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Abstract

In this paper, we estimate the the effects of the introduction of a labor-saving technology in agriculture on violence, by examining the case of the adoption of genetically-modified soy seeds in Brazil. Previous literature has shown that this technological change leads to job displacement, increases in land conflicts and gender inequality. We show that the effects also spread to homicide rates, which increase significantly after the adoption of the modified soy seeds.

Keywords: agricultural productivity; violence; crime; Brazil.
JEL Codes: D74, J43, O13, Q16, K42

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1 Introduction

Technological advances that increase agricultural productivity bring several positive effects to economic development, including income gains and poverty reduction. However, they may also have detrimental effects, especially if they are labor-saving. Brazil is the largest producer of soybeans, largely due to the introduction of genetically engineered (GE) soy seeds in 2003. These seeds are herbicide-resistant and thus reduces the need for labor-intensive weed control, increasing soy output per worker, but also leading to job displacement in the agricultural sector (Bustos et al., 2016).

In this paper, we study the impact of the adoption of modified soy seeds on violent deaths in Brazil. Because the adoption of new technology is likely endogenous, we follow Bustos et al. (2016) and calculate potential yield gains based on climate and soil characteristics, which are arguably exogenous to actual production. We find that the expansion of GE soy led to significant increases in the homicide rate. To our knowledge, our results provide the first direct evidence of increases in violent mortality following the introduction of a labor-saving technical change in agriculture.

Our work adds to the growing literature studying the effects of technical change in agriculture, and in particular, of the introduction of GE soy in Brazil. Previous studies have examined its effects on structural transformation (Bustos et al., 2016), capital accumulation (Bustos et al., 2020), industrial productivity (Bustos et al., 2022), fertility and gender inequality (Moorthy, 2022), deforestation (Carreira et al., 2023), greenhouse gas emissions (Da Mata et al., 2023), infant mortality (Dias et al., 2023), and land invasions (Falcone & Rosenberg, 2022).

Though a large body of literature has shown that adverse economic shocks may lead to increases in violence, through channels such as commodity price shocks (Miguel et al., 2004; Dube & Vargas, 2013), and weather anomalies (Blakeslee & Fishman, 2018; Ishak, 2022), the effects of seemingly positive economic shocks on violence have received less attention.

2 Data and methodology

In this paper, we use individual-level data on all registered violent deaths in Brazil between 1991 and 2019 to calculate the yearly homicide rate for each municipality [1].

We then combine the mortality data with a measure of the technical change in soy production to assess causal effects of the introduction of GE soy. Because the adoption of new technology is likely endogenous, we follow Bustos et al. (2016) and calculate potential yield gains based on climate and soil characteristics, which are arguably exogenous to actual production. The United Nations FAO-GAEZ database provides data on potential yields for different agricultural crops under several technological assumptions, based on agricultural models that take into account geographical characteristics. Bustos et al. (2016) therefore suggests that the difference between gains using traditional technology and no chemicals and using advanced technology, improved seeds and herbicides, provides an exogenous measure of potential yields of adopting the GE soy seeds. For each municipality j, we thus define the potential yield gain calculated as:[2]

$$\Delta A_j^{Soy} = A_j^{Soy-High} - A_j^{Soy-Low}$$

where $A_j^{Soy-High}$ is the potential production yields in tons per hectare using modern mechanisation, fertilizers and herbicides, while $A_j^{Soy-Low}$ considers traditional production techniques and no use of chemicals.

A first look at the data suggests that since the early 2000's there has been a divergence between the homicide rate in municipalities with high potential for soy production and those with lower potential (Figure 1 below). This period coincides with a large increase in the soy production in Brazil, markedly after the introduction of the GE modified seeds (Figure 2).

With the data in hand, we estimate the following equation:

[1]The data come from the Brazilian Ministry of Health (SIM-DATASUS — https://datasus.saude.gov.br/transferencia-de-arquivos/. To categorize deaths as violent deaths, we consider ICD-10 codes X85-X99 and Y00-Y09, and ICD-9 codes E960-E969 (for data from before 1996). The population data to calculate per capita rates are obtained from the Brazilian Institute of Geography and Statistics (IBGE — https://www.ibge.gov.br/estatisticas/sociais/populacao/9103-estimativas-de-populacao.html).

