Labor Supply and Directed Technical Change: Evidence from the Abrogation of the Bracero Program in 1964

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Directed technical change theories suggest that the relative abundance of production factors determine the pace and direction of technical advances (Acemoglu 2002). A particularly important application in economic history is the impact of labor supply on technological change. The famous Habakkuk hypothesis claims that labor scarcity in the Nineteenth-century United States induced the rapid US technological progress relative to Britain (Habakkuk 1962).

Notwithstanding the interest in this theory, there has been relatively little documentation of the actual impact of the relative abundance of labor supply on the direction of technical change. This paper provides the first well-identified study of the impact of a shift in relative labor supply on the invention of new technology. To do so, it utilizes a massive exogenous shock to the labor supply in the US agricultural sector caused by the abrogation of the bracero agreements between the United States and Mexico at the end of 1964. Varying substantially between crops, bracero workers in the median crop accounted for one-fifth of the seasonal labor force during the program. The exclusion of those workers from the labor force generated a sharp decline in the labor supply available to produce those crops.

The first contribution of this paper is to document the pattern of directed technical change caused by the shock to labor supplies. Using a text-search algorithm to allocate patents to crops, I show that the bracero exclusion induced a sharp increase in innovation in crops that were more exposed to the bracero program relative to less-exposed crops. Innovators reacted fast, introducing new technologies right after the termination of the program. Innovation in technologies related to high-exposed crops remained high more than fifteen years after the end of the program. Thus, the patent data reveal substantial directed technical change towards technologies related to crops with labor scarcity.

The second contribution of this paper is to study the heterogeneous effect of labor supply on different types of technology. Using detailed data on labor requirements by task and crop, I build a measure of labor intensiveness of the technology classes for each one of the crops. Then, I compare the effect of exposure to the bracero program in technical classes that are more labor-intensive with the effect in technical classes that are less labor-intensive. Triple difference estimates confirm that the labor-supply shock encouraged patenting in labor-intensive technological classes, relative to other technological classes. Assuming that technologies related to more labor-intensive tasks tend to be more labor-saving on average, these results suggest that labor scarcity encourages labor-saving technological progress relatively more than labor-augmenting technological progress.

In the last part of the work, I complete the analysis of the bracero shock by checking whether the farm owners gained or lose from it. Using information from the US agricultural census, I show that counties that were more exposed to the shock experienced a greater decline in their farm values after the shock relative to less-exposed counties. These results, however, are valid only for states that participate in the bracero program. Taking together, the results of this section show that the policy change was unexpected and undesirable for farm owners.

A few studies provide evidence on the effect of factor supplies on technological progress. Hanlon (2015) finds that the scarcity of US cotton in England during the US Civil War induced the development of new technologies that augmented Indian cotton. Lewis (2011) and Hornbeck and Naidu (2014) find that areas with a lower relative supply of low-skilled labor adopted more advanced technology. The closest to the current project are recent papers by Doran and Yoon (2019) and Andersson et al. (2019) who study the effects of mass migration waves on technological innovation using geographical variation in receiving and sending communities, receptively. My research complements these papers in two ways. First, my identification strategy takes advantage of an exogenous policy shock that affected only low-skilled workers. Second, I use patents issued in the United States, the technological leader of the time. Thus, these patents should reflect frontier inventions. This is aided by the fact that my variation is in the "idea space" as opposed to spatial variation. Giving that technological invention is to a large extent globally applicable, the variation between different types of technological fields should better capture real "path-breaking" inventions, as opposed to local adjustments of already-existing technologies.

Clemens et al. (2018) exploit the abrogation of the bracero program to study the effect of labor scarcity on the labor market. They use state-level variation in the exposure to the bracero program to show that the abrogation of the program did not affect local wages or employment. One might conjecture that the technological response for the labor-supply shock was the mechanism that prevented the rise in wage rates and local employment.

Recently, there is an increasing interest in the joint dynamics of artificial intelligence (AI) technology and the labor market (Acemoglu and Restrepo 2018). Whether an increase in the available labor supply encourages or discourages further technological progress is crucial for the rate of development of AI. If greater labor supply discourages the development of automated technologies, as suggested by the results of this paper, an initial positive shock to AI technologies will increase the available supply of labor (or reduce the wages) and hence will discourage the development of further AI technology. In other words, the fact that an increase in the labor supply discourages the development of labor-saving technologies limits the long-run growth rate of AI technology on the one hand, and unemployment due to automation on the other hand.

