Genetically Modified Crop Diversity after Regulatory Streamlining

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Abstract

In industries with high sunk costs, regulations may affect not only the price but the types of products offered. For over thirty years, most genetically engineered seeds in the United States were corn, cotton, or soybean, three of the largest crops grown. Most of the products were put out by four or five multinational agrichemical companies. In 2021, the United States Department of Agriculture streamlined its approval for GM crops. This paper describes how the set of deregulated articles changed under the new regulations. I show four novel facts, most notably the growth in product diversity and the diversity of the researching institutions. Using data on cash receipts for different crops, I then show how the new regulations affected the minimum market size necessary for firms to engage in R&D.

1 Introduction

Regulations affect the scope and structure of an industry in ways that go beyond what they directly address. In this paper, I study the effects of a major regulatory change in 2021 on the types of firms engaging in biotech research and development and the types of products they invest in. The United States Department of Agriculture Animal and Plant Health Inspection Service (USDA APHIS) issued new rules that allowed many more potential varieties to be automatically exempt from regulation and provided a faster ways for those that were not automatically exempt to become deregulated. Using data collected by APHIS, I show:

1. Variety increased under the new regulations, with more crop species being approved in three years than had been in the preceding 29.

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2. About as many institutions have applied for an article to be deregulated since 2021 as applied over the entire period from 1992 to 2021.

3. This growth in variety has come from institutions that are much smaller than incumbents that generally focus on only one or two crops, rather than an expansion in scope by large multinationals.

4. These new varieties are for seeds with much smaller market sizes than corn, cotton, and soybean, which made up a majority of the pre-2021 petitions for deregulation.

These facts motivate a model where falling sunk costs lead to greater market entry.

Several authors have estimated the cost of biotech regulations and found varying ranges. Based on expenses provided by the four largest firms at the time (Bayer, DuPont, Monsanto, and Syngenta), Kalaitzandonakes et al. (2007) estimate compliance costs for herbicide-tolerant corn were \$6.18-14.51 million and compliance costs for insect-resistant corn were \$7.06-15.44 million. A survey by Phillips McDougall of the same four plus BASF found much higher costs, closer to \$35 million (McDougall, 2011). One of the authors from the earlier study estimated 2016 costs to be \$14-21 million (Kalaitzandonakes et al., 2023). In its environmental impact statement on the new rule, APHIS estimated that the costs attributable to APHIS alone were \$2.36-13.03 million out of a total of \$4.3-19.96 million (USDA APHIS, 2020). Bullock et al. (2021) interviewed eight large firms and found costs between \$20 million and \$50 million. All of these studies were based on surveys or, in the case of Kalaitzandonakes et al. (2007), surveys and individual firm-level accounting data.

The effects of regulations on market structure are well-studied. Ryan (2012) uses a dynamic oligopoly model to measure the effects of 1990 amendments to the Clean Air Act on the cement industry. He finds Thomas (1990) finds that 1962 amendments to the Food, Drug, and Cosmetic Act lowered the number of new chemical entities developed but affected large and small firms differently, with large firms on net helped by the reduced competition. The papers closest this one are Bullock et al. (2021) and Ollinger and Fernandez-Cornejo (1998). Bullock et al. (2021) use a real option valuation model to simulate the returns from investment in "traditional" genetic modification R&D and newer gene editing R&D. Using parameters collected from interviews with industry participants, they find the break-even market size for gene edited traits is 93% lower than genetically modified. If the regulatory phase is faster for gene edited traits, the required break-even market size is 96% lower. Unlike Bullock et al. (2021), the current paper does not consider the full development pipeline as I am studying articles that have been deregulated, not that have necessarily been commercialized. However, I can bound

2 Background

2.1 Before 2021

Since 1986, the United States has regulated genetically engineered crops under the Coordinated Framework for the Regulation of Biotechnology. This agreement shares responsibilities between the United States Department of Agriculture, the Environmental Protection Agency, and the Food and Drug Administration. Table 1 lists the situations under which each agency plays a role in regulation.

