# The General Equilibrium Effect of Genetically Modified Crops and Trade Policies

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December 2025

# Outline


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# Introduction

- Genetically modified crops (GMs) are plants whose DNA has been modified to give them new traits.
- GMs are designed to achieve higher yields and to exhibit greater resilience to catastrophic events (surveyed in Pellegrino et al. 2018).
- Most commercialized GMs today have the following traits:
  - Insect resistance.
  - Herbicide tolerance.
  - Stacked.
- Frontier research in crop science suggests that GMs may also have various traits in the near future, such as:
  - Heat resistance.
  - Drought resistance.
  - Nitrogen fixation.

# Barriers to GM Cultivation

- Despite high potential gains, the cultivation of GMs is severely limited by governmental policies.
- Data from the International Service for the Acquisition of Agri-Biotech Applications (ISAAA) reveal that:
  - Less than 5% of country-crop pairs allow GM cultivation.
  - Less than 10% of country-crop pairs allow GM imports.
- The table below details the number of countries that permit GM use for selected major crops.

| **Policy Type** | **Cotton** | **Maize** | **Soybean** | **Alfalfa** | **Potato** | **Rice** | **Wheat** | **Sugarcane** |
|---|---|---|---|---|---|---|---|---|
| **Cultivation** | 21 | 21 | 15 | 5 | 4 | 4 | 2 | 1 |
| **Import** | 24 | 31 | 28 | 11 | 14 | 12 | 7 | 1 |

# Current Global GM Production Area

- According to James (2020), the global farm area for GMs was approximately 190.4 million hectares in 2019.
- The table below details the country-crop area shares of total global GM cultivation in 2019.

| Country | Soybean | Maize | Cotton | Other Crops* | Total |
|---|---|---|---|---|---|
| 1. USA | 16.0% | 17.5% | 2.1% | 2.0% | ≈ 37.6% |
| 2. Brazil | 18.5% | 8.5% | 0.7% | 0.0% | ≈ 27.7% |
| 3. Argentina | 9.2% | 3.1% | 0.2% | 0.0% | ≈ 12.5% |
| 4. Canada | 1.3% | 0.8% | 0.0% | 4.5% | ≈ 6.6% |
| 5. India | 0.0% | 0.0% | 6.3% | 0.0% | ≈ 6.3% |
| 6. Others | 3.5% | 1.6% | 3.7% | 0.5% | ≈ 9.3% |
| **Global Total** | **48.5%** | **31.5%** | **13.0%** | **7.0%** | **100%** |

* Other Crops are primarily Canola, Sugarbeet, and Alfalfa.

# Literature Review

- Micro-level benefits of GMs are well-documented in the literature. For example:
  - Klümper & Qaim (2014) surveyed farm surveys and field trials globally, showing increased crop yields by 22% and farm profits by 68%.
  - Brookes (2022) estimated the global value of GM crops in agriculture at the farm level, reporting cumulative global farm income gains of $261.3B between 1995 and 2020.
- Recently, Hansen & Wingender (2023) conduct a global analysis by using a triple-differences rollout design that exploits variation in the availability of GM seeds across crops, countries, and time.
- Our paper contributes to this literature by showing the equilibrium effects of GM crops on welfare, expenditure, and trade shares. Importantly, we also analyze how these economic outcomes are affected by cultivation and import bans.

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# Model: Extensions and Core Ideas

- We build upon the spatial model developed by Farrokhi & Pellegrina (2023), which captures farmers' decisions regarding land allocation, crop choice, and input use.
- We extend this benchmark model to incorporate three key elements relevant to genetic engineering technology, the crop industry, and agricultural economics:
  1. The risk-averse behavior of farmers (Bar-Shira et al. 1997, Binswanger 1980).
  2. The introduction of genetic engineering as an additional production input for farmers.
  3. The modeling of consumers' differentiated tastes between GM and non-GM varieties.