[2]Throughout the text, we use the word "municipality" for simplicity, but in reality all data is aggregated into minimum comparable areas since municipality boundaries change between years. See Bustos et al. (2016) for details.

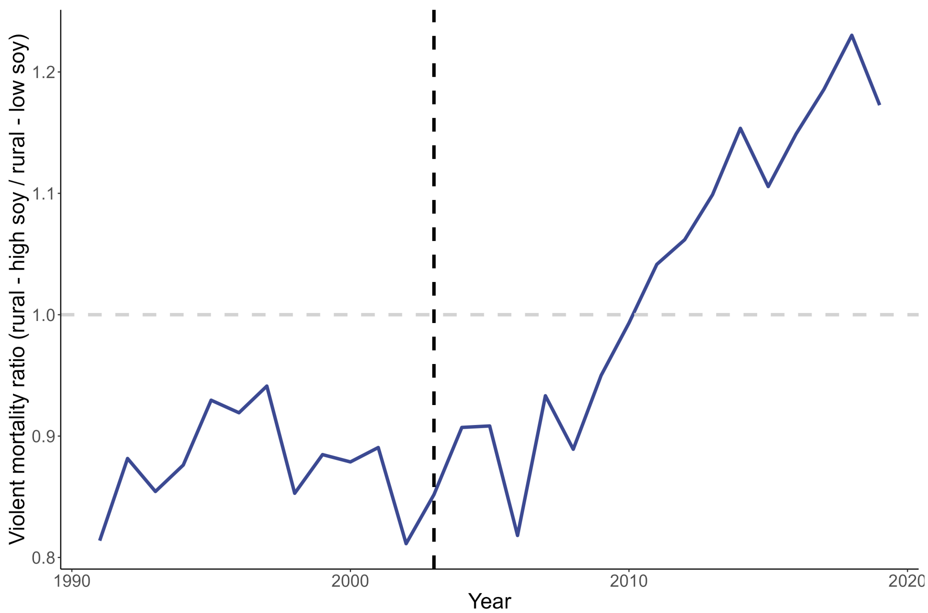

Figure 1: **Violent Mortality Ratio**. This figure shows the ratio of the violent mortality rate (homicides per capita) between rural municipalities with high potential yield gains in adopting GE soy (ΔA_j^{Soy} above median, N = 1,156) and lower potential (below median, N = 1,157), between 1991 and 2019. The dashed line marks the legalization of GE soy seeds in 2003.

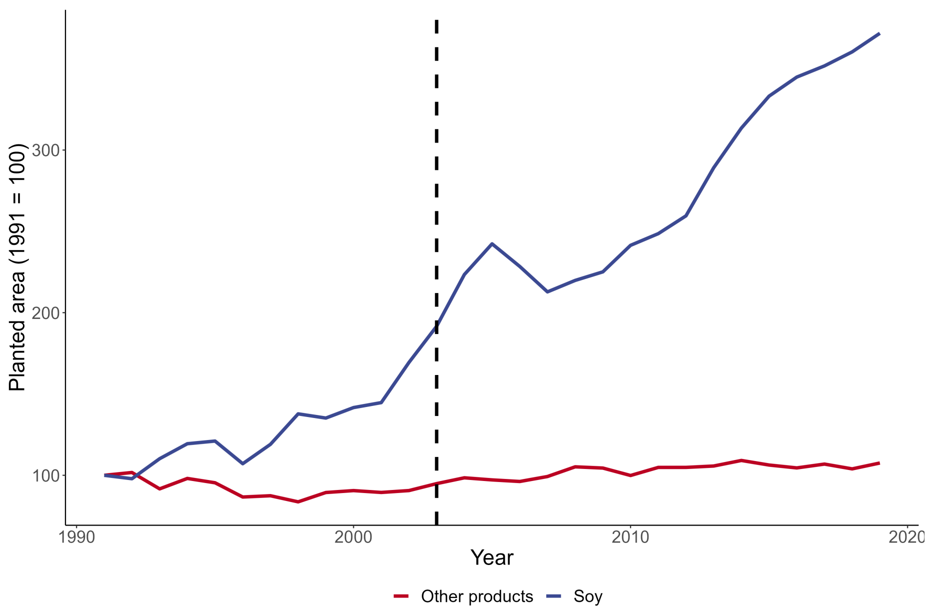

Figure 2: **Soy Planted Area**. This figure shows the total area cultivated with soy and other cultures in Brazil between 1991 and 2019, relative to the amount planted in 1991. The dashed line marks the legalization of GE soy seeds in 2003.