	Insect Resistant Food Plant	Herbicide Tolerant Food Plant	Altered Nutritional Content in Food Plant	Fungal Resistant Plant not for Human Food	Altered Appearance of Ornamental Non-Food Plant
Example of product type	*Rootworm-resistant corn*	*Glyphosate-tolerant soybean*	*Soybeans producing increased levels of oleic acid*	*Fusarium-resistant bentgrass*	*Blue petunia*
EPA	X	*		X	
FDA	X	X	X	**	
USDA	X	X	X	X	X

Table 1: US regulators for GM crops
* EPA does register the herbicide used in conjunction with seed.
** If product goes into animal food.
Source: Coordinated Framework for the Regulation of Biotechnology: Plain language information on the biotechnology regulatory system

EPA registers all crops with "plant-incorporated protectants" (PIPs), which includes Bt crops. (US EPA, 2015). It does not regulate crops that are tolerant of herbicides, though the herbicides themselves must be registered. It is possible for seeds tolerant of specific herbicides to be sold on the market even as it is illegal for farmers to apply those herbicides. Such an incident occurred in 2016. APHIS deregulated dicamba-tolerant cotton and dicamba-tolerant soybeans in January 2015. At the end of 2015 and beginning of 2016, Monsanto sold these seeds in anticipation of the EPA registering dicamba use for post-emergent, over-the-top soybean and cotton in the 2016 growing season. However, the EPA did not permit such use until late 2016, meaning there was a full year when farmers could plant the dicamba-tolerant seed but could not take advantage of that trait (Gullickson, 2020).

FDA does not legally require any premarket screening of GM foods. (US FDA, 2024). However, since 1992, it has encouraged developers to engage in voluntary consultations with the agency to review that their product does satisfy FDA's postmarket safety regulations. Most developers take part in these consultations. As of August 2024, the average consultation took about fourteen months.

The Plant Protection Act of 2000 gives USDA the power to regulate movement and dissemination of organisms that could be considered "plant pests or noxious weeds." Until 2021, a genetically engineered organism was regulated if the organism itself, the organism that was the source of inserted genetic material, or a vector organism was on a list of plant pests (7 CFR 340 pre-2020). A common method for inserting genetic material is to first insert the gene of interest into an *Agrobacterium* plasmid and then put the bacteria in the plant. *Agrobacterium* falls on the list of plant pests, so any crop created with this technique was automatically under review. After years of field tests, applicants could request the trait be deregulated so that it could be commercialized. As Table 1 shows, nearly all genetically engineered crops grown in the United States fall under the jurisdiction of USDA, so this pipeline of permit to deregulation to commercialization was one nearly all developers would need to go through.

2.2 After 2021

In 2015, the White House issued a memorandum telling the agencies in the Coordinated Framework to clarify and modernize their regulations. APHIS was the first agency to issue new rules, the final version of which it announced in 2020. The changes were made to "change the basis for APHIS regulatory review from one in which GE plants are regulated based on the use of plant pests in their development, to one in which APHIS reviews the GE plants themselves for plant pest risks" (USDA APHIS, 2020). Under the new rules, a plant is exempt from regulation if it could have, in theory, been produced through conventional breeding methods, or if the plant-trait-mechanism of action combination (PT-MOA) has already been deregulated by a previous ruling (USDA APHIS, n.d.).[1] A new variety is considered to be conventionally bred if it satisfies one of the following:

1. the modification is the result of disabling a gene,
2. the modification is the result of a single base pair substitution, or
3. the modification is the result of introducing a gene that already exists in the plant's gene pool.

If a plant does not meet one of the exemptions listed above, the developer must apply for a permit for field tests or ask for a regulatory status review (RSR). The RSR is similar to the earlier petitioning for deregulation, but unlike that older process, APHIS no longer considers the use of a plant pest in the modification to be a prima facie reason for regulation. These new rules were announced in May 2020 and went into effect October 2021.