# Model Overview

- The model features multiple countries, each containing multiple locations.
- There are two sectors: agriculture and non-agriculture.
- The agriculture sector comprises multiple crops, while the non-agriculture sector produces one composite good.
- Farmers make decisions on:
  1. Land Usage: Allocating land between farming and non-farming activities (empty land).
  2. Crop Choice: Selecting crops (e.g., rice, maize, tomato, etc.).
  3. Input Choice: Selecting inputs, including fertilizer, machinery, pesticides, and genetic engineering.

# Model: Farmer Risk Aversion and Uncertainty

- Farmers' equilibrium decisions are jointly determined by market conditions and the soil/climate characteristics of their location.
- To mimic reality, we assume farmers face uncertainty regarding location-specific climate conditions.
- Specifically, farmers adopt a conservative (risk-averse) strategy by making choices (e.g., crop and input selection) based on the worst-case climate scenario observed over a ten-year period, not the historical average.
- This timing assumption reflects real-world behavior: farmers must choose crops and inputs before actual climate conditions are known.
- Production equilibrium values in the model are calculated using the historical average.

# Model: Genetic Engineering as an additional Input

- Agricultural goods can be produced using four distinct technology types ($\tau$):
  1. Low inputs (Labor only)
  2. Low inputs + Genetic Engineering
  3. High inputs (Labor, machinery, fertilizers, and pesticides)
  4. High inputs + Genetic Engineering

- The production function for crop $k$ using technology $\tau$ on location $f$ in country $i$ is:

$$Q^f_{i,k\tau} = \bar{q}_{k\tau} \left( z^f_{i,k\tau} L^f_{i,k\tau} \right)^{\gamma^L_{k\tau}} \left( N^f_{i,k\tau} \right)^{\gamma^N_{k\tau}} \left( M^f_{i,k\tau} \right)^{\gamma^M_{k\tau}}$$

  - $Q^f_{i,k\tau}$: Crop output.
  - $\bar{q}_{k\tau}$: Technology-specific constant (efficiency scalar).
  - $z^f_{i,k\tau}$: Land productivity of the location.
  - $L^f_{i,k\tau}, N^f_{i,k\tau}, M^f_{i,k\tau}$ are the use of land, labor, and material inputs, respectively.
  - $\gamma$'s: Factor intensity parameters.

# Model: Consumer Preferences and Demand Structure

- Our model employs a four-tiered CES demand system to capture consumer behavior.
  1. Tier 1: Consumers choose between a composite agricultural good and a non-agricultural good.
  2. Tier 2: The composite agricultural good consists of multiple crops.
  3. Tier 3: Each crop is a composite of its GM and non-GM varieties.
  4. Tier 4: Each variety is a composite of all imports and domestic products.
- Specifically, the demand aggregation at the third tier is:

$$C_i^k = \left[ \left( B_i^{\text{GM}} \right)^{1/\sigma} \left( C_i^{k,\text{GM}} \right)^{(\sigma-1)/\sigma} + \left( B_i^{\text{non-GM}} \right)^{1/\sigma} \left( C_i^{k,\text{non-GM}} \right)^{(\sigma-1)/\sigma} \right]^{\sigma/(\sigma-1)}$$

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# GMs and Productivity

- In our model, genetic engineering technology acts by increasing the productivity of land.
- Following prior literature[1], we use the "potential yields" from the Food and Agriculture Organization's Global Agro-Ecological Zones (FAO-GAEZ) to describe land productivity.
    - Potential yields describe the agronomically possible upper limit to produce individual crops under given agro-climatic, soil and terrain conditions and applying specific management and input assumptions.
    - FAO provides these values for non-GM technologies for approximately 2.3 million global locations.
- We use potential yield information to determine the location-level Production Possibility Frontiers (PPFs) in the model.
- Therefore, we utilize the same crop model as FAO to determine the corresponding potential yields with genetic engineering.

[1] For example, Costinot et al. (2016), Farrokhi & Pellegrina (2023), etc.