$$Y_{jt} = \alpha_j + \gamma_t + \beta \Delta A_j^{Soy} \times Post_t + \lambda X_j' \times Post_t + \varepsilon_{mj} \quad (1)$$

where Y_{jt} is the homicide rate in municipality j and year t, α_j are municipality fixed effects, γ_t are year fixed effects, ΔA_j^{Soy} is the potential yield gains in adopting GE soy seeds, $Post_t$ is a dummy equal to 1 for $t \geq 2013$, X_j' is a vector of controls of municipality characteristics in 1991 (share of rural adult population, log income per capita, log population density, and the literacy rate), and ε_{mj} in a random error. In Equation 1, these controls are interacted with the indicator for post-2003 to account for the possibility of differential trends in mortality according to municipality characteristics.

To account for the fact that there may be differential pre-trends between municipalities with different levels of potential yield gains, and analyse the timing of the effect, we estimate time-varying coefficients using a slightly different regression:

$$Y_{jt} = \alpha_j + \gamma_t + \sum_{t \neq 2003} \beta_t \Delta A_j^{Soy} + \sum_{t \neq 2003} \lambda_t X_j' + \varepsilon_{mj} \quad (2)$$

In this specification, ΔA_j^{Soy} and the municipal controls X_j' are interacted with a dummy for each year (omitting 2003) instead of a post-2003 dummy. This analysis thus works as a placebo for years prior to 2003, and explores the timing and persistence of the effects for the following years.

We also conduct sensitivity tests by adding different sets of controls and state-specific trends, using age-adjusted mortality, and restricting the sample to rural municipalities and municipalities in soy-producing regions in Brazil.

3 Results and Discussion

Table 1 displays our main results. In column (1), the only control is the share of the rural adult population in 1991. Column (2) adds the other controls suggested by Bustos et al. (2016), while column (3) includes state dummies interacted with year fixed effects to capture state-specific time trends. All columns show positive effects of the GE soy on the homicide rate. The effect is highly significant on columns (2) and (3). In terms of magnitude, column (2) suggests that an increase in one ton per hectare of the potential soy output leads to a 0.78 relative increase in the homicide rate per 100k people (or to a 0.66 increase for a one standard deviation increase). Considering the mean population across municipalities in our sample, this effect translates to about 0.2 yearly homicides in the municipality with a one standard deviation gain in the potential soy yield.

Table 1: Results

	Violent Mortality Rate		
	(1)	(2)	(3)
ΔA_j^{Soy}	0.041	0.779***	1.091***
	(0.186)	(0.172)	(0.199)
N	122,369	122,369	122,369
Rural Population (1991)	Y	Y	Y
Other controls (1991)	N	Y	Y
State fixed-effects	N	N	Y

Notes: This table shows results from fixed-effects regressions that estimate effects of the soy technical changes on the homicide rate based on Equation 1. The dependent variable is the total number of violent deaths per 100k residents for each municipality and year between 1991 and 2019. ΔA_j^{Soy} is the potential yield gains in adopting GE soy seeds for each municipality and is interacted with a dummy equal to 1 for 2003 and after. Column (1) controls only for the share of the rural adult population in 1991 interacted with the post-2003 dummy. Column (2) further controls for other characteristics measured in 1991 and interacted with the post-2003 dummy: log income per capita, log population density, and the literacy rate. Columns (1) and (2) have municipality and year fixed effects. Column (3) has municipality fixed effects and state-year fixed-effects to capture common trends. Standard errors shown in parentheses are clustered at the municipality level. *p$<$0.1; **p$<$0.05; ***p$<$0.01

To ensure our results are not driven by specification choices, we estimate alternative models in Table 2. Specifically, in column (1) we apply age-standardization to the mortality rate, to account for differential trends in age structure of municipalities that may affect socioeconomic behavior [3]. Because the age composition of municipalities is only available for Census years, this model is a first-differenced version of Equation 1, comparing the change in the homicide rate between 2000 and 2010. In column (2) and (3) we restrict the sample to municipalities that are located in regions that produce soy (South, Southeast and Center-West of Brazil), and in municipalities categorized as rural. Column (4) repeats the specification in column (2) of Table 1, but clusters standard errors by a broader geographical unit. Finally, column (5) controls for the potential yield gains in the adoption of a different technology: second-harvest maize. As shown by Bustos et al. (2016), this variety allows farmers to increase the numbers of crops they grow per year, representing a land-augmenting technical change that occurred around the same time as the GE soy introduction. All tests confirm the robustness of our results, as the significance and magnitude of the coefficients is largely unchanged.