[1] The "mechanism of action" is the biochemical process producing the new trait. For the purposes of our discussion here, it is more specific than a trait (several different MOAs confer glyphosate resistance) but less specific than the specific genetic alteration (the same MOA may be caused by one of several genes)

2.2.1 Other agencies

In May 2023, the EPA released a new rule on how it would regulate plant-incorporated protectants. It exempted from registration genetically engineered crops whose pesticidal properties were either 1) solely the result of gene insertion from another sexually compatible plant or 2) solely the result of "loss-of-function," that is, an existing gene getting knocked out but with no inserted gene or alteration of other genes (EPA website).

In February 2024, the FDA released nonbinding recommendations to producers using gene editing technology. Unlike APHIS and EPA, FDA's guidance reaffirms existing policies on voluntary consultations. They listed some additional questions developers using gene-editing may want to consider, such as whether a new gene is similar to one known to produce allergens, but the procedures for premarket consultation remain the same (FDA 2024).

In this paper I focus on changes in APHIS regulations. As Table 1 shows, almost all crops go through this step even if they do not go through EPA or FDA. A caveat to this approach is that for many crops, the decisions of overseas regulatory agencies may be just as important as domestic ones. For example, DuPont Pioneer received approval to grow a high-oleic acid soybean with a greater proportion in 2010.[2] It took eight years before commercialization, though, as the company waited for approval from Chinese and European Union regulators (Unglesbee, 2018). Had any farmer grown the new variety before foreign approval, he or she would have been missing out on a valuable export market and would have to had taken extra precautions that the high-oleic soybean remained separate from everything else. With these constraints, DuPont expected demand to be low enough it did not even bother to sell the seed.

2.3 New Technology

These new regulations coincide and complement new techniques for genetic modification. Traditionally, researchers used vector bacterium or literally shooting the cell with tiny bullets covered in DNA, "biolistics." This is not very precise, and as the researchers cannot control where new genetic material appears in plant genome, it may behave differently depending where it falls. It also almost always involves using DNA foreign to the species: the process is transgenic rather than cisgenic. Under new techniques such as CRISPR or TALENS, the process is as follows: a developer gives a Cas9 enzyme the "address" of the plant's genome where it wishes to make a cut. The enzyme matches with that segment and cut the gene. At this point, the host will try to repair the cut DNA. Without anything else, it will do "non-homologous end joining" (NHEJ), which successfully reconnects the two strands but does not fix the segment directly affected. Depending on the gene affected, the plant will otherwise be healthy but that gene has been knocked out. Alternatively, developers may include with the Cas9 enzyme another enzyme called reverse transcriptase that acts as a template for new genetic material to replace the material cut. This process

[2]Soybean oil higher in oleic acid has a longer shelf-life.

is called "homologous recombination" (HR) and allows for not just an old gene to be deactivated but an entirely new one to be inserted (Parthasarathy, 2022). These methods still often use a vector bacterium but, under APHIS's new regulations, this in itself is not a problem unless some of the bacterial DNA remains in the plant.

3 Data

Biotechnology Regulatory Services in USDA APHIS publishes data on permits for field trials, letters confirming non-regulatory status, petitions for deregulation (before October 2021), and regulatory status reviews (after October 2021). Permits are applied for in earlier stages of R&D. A better indicator that an institution hopes to commercialize a trait is the institution filing a petition or RSR, or requesting a confirmation of exemption letters (called "Am I Regulated?" or AIR letters before October 2021). Not all deregulated articles are commercialized, in fact most are not, but deregulation from APHIS is one of the last steps in the regulatory process and suggests commercial intent. (For example: in the early 2000s, Monsanto received field permits to test GM wheat and even did a voluntary consultation with the FDA, but did not bother to petition APHIS when it became clear it would have difficulty selling.) Ideally, I would also include the confirmation of exemption letters and AIR letters, but these are not already in tabular data.[3]

As a proxy for crop market size, I use the cash receipts published under the Farm Income and Wealth Statistics by the USDA Economic Research Service (https://www.ers.usda.gov/data-products/farm-income-and-wealth-statistics/). These are based on surveys currently conducted by the National Agricultural Statistics Service. For certain crops and for rougher levels of aggregation, these data go back to the early 20th century. Some crops only appear separately after 2008. For these, I extrapolate backwards based on the percent change in the larger grouping they are in. (E.g., I extrapolate blackberries backwards based on the movement of "Fruits and nuts.")