# GMs and Potential Yields: FAO Methodology

- The FAO crop model calculates potential yields via two steps:
  1. Determining the constraint-free potential yield based on a location's climate, soil, terrain, and crop-specific parameters.
  2. Determining the location-level loss factors attributed to water deficit, diseases, and pests.
- Examples of the Crop-Specific parameters used in the model include:
  - Phenology & Temperature: Growth cycle length, minimum temperature, heat-unit boundaries, and yield formation period.
  - Photosynthesis & Biomass: Maximum photosynthesis rate and the bna/bnm ratio.
  - Yield Formation: Harvest ratio.
  - Canopy: Leaf area.
  - Water & Soil: Soil water depletion factor group.
- FAO provides all crop parameter values for non-GMs (Kassam 1977). Hence, we only need to determine the relative changes in these parameters due to genetic engineering.

# GMs and Potential Yields

- We use crop science literature to determine how using genetic engineering as an input changes these crop-specific parameters.
  - While multiple GM varieties exist for each crop in practice, we simplify the model by assuming one GM variety per crop.
  - We select the most commonly used GM variety for parameterization.
- For example, the changes for Maize are based on the GM variety, SmartStax.
  - According to Reinders et al. (2023), SmartStax reduced ear damage from insects by approximately 87% compared to non-Bt corn.
    $\rightarrow$ Loss factor due to pest decreases by 87%.
  - According to Thomas et al. (2007), herbicide-tolerant maize hybrids (e.g., SmartStax) enable weed control exceeding 90% relative to untreated conventional maize.
    $\rightarrow$ Loss factor due to weed decreases by 90%.

# GMs and Potential Yields: Parameter Changes

- Currently commercialized GM crops primarily focus on insect resistance (e.g., Bt) and herbicide tolerance (e.g., HT) traits.
- Below table shows the relative changes in crop parameters.

| **Crop Parameters** | **Maize** | **Sugarcane** | **Cotton** | **Soybean** |
|---|---|---|---|---|
| Pest Loss Factor | -87% | -75% | -93% | -90% |
| Weed Loss Factor | -90% | -60% | -95% | -95% |
| Harvest Index | . | . | 40% | . |
| Leaf Area | . | . | . | 4.2% |
| Water Deficit Loss Factor | . | -20% | . | -5% |

Note: Values represent the percentage change in crop model parameters due to GM technology, based on literature review, relative to conventional (non-GM) varieties.

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# Counterfactual Method

- The following counterfactual approach is introduced to estimate the general equilibrium effects of GM crops and associated government policies.
- The model is first estimated based on a world without any genetic engineering technology.
  - This ensures all parameters unrelated to GM technology are estimated accurately.
- Genetic engineering is then introduced as an additional input that farmers can use in counterfactual scenarios.
- At this stage, various policy scenarios related to GMs can be introduced. Two particular scenarios are studied:
  1. All governments do not impose any additional restrictions on GMs for cultivation and imports.
  2. Mimicking the current global policies on GMs (according to ISAAA data).

# Counterfactual Method

- To run a counterfactual scenario, parameters and policies specific to GM technology must be specified.
- Demand-side parameters and supply-side parameters are obtained from recent surveys and USDA Cost data, respectively (Lusk et al. 2005).
- Counterfactual policies are defined by two regulatory bans: cultivation bans and import bans.
  - If a nation bans GM cultivation: Its ability to produce genetic engineering is set to zero, and the trade cost of GM seed is set to $\infty$.
  - If a nation allows GM cultivation: Its ability to produce genetic engineering is equated to its non-agricultural production ability, and the GM seed trade cost equals the trade cost of non-GM seeds.
  - If a nation bans GM imports: The trade cost for GM crops is set to $\infty$.
  - If a nation allows GM imports: The trade cost for GM crops is set equal to that of non-GM crops.

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# Preliminary Results

- Here, we present some preliminary results of our paper.
- Below table shows the percentage changes in potential yields for selected country-crop pairs due to genetic engineering.

| Crops | Maize | | Soybean | | Cotton | |
|---|---|---|---|---|---|---|
| Technology | Low | High | Low | High | Low | High |
| **Global** | **46%** | **39%** | **136%** | **82%** | **104%** | **51%** |
| USA | 18% | 21% | 19% | 14% | 18% | 19% |
| China | 17% | 39% | 6.2% | 17% | 8.5% | 16% |
| India | 47% | 37% | 159% | 81% | 123% | 38% |
| Brazil | 32% | 18% | 186% | 52% | 80% | 30% |
| Russia | 0.5% | 0.4% | 3.8% | 2.8% | 4.7% | 1.6% |
| Low Income | 67% | 53% | 194% | 113% | 130% | 83% |

- The values are mainly based on how a nation's farms are susceptible to weeds and pests.