Another concern is the existence of pre-trends violating the parallel trends assumption. In Figure 3, we show that the effects were statistically null before 2003, and remain positive and significant following the authorization of GE seeds. The figure also suggests the effects were persistent, lasting more than 10 years after the technological adoption.

We also conduct a placebo test considering ”never takers” — that is, municipalities with high potentials for soy suitability (above median) but no history of soy cultivation between 1988 and 2021 (according to agricultural output data from IBGE). Figure 4 below displays these coefficients, showing that results are statistically null. This supports the idea that our results are indeed running through GE soy adoption.

Though we are not able to pinpoint the specific mechanism explaining this finding, the literature provides insights that suggest two possible pathways. The first possibility is that labor-saving technical change increases unemployment, which tends to increase crime. Previous research has showed, for example, that displacement in the manufacturing sectors due to trade liberalization was associated with increases in homicide rates in Brazil and Mexico (Dix-Carneiro et al., 2018; Dell et al., 2019). A similar mechanism could be at play here, with local displacement in the agricul-

[3]For each municipality and year, we calculate the crude mortality rate by age group by dividing the number of deaths across different age groups (0-1 year, 1-5 years, 5-10, ..., 75-80 and 80+) by the population in each group. Then, age adjusted mortality rates are obtained as a weighted average of the crude rates across age categories, with each group’s share in the Brazilian population in 2000 as weights.

Table 2: Robustness Tests

	Age-adjusted (1)	Soy Regions (2)	Rural (3)	Mesoregion SE (4)	Maize control (5)
ΔA_j^{Soy}	1.180**	0.638***	0.392**	0.779*	2.220***
	(0.574)	(0.199)	(0.199)	(0.464)	(0.369)
N	4,228	73,387	66,854	122,369	122,369
Model	$\Delta_{2000-2010}$	Panel	Panel	Panel	Panel
Sample	All	Soy	Rural	All	All

Notes: This table shows results from fixed-effects regressions that estimate effects of the soy technical changes on the homicide rate. In Column (1), the dependent variable is the change in age-adjusted violent mortality rate per 100k residents between 2000 and 2010, and ΔA_j^{Soy} is the potential yield gains in adopting GE soy seeds for each municipality. It includes state fixed effects and standard errors are clustered by microregion. In Columns (2) to (5), the dependent variable is the total number of violent deaths per 100k residents for each municipality and year between 1991 and 2019, and ΔA_j^{Soy} is interacted with a dummy equal to 1 for 2003 and after. These columns all include controls for municipality characteristics measured in 1991, as well as municipality and year fixed-effects. Column (2) restricts the sample to municipalities in the South, Southeast and Center-West, while column (3) restricts the sample to rural municipalities. Column (4) replicates the main specification in Column (2) of Table 1, but with standard errors clustered by mesoregion. Column (5) includes controls for the potential yield gains in maize production.