4 Facts

4.1 Crops

Table 2 lists all non-flower crops that have been deregulated[4]. The first section are crops where a majority of the crop is current grown with GM seed. The middle section (just potatoes and apples at this point) are crops with commercialized GM varieties but which are still mostly conventional. The third section are crops which do not currently have a commercialized GM variety in the U.S. Because the petition era was so much longer than the period under RSRs, I also

[3] I am currently in the process of converting the information in these letters into a usable format.

[4] The "Total distinct" at the bottom of the table includes ornamental flowers.

list the numbers scaled to average deregulation per year. Since the switch to RSRs, there have been thirteen crops with at least one GM variety approved that had no approvals before. Nineteen crops have had more approvals per year under RSRs than under petitions and eleven had more under petitions. The difference is even starker when we split the pre-2021 period into three roughly 10-year periods, as in Table 3. Instances of 12 different crops were deregulated from 1992 to 2001 but for each decade after, only 9 were. Such shakeout is common in any new industry (Klepper & Graddy, 1990), but it is striking nearly twice as many species have had a variety deregulated in three years as happened in ten.

> **Fact 1: More species of crop have been approved under the new RSRs in the past three years than were approved over the 29 year period preceding it.**

4.2 Institutions

Table 4 lists institutions that filed petitions or RSRs for deregulation. For the sake of brevity, the table only shows those institutions that filed at least two in either period. I do not list petitions or RSRs by year as not all were present for the full period. There are four petitions from universities and one from the USDA Agricultural Research Service. Monsanto and AgrEvo together accounted for over 30 percent of petitions filed. There are four firms tied for the next most petitions, and adding any two of them to Monsanto and AgrEvo would account for over half. The distribution post-2021 is still skewed: CoverCress and Yield10 account for around 38 percent and adding Bayer or Inari to those two makes a majority. Since 2022, Bayer has been a majority owner in CoverCress. Treating those two firms as a single entity would skew the distribution even further.

Even with these caveats, the top filers of RSRs are clearly different than those who filed petitions. Eight RSRs were from five universities or not-for-profit research centers. The for-profit institutions are also much smaller. In August 2017, shortly before it was sold, Monsanto had about 20,500 employees worldwide (Monsanto 10-K 2017). Another large company, Corteva[5], had about 22,500 employees as of January 2024 (Corteva 10-K 2023). Inari and Bioheuris had fewer than 20 employees in 2024 and Yield10 Bioscience had 29 (Pitchbook, Yield10 10-K 2023). This is the second fact.

> **Fact 2: Almost as many institutions have applied for deregulation in the past three years as the 29 preceding years. More of these firms are small start-ups.**

Tables 5 and 6 list the institutions that have filed for the most *crops* before and after the changes. (Table 4 listed firms with the most total applications,

[5]Corteva was spun off from the Dow DuPont merger in 2019 and owns the Pioneer brand.

Crop	Petition	RSR	Petition (per year)	RSR (per year)
Corn	41	10	1.41	0.667
Soybean	21	17	0.724	5.67
Cotton	19	1	0.655	0.333
Alfalfa	2	0	0.0690	0
Sugar beet	3	1	0.103	0.333
Canola	12	2	0.414	0.667
Papaya	2	0	0.0690	0
Potato	9	8	0.310	2.67
Apple	3	0	0.103	0
Wheat	0	1	0	0.333
Tomato	11	2	0.379	0.667
Orange	0	1	0	0.333
Tobacco	1	0	0.0345	0
Rice	2	1	0.0690	0.333
Grapefruit	0	1	0	0.333
Plum	1	0	0.0345	0
Squash	2	0	0.0690	0
Flax	1	0	0.0345	0
Safflower	0	1	0	0.333
Blackberry	0	1	0	0.333
Mustard	0	2	0	0.667
Banana	0	1	0	0.333
Camelina	0	6	0	2.00
Chicory	1	0	0.0345	0
Cowpea	0	1	0	0.333
Creeping bentgrass	1	0	0.0345	0
Hemp	0	2	0	0.667
Pennycress	0	10	0	3.33
Teff	0	1	0	0.333
Walnut	0	1	0	0.333
Total distinct	19	23	0.586	7.00

