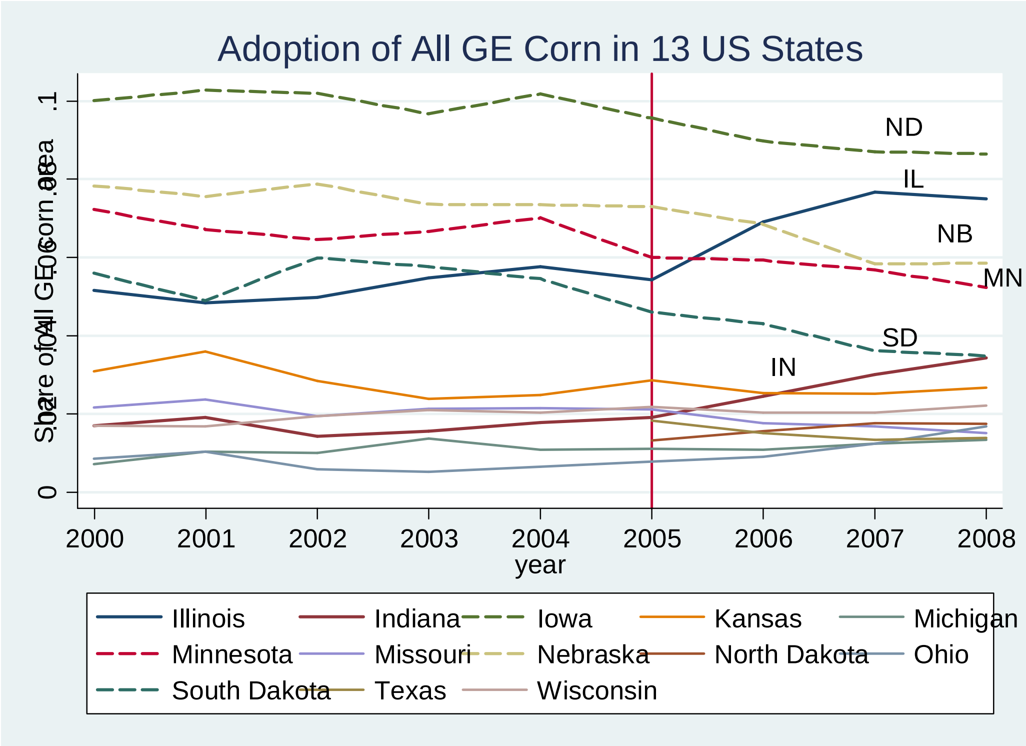

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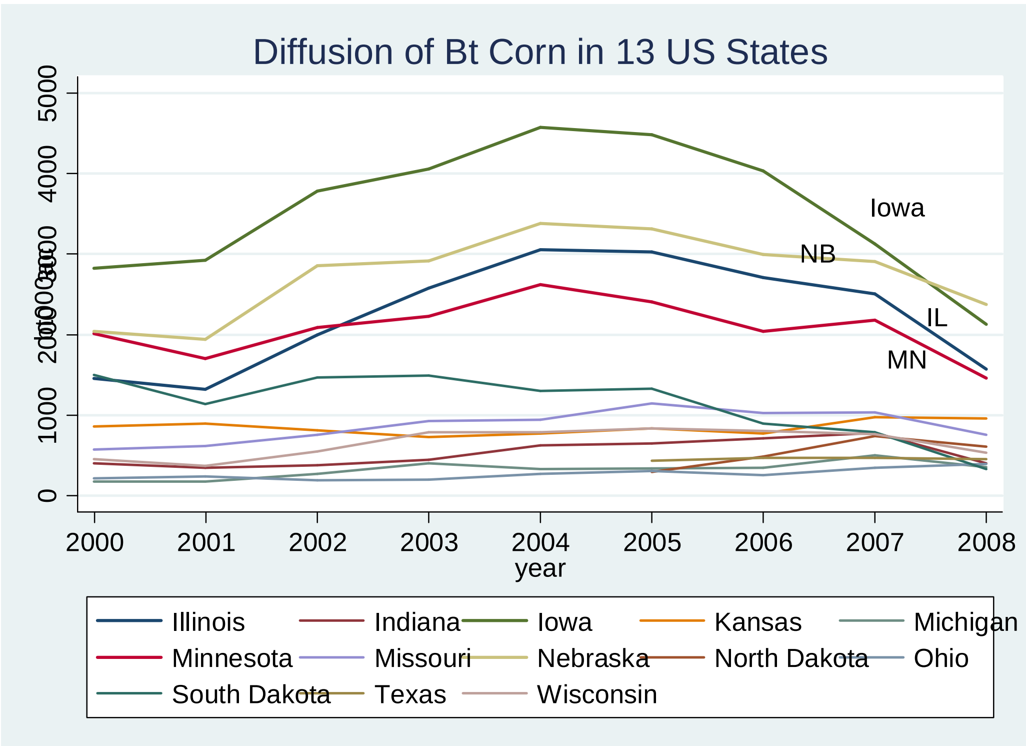