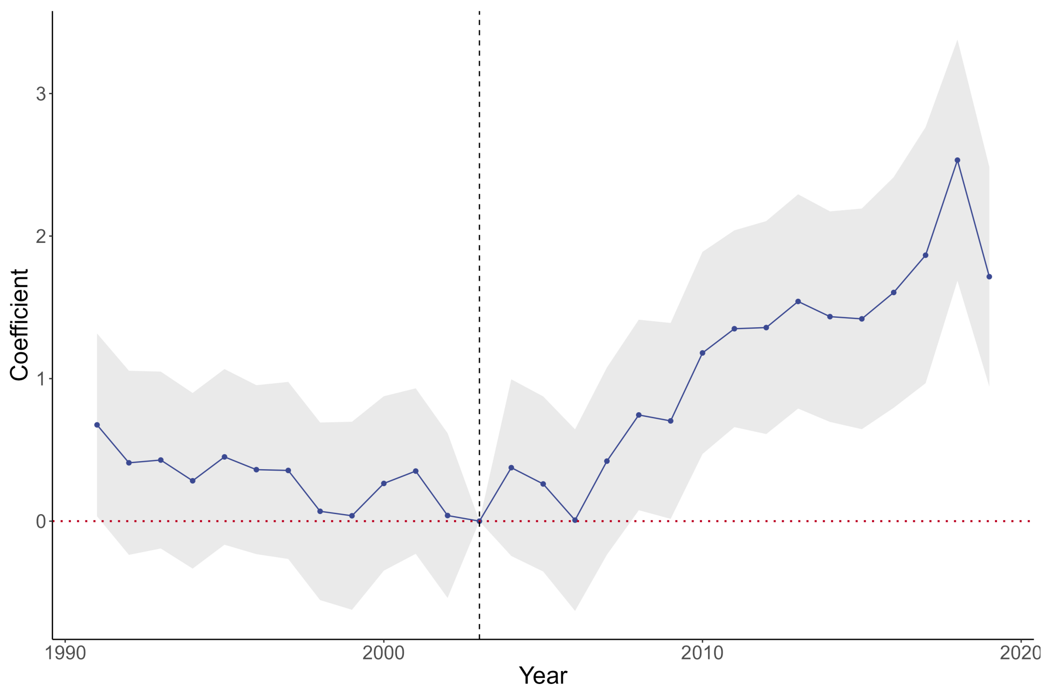

Figure 3: **Dynamic effect of soy technical changes on violent mortality**. This figure shows $\hat{\beta}_t$ coefficients from Equation 2.

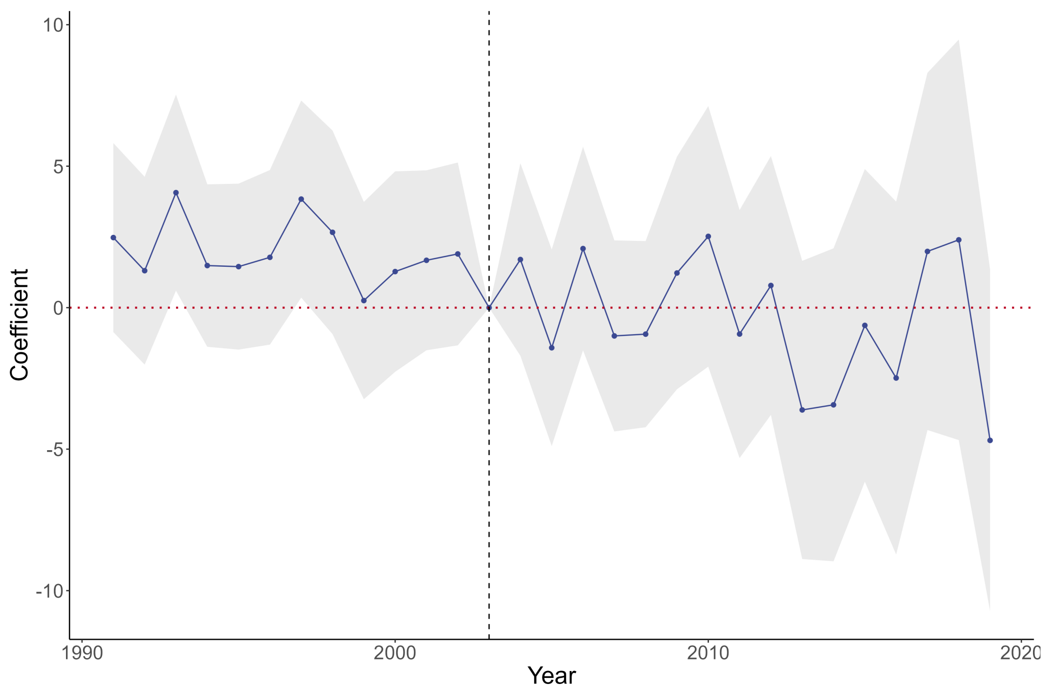

Figure 4: **Placebo effect of soy technical changes on violent mortality**. This figure shows $\hat{\beta}_t$ coefficients from Equation 2 only considering municipalities with high potentials for soy suitability but no history of soy cultivation (N = 511).

tural sector leading to a reduced opportunity cost of crime and hence more criminal activity and violence.