Table 2: Crops deregulated by petition (1992–2021) or RSR (2021–2024). Source: USDA APHIS BRS

1992–2001	2002–2011	2012–Oct. 2021	Oct. 2021–2024
12	9	9	21

Table 3: Number of distinct crops by decade and post-2021. Source: USDA APHIS BRS

including applications for the same crop.) I list the total number of crops for each institution applied for approval as well as the total number of crops that are not corn, cotton, or soybean. The seed markets for these three crops, especially corn, have been concentrated even before the arrival of GM seeds. In 1994, at

Company	Petition	RSR
Monsanto	42	NA
AgrEvo	10	NA
Calgene	9	NA
Dow	9	NA
Pioneer	9	1
Syngenta	9	0
Bayer	7	5
Simplot	4	1
Aventis	3	NA
BASF	3	0
Okanagan Specialty Fruits	2	0
DeKalb	2	NA
DuPont	2	NA
CoverCress	0	8
Yield10 Bioscience	0	6
Bayer	7	5
Inari	0	5
Bioheuris	0	4
Michigan State University	0	4
Hjelle Advisors	?	4
InnerPlant	0	3
Nuseed	0	2
Ohalo Genetics	0	2
Pairwise	0	2
ToolGen	0	2
ZeaKal	0	2
University of Florida	1	2
Total distinct	36	35

Table 4: Institutions filing petition (1992–2021) or RSR (2021–2024). Source: USDA APHIS BRS

least two years before any GM traits were commercialized in these crops, the four largest firms accounted for 57.7 percent of corn, 60 percent of soybean, and 87 percent of cotton seed sales (Fernandez-Cornejo, 2004). As before, these data are based on the institution's name on the application, and may not reflect the actual ownership structure or mergers after the fact.

Although there is a greater variety of crops under the post-2021 regulations, firms have no so far appeared to increase their individual scopes: if anything, the scopes are smaller. So far, there has been no firm like Monsanto with nine separate crops (though Monsanto's successor, Bayer, still has the most). Of the 13 institutions that submitted at least two articles for approval under the old regulations, three focused on a single crop: Simplot (potatoes), Okanagan (apples), and DeKalb (corn). Fourteen institutions have submitted at least two

articles for approval under the new regulations and five of those have focused on a single crop: CoverCress (pennycress), Yield10 (camelina), Michigan State University (potatoes), Ohalo Genetics (potatoes), and ZeaKal (soybean). The average institution before 2021 had petitions for 1.72 crops and after 2021 that number was 1.37. Weighing crops equally may be misleading if some are purely experimental or dead ends commercially, so I also calculate the Hirschman-Herfindahl index (HHI) as a measure of dispersion for each institution.[6] Before 2021, the average HHI was 0.840. After 2021, it was only slightly higher, 0.853.

Finally, for each institution, I measure the "distinctness" of its R&D by looking at each petition or RSR and counting how many other institutions requested deregulation for the same crop. Before 2021, there were seven institutions that worked entirely on crops that no other institution did. After 2021, there were nine such institutions. For the average institution, the average petition was for a crop 5.4 other institutions were working on. After 2021, that number fell to 4.0.

Fact 3: The greater variety of crops is not a result of institutions increasing their scopes. There is less overlap in the crops that institutions are studying after 2021 than before 2021.