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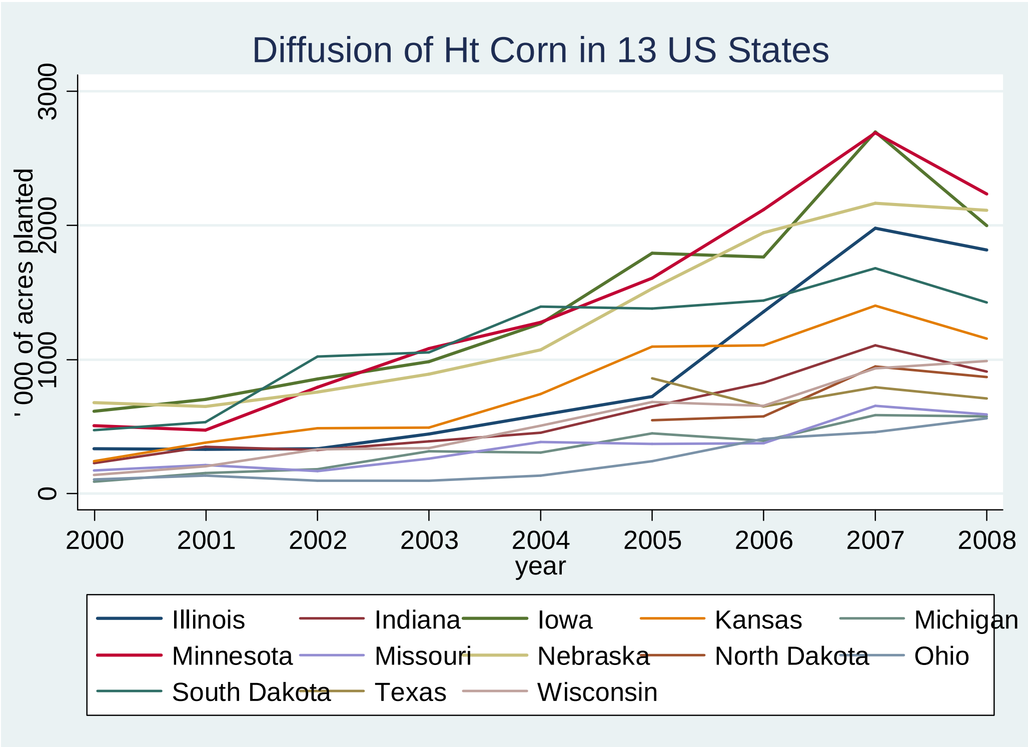

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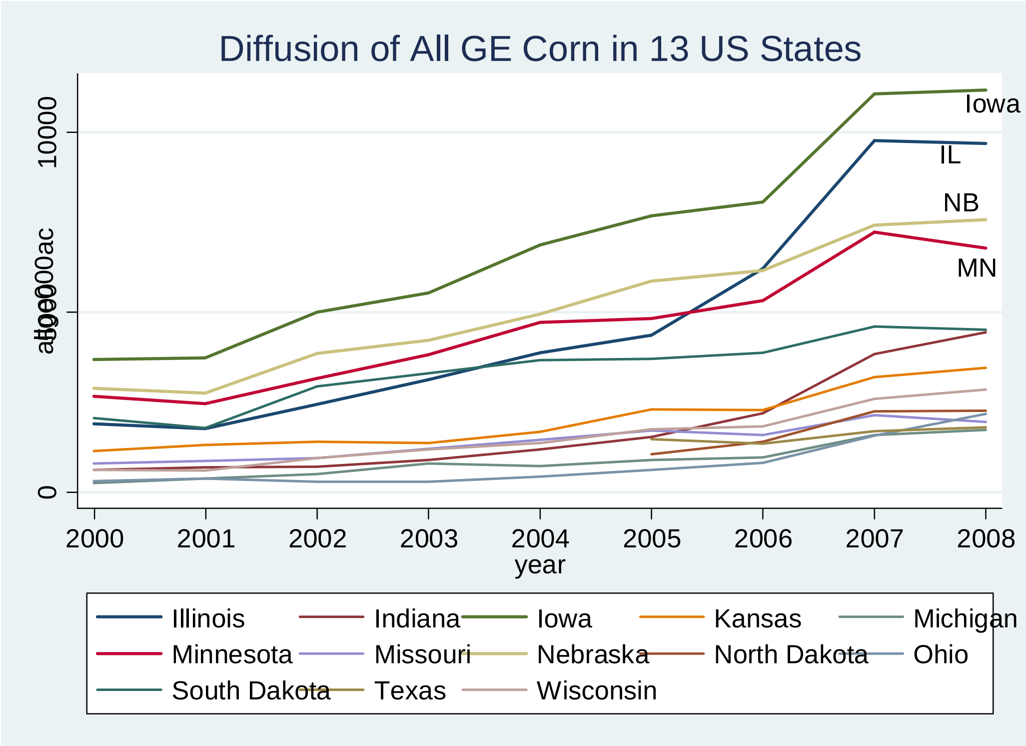

Source: Authors' computation on NASS, ERS Data

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