Another possibility is that the introduction of the GE soy seeds leads to the expansion of the soy-cultivated area, with farms transiting from subsistence local-owned models to larger agribusiness properties, leading rural workers to lose informal access to their lands and to social unrest. Brazil faces stark land distribution inequalities rooted in colonial legacies and compounded by unclear property regulations, with larger landholdings covering a disproportionate share of farmland compared to smaller plots. Peasant movements have resorted to land occupations to advance reform, which often escalates to violent confrontations. These conflicts frequently arise between subsistence local workers who lack property titles on the land and are evicted by new landowners who have either proper or fraudulent titles acquired through falsification or bribery (Falcone & Rosenberg, 2022). Indeed, weak property rights have been shown to be the main determinant of local land-related violence in the country (Fetzer & Marden, 2017).

The available evidence seems to suggest that the land-conflict mechanism, and not unemployment, is the main driver for the effect on violent deaths that we find. In this sense, Bustos et al. (2016) documents that while GE soy led to displacement in agriculture, it led to increases in local industrial employment (structural transformation), suggesting that a significant share of displaced labor force is absorbed by other sectors, with little or no effect on overall unemployment. This would alleviate the increases in violence due to displaced workers turning to criminality. We can observe these results by analysing Census data. Table 3 shows coefficients from regressions that estimate the effect of the potential gain in GE soy adoption on different labor market variables. In line with findings by Bustos et al. (2016), it shows that there was no overall effect in unemployment because the manufacturing sector absorbed the workforce that was displaced from the primary sector. In fact, these results suggest there was even an *increase* in the employment-to-population rate. Therefore, unemployment does not seem to be the driver of the effects on violence.

Falcone and Rosenberg (2022) provide robust evidence that the GE soy introduction led to an increase in the number of land conflicts [4]. They

[4]One methodological difference is worth noting. While most papers studying the introduction of GE soy in Brazil consider the actual legalization of these seeds in 2003,

Table 3: Mechanisms: labor market

	Dependent variable:			
	Unemployment	Employment	Manufacturing share	Primary share
	(1)	(2)	(3)	(4)
ΔA_j^{Soy}	0.001	0.009**	0.016***	$-$0.009**
	(0.003)	(0.005)	(0.004)	(0.004)
N	4,228	4,228	4,228	4,228
R^2	0.244	0.485	0.116	0.406

Notes: This table shows results from regressions that estimate effects of the soy technical changes on labor market variables between 2000 and 2010. The regressions include controls for municipal variables measured in 1991 (share of rural adult population, log income per capita, log population density, and the literacy rate), as well as state fixed effects. Standard errors are clustered by microrregion. *p<0.1; **p<0.05; ***p<0.01

show that this was accompanied not only by an increase in the number of large farms and specialization in soy production among largest farms, but also in the share of registered farmlands and in the number of indigenous occupations. This implies an increase in the share of land that is unavailable to traditional farmers who rely on informally accessible land. Additionally, the participation of indigenous movements in occupations also provides evidence of the informally accessible land mechanism, as traditional communities are most threatened by the expansion of soy production on the territories they are settled in.

Therefore, it seems that most of the effect we observe may be attributable to land-ownership related conflict. Particularly, it may be due to conflicts by workers who have lost informal access to land due to the increased profitability of soybean production and turn to farmland invasions. For a comparison of magnitudes, according to data from the *Comissão Pastoral*

Falcone and Rosenberg (2022) consider the introduction of these seeds in the United States, in 1996. Reasons for this discrepancy are discussed in the Appendix, where we provide aggregate data showing that while land conflict started rising in the late 1990's, the number of evicted families and deaths only rose expressively after 2003.

da Terra, an organization linked to the National Conference of Bishops of Brazil that represents rural workers, 38 people died per year between 2001 and 2010 due to land conflict.