Company	Crops/Non-CCS crops petitioned	Crops/Non-CCS crops under RSR
Monsanto	9/6	NA
AgrEvo	5/3	NA
Bayer	4/2	4/2
Syngenta	3/0	0/0
Pioneer	3/1	1/0
Dow	3/0	NA
Calgene	3/2	NA
DuPont	2/0	NA
Aventis	2/1	NA
BASF	2/1	0/0

Table 5: Firms with most crops petitioned. "CCS" is "corn, cotton, or soybean." Source: USDA APHIS BRS

4.3 Crop Market Size

Table 7 shows the net prevent value of crops that have at least one GM variety deregulated by APHIS. To calculate the net prevent value I use a 5% discount rate and a time period of 20 years, the length of a patent.

[6]HHI is the sum of the squared shares, $HHI = \sum_i^N \left(\frac{x_i}{\sum_j^N x_j} \right)^2$. A value of exactly 1 means the firm only produced one crop. If the firm applied for deregulation for two crops an equal number of times, the index would be 0.5. If it applied for two crops but one much more than the other, the index would be closer to 1.

Company	Crops/Non-CCS crops petitioned	Crops/Non-CCS crops under RSR
Bayer	4/2	4/2
Hjelle Advisors	0/0	3/2
Bioheuris	0/0	2/0
Inari	0/0	2/0
InnerPlant	0/0	2/1
Moolec	0/0	2/1
Nuseed	0/0	2/2
Pairwise	0/0	2/2
ToolGen	0/0	2/1
University of Florida	0/0	2/2

Table 6: Firms with most crops under RSRs. "CCS" is "corn, cotton, or soybean." Source: USDA APHIS BRS

The crops that are a majority GM have two obvious characteristics: they tend to have large markets and they tend to not be food crops. (Sugar beet and canola products are consumed by humans but only after extensive processing.) Corn, soybean, and cotton each have an NPV of over $100 billion. Wheat is the only crop with a similarly high NPV that does not currently have a commercialized GM variety.

The crops deregulated under the new regime have smaller market sizes. Forty-seven percent of the pre-2021 petitions issued were for corn or soybeans and 38 percent of the RSRs are. Assuming crops for which cash receipt data are not collected all have receipts smaller than the lowest for which we do have data, he median NPV of cash receipts for the old regulations is $116,374 million. Under the new regulations, it is $66,846 million. I also calculate the mean NPV of the petitions/RSRs under two extreme assumptions. For crops where revenue data are missing, I first calculate the mean assuming their revenues are zero and then calculate the mean assuming they are equal to the lowest revenue for which I do have data (bananas, $170 million). Under the zero-revenue assumption, the mean NPV is $281,232 for the old regulations and $202,709 under the new. The alternative assumption returns very similar results, $281,235 and $202,757, respectively. This is a difference of about $78,500 for either.

Fact 4: The median article deregulated since 2021 is for a crop whose market is 57% as large as the median of the pre-2021 median. The mean NPV for articles deregulated since 2021 is 72% of the pre-2021 mean.

Crops	NPV cash receipts (millions)	Food/Feed/Other
Corn	$584,986	Feed/Other
Soybean	$439,947	Feed
Cotton	$116,374	Other
Alfalfa	$48,395	Feed
Sugar beet	$23,774	Other
Canola	$4,541	Other
Papaya	$269	Food
Potato	$66,846	Food
Apple	$47,173	Food
Wheat	$181,147	Food
Tomato	$46,921	Food
Orange	$43,506	Food
Tobacco	$40,252	Other
Rice	$39,147	Food
Walnut	$14,583	Food
Grapefruit	$5,368	Food
Plum	$5,181	Food
Squash	$4,092	Food
Flax	$1,258	Other
Safflower	$668	Other
Blackberry	$602	Food
Mustard	$181	Food
Banana	$170	Food
Camelina		
Chicory		
Cowpea		
Creeping bentgrass		
Hemp		
Pennycress		
Teff		

Table 7: Net present value of crops, 2024 dollars Using revenues from 1996-2016, 5% discount rate. Source: ERS Farm Income and Wealth Statistics