# Preliminary Results

- Below table shows the percentage changes in equilibrium crop prices due to genetic engineering.

| | All Crops | Maize | Soybean | Cotton | Other Crops |
|---|---|---|---|---|---|
| **Global** | **-1.33%** | **-1.45%** | **-3.61%** | **-3.52%** | **-0.57%** |
| USA | -0.38% | -0.46% | -0.47% | -0.70% | -0.30% |
| China | -0.83% | -1.28% | -1.14% | -1.12% | -0.66% |
| India | -0.43% | -0.44% | -1.59% | -0.85% | -0.16% |
| Brazil | -1.17% | -1.25% | -1.66% | -1.84% | -0.96% |
| Russia | -0.27% | -1.09% | -0.31% | -0.38% | -0.11% |
| Low Income | -0.87% | -0.43% | -1.52% | -4.72% | -0.20% |

- Most country-crop pairs see price decreases.

# Preliminary Results

- Below table shows the percentage changes in equilibrium for selected variables due to genetic engineering.

| | Farmer's Wage | Total Agr. Consumption | Maize Prod. | Soybean Prod. | Cotton Prod. | Other Crops Prod. |
|---|---|---|---|---|---|---|
| **Global** | **0.88%** | **0.28%** | **1.20%** | **13.81%** | **10.97%** | **4.49%** |
| USA | 0.44% | 0.86% | 0.82% | 0.96% | 1.11% | -0.10% |
| China | -0.09% | -1.04% | -2.56% | -3.41% | -4.15% | 2.01% |
| India | 0.51% | -0.03% | -4.42% | -1.06% | -4.44% | 1.11% |
| Brazil | -2.62% | -1.46% | -1.68% | -0.53% | -2.36% | 2.41% |
| Russia | 1.38% | 0.06% | -4.07% | -5.96% | -6.22% | 0.25% |
| Low Income | 0.01% | 0.59% | -0.01% | 3.85% | 12.97% | -0.40% |

- Global welfare (real consumption) increases unambiguously.
- Country-level effects depend on their trade patterns, relative gains from genetic engineering, and purchasing power of inputs.

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# Future Research

- First, we will introduce counterfactual trade policies that mimic the current government policies, cultivation and import bans on GM, to see their effects.
- Also, we believe the benefits of GM technologies shown today are significantly underestimated because the model is benchmarked only against currently commercialized varieties (limited to four crops with restricted traits).
- Frontier crop science research suggests much higher, potentially safer, productivity gains from future GM technologies.
  - They include 1) Heat Tolerance and 2) Drought Tolerance.
- Utilizing these future traits to determine the GMs' Production Possibility Frontiers (PPFs) could reveal a more realistic cost of government restrictions on GM crops.

# Future Research

- Since the crop biomass model uses climate as an input, it allows for analysis of climate change impacts on the global agricultural sector.
- By employing the same methodology used in this analysis—and considering GM traits that confer resilience to extreme climate events—it is possible to quantify how genetic engineering could mitigate the negative impacts of climate change.
- This finding holds significant importance, given that global food security is frequently projected to be threatened by the end of the century.

# Conclusions and Limitations

- In this paper, we analyze the general equilibrium effect of genetic engineering as an additional input, and the effects of government policies that restrict its potential.
- Our preliminary results suggest that genetic engineering has great potential to increase consumer welfare and farmers' income globally.
- Our analysis makes certain assumptions due to data limitations, which could potentially affect the reliability of our estimates.
  - The main limitation is that we do not observe trade flows for GMs separately from non-GMs.
  - Additionally, a significant portion of crop consumption is for animal feed, a component that is currently not included in our analysis.

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