In sum, we have shown that a labor-saving technology in agriculture (the GE soy) has led to an uptake in the homicide rate in Brazil. These findings complement the results observed by Falcone and Rosenberg (2022) who showed that the GE soy in Brazil led to increased land invasions. More generally, the results are aligned with effects observed in 19th-century England by Caprettini and Voth (2020), who show that the early adoption of threshing machines — a labor-saving technology in the manufacturing sector — led to more conflicts in the form of riots.

4 Conclusions

Labor-saving technological change in agriculture, which generally increases productivity and income, can also have important social consequences that need to be addressed. In this paper, we examine the effects of the introduction of genetically-modified soy beans in Brazil and find that it increased violence in the municipalities most affected. The most likely mechanism is that the expansion of farmlands dedicated to growing soybean deprived workers of their informal access to land and subsistence agriculture, provoking social unrest and increasing deaths.

These factors need to be taken into account in the design of policies that alleviate the consequences of such technologies. Further research should investigate detailed mechanisms and consolidate different findings to estimate the overall net effects of similar technologies.

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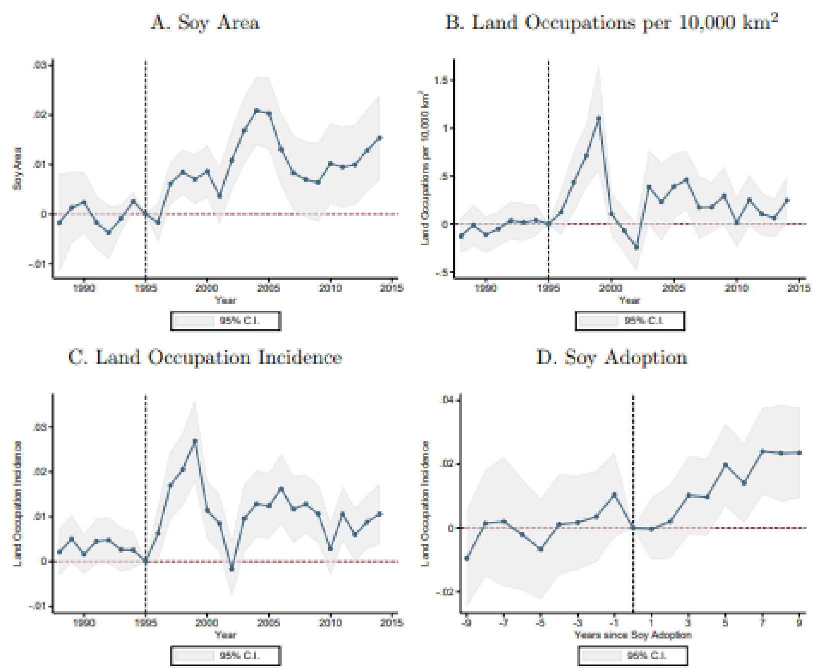
Appendix

Falcone and Rosenberg (2022) provide evidence of an increase in land conflicts following the introduction of GE soy, which we suggest is the main mechanism for our findings that this technology increased homicide rates. However, there is an important discrepancy. While their shock hits in 1996, ours hits in 2003. This is because Falcone and Rosenberg (2022), differently than other GE soy papers (e.g. Bustos et al. (2016), Bustos et al. (2020), Dias et al. (2023)), consider the date of the introduction of this technology in the United States, and not in Brazil. While it is true that there was smuggling, such that one could think of a channel associating the 1996 date with an increase in land conflicts, it is interesting that we do not observe any change prior to 2003 (Figure 3).

Importantly, however, Falcone and Rosenberg (2022) do find a second peak shortly after 2003 (see their plot shown below in Figure A1). This could mean that what is happening is that the land conflicts that happened before the 2000's had a different profile and hence did not lead to large increases in violence.

While we cannot completely discern that this is in fact the source of the discrepancy, as we do not have municipal level data on these detailed land invasion variables — and there is significant measurement error and underreporting in this kind of data —, aggregate numbers from *Comissão Pastoral da Terra* may be helpful in providing some insights. For example, Figure A2 displays the total number in Brazil of families who were evicted from their lands, land invasions, land-conflict-related homicides and attempted homicides, as well as land-conflict-related death threats in Brazil, between 1992 and 2021. While we see the two peaks in terms of the number of land invasions after 1996 and 2003, this is not accompanied by increases in the other variables. The number of families evicted, homicides and attempted homicides, and of death threats only increased after 2002. This supports our argument that there is a different profile in invasions: though land invasions may have increased prior to 2003, perhaps they became more violent after the introduction of GE soy increased the number of evicted families. This, however, cannot be confirmed in our analysis due to lack of data, which calls for further