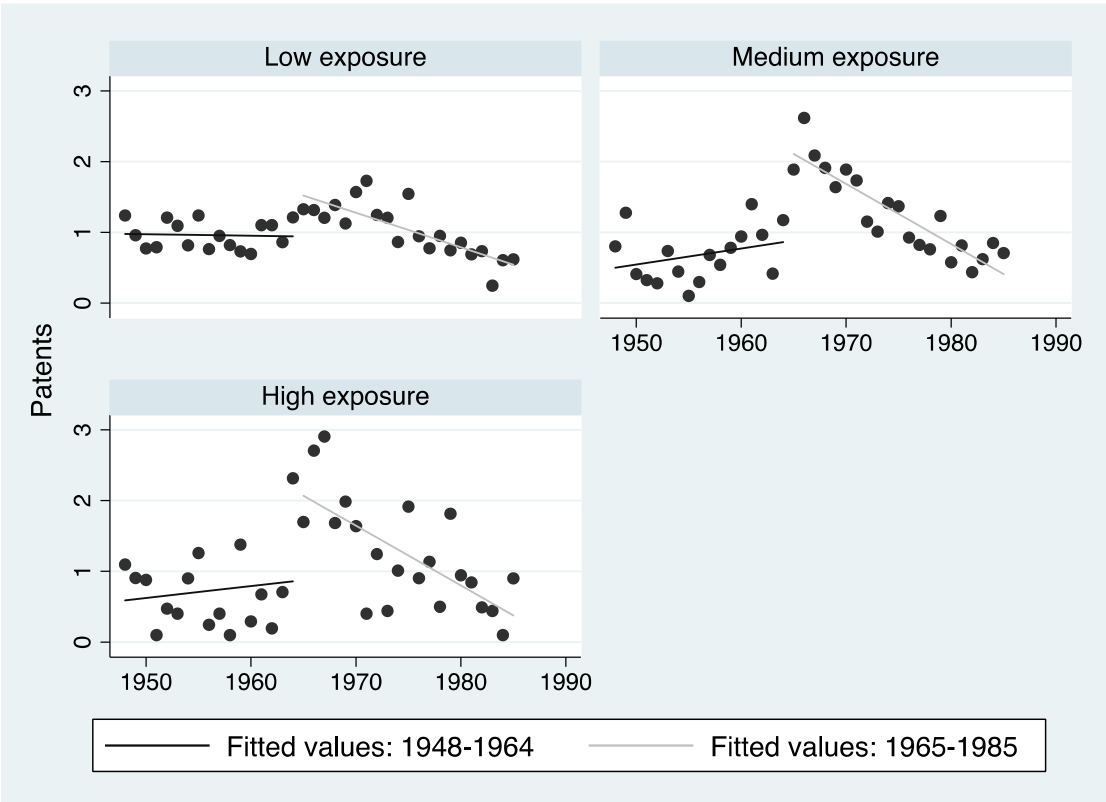
Effects of Labor Scarcity on Invention in the United States

My empirical strategy compares changes in invention across crops that were differentially affected by the termination of the bracero program. Figure 1 illustrates the primary results of this section. The first graph shows the relative number of patents for crops with low exposure to the bracero program. The raw data reveal no change before and after 1965. However, for crops that in the medium and high exposure groups there is a noticeable jump around the end of the bracero program. The rest of this section explores this pattern more rigorously.

The primary outcome variable is a crop's number of patents. I match a patent to a crop by searching the text of the patent for the crop names. I perform a quality adjustment by weighting each patent by its number of citations. The estimating equation relates crop i's output in year t to characteristics of i:

$$ln[\mathbb{E}(y_{it}|X_{it})] = \beta \cdot \%Foreign_i \cdot post_t + \gamma_i + \delta_t \quad (1)$$

Figure 1: Invention over Time for Crops with Low, Medium and High Exposure to the Bracero Program



Notes: The patents measure is the average normalized number of patents for the crops in the exposure group, where each crop-year observation is divided by the crop's 1948-1985 average.

Table 1: Effects of Bracero Exclusion on Invention: Baseline Estimates

	patents	citations
	(1)	(2)
%Foreign x post	0.033***	0.023***
	(0.013)	(0.008)
Average response	2.17	8.91
N (crops × years)	608	608
Mean patents/citations before 1965	4.06	23.90
Treatment mean	0.19	0.19
Treatment sd	0.16	0.16
Year FE	Yes	Yes
Crop FE	Yes	Yes

Notes: This table reports the Poisson quasi-maximum likelihood estimators of equation 1. The average response is the estimated change in the number of patents/citations per year for a one standard deviation increase in the exposure at the average number of patents/citations per crop and year before 1965. Standard errors clustered at the crop level.

where y_{it} is a measure of innovation output at crop i at year t, $\%Foreign_i$ is the share of foreign workers in the total number of seasonal workers in crop i one year before the termination of the bracero program, $post_t$ denotes an indicator variable that switches to one after 1965, the γ_i's correspond to crop fixed effects, the δ_t's stand for a full set of calendar year indicator variables, and X_{it} denotes all the independent variables on the right-hand side of the equation.

Table 1 presents the core results. Column 1 examines the determinants of the 16 crops' patent count. I find a significant increase in the yearly number of patents produced after 1965 in crops that were more exposed to the bracero program. Not only are the coefficient estimates statistically significant, but they are also economically meaningful. An increase of one percentage point in the share of foreign workers before the policy change increases the innovation activity by 3.3 percent. Compared with an average of 4.2 annual patents in the average crop in 1948-1985, an increase of one standard deviation in the labor-supply shock adds about seven patents per year.

Column 2 provides the results for citation-weighted patents, a measure that takes into account the quality of the innovation. The effect is somewhat smaller—An increase of one percentage point in the exposure to the chock increases the quality-adjusted innovation