5 Motivating Model and Estimation

5.1 Model

I use the demand model presented in Schmalensee (1992) and Ollinger and Fernandez-Cornejo (1998). For a crop with total market S, the demand for seed type i is

$$X_i = S_c \frac{p_i^{-e}}{\sum_{j=1}^{N} p_j^{-e}} \tag{1}$$

Here e is a measure of toughness of price competition. As e increases, the market moves closer to perfect competition. If the unit cost of producing the seed is c and the cost of entry is σ, then profits are

$$\pi_i = (p_i - c)\, S_c \frac{p_i^{-e}}{\sum_{j=1}^{N} p_j^{-e}} - \sigma \tag{2}$$

If firms are symmetric and $e > 2$, the equilibrium number of firms in the market is

$$N^* = \frac{c\frac{S}{\sigma} + e}{e - 1} \tag{3}$$

This model predicts the following comparative statics.

$$\begin{aligned}
\frac{\partial N^*}{\partial \sigma} &= -\frac{c\frac{S}{\sigma^2}}{(e-1)} < 0 \\
\frac{\partial^2 N^*}{\partial \sigma \partial S} &= -\frac{c\frac{1}{\sigma^2}}{(e-1)} < 0 \\
\frac{\partial N^*}{\partial e} &= -\frac{c\frac{S}{\sigma} + 1}{(e-1)^2} < 0 \\
\frac{\partial N^*}{\partial S} &= \frac{c}{(e-1)\,\sigma} > 0 \\
\frac{\partial N^*}{\partial c} &= \frac{\frac{S}{\sigma}}{(e-1)} > 0 \\
\sigma \to 0 &\Rightarrow N^* \to \infty \\
\sigma \to \infty &\Rightarrow N^* \to \frac{e}{e-1}
\end{aligned}$$

Entry costs decrease the equilibrium number of firms, as one would expect. Maybe less obvious is that tougher price competition (higher e) will also have fewer firms, all else equal. When e is higher, a firm's markup will be smaller. All firms must be making at least some profit to repay positive entry cost, though, so a higher e is matched by a lower N^*.

5.2 Estimation

I regress the count of articles of a specific crop i in year t against the market size in t ($\log REVENUE_{it}$), an indicator for whether the new regulations are in place ($\mathbb{1}_{\{NEWREGS_t\}}$), and a linear time trend t. I assume that unit costs and the toughness of competition are either constant or changing at the same linear rate (and hence picked up by the trend variable). As written, this equation does not consider future revenues from the crop, which firms must certainly do. I

assume that firms' discount the future at a constant rate and expect the annual revenue to continue in real terms in the future. Under this assumption, the firms expected NPV is a constant multiple of the annual revenue and when logged, this constant is absorbed by β_0.

$$y_{it} = \beta_0 + \beta_1 \mathbb{1}_{\{NEWREGS_t\}} + \beta_2 \log REVENUE_{it} + \beta_3 \mathbb{1}_{\{NEWREGS_t\}} \log REVENUE_{it} + \delta t + \varepsilon_{it} \tag{4}$$

Equation 4 shows the estimation equation. Because y_{it} is a count variable, I use a Poisson regression.

In the model described in 5.1, we would expect β_1 and β_2 to both be positive. The object of most interest in β_3. This coefficient on the interaction term shows how much the new regulations change the revenue necessary for a product to be petitioned for deregulation. It corresponds to the second partial derivative $\frac{\partial^2 N^*}{\partial \sigma \partial S}$ Based on the model and summary statistics above, we would expect this to be negative.

6 Results

Forthcoming

7 Conclusion

Regulatory costs shape the market structure and product offerings. In 2021, the USDA began exempting more GM crops from regulation and made seeking approval for deregulation easier. I show the market changed soon after. Most notably, there was much greater product diversity even in shorter period of time. The types of institutions applying changed, too, with more small firms and non-profits. These new products were more often in crops with smaller market size that in the past may not have been worth the R&D and regulatory sunk cost.

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