FIGURE 3: Timing of Effect on Land Occupations and Soy Area



Notes: Panel A: estimates of equation (2); dependent variable is soy area as municipal share. Panel B: estimates of equation (2) for soy regions; dependent variable is number of land occupations per 10,000 km^2. Panel C: estimates of equation (2) for soy regions; dependent variable is equal to 1 if number of land occupations is higher than 0. Panel D: estimates of equation (3); dependent variable is equal to 1 if number of land occupations is higher than 0. Soy regions: South, South-East and Central-West (Figure A.7). Sources: soy area: PAM; land occupations: *Dataluta*.

Figure A1: Plots from Falcone and Rosenberg (2022)

analysis with more detailed and granular data.

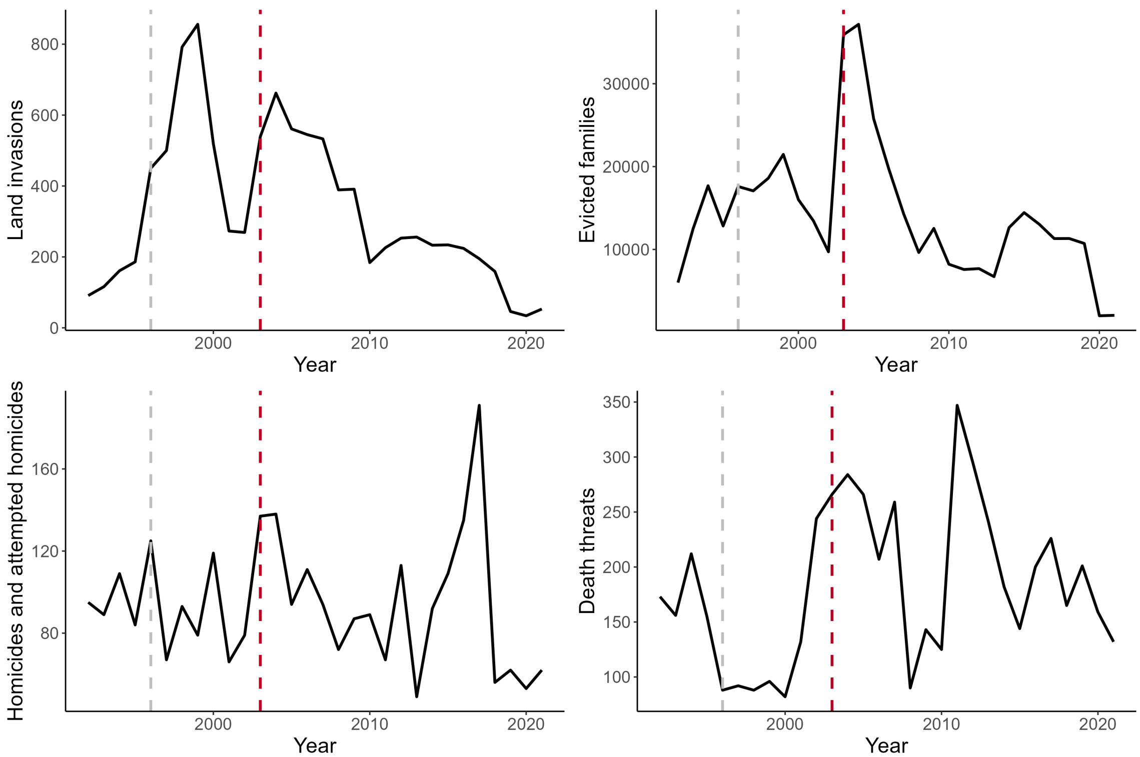


Figure A2: **Land conflict in Brazil**. This figure shows the total number of different variables related to land conflict in Brazil, between 1992 and 2021: land invasions; families that were evicted from their lands; homicides and attempted homicides related to land conflict; and death threats related to land conflict. The data was obtained from the reports published by Comissão Pastoral da Terra. The red dashed line marks the legalization of GE soy seeds in 2003, while the gray dashed line marks the introduction of these seeds in the United States in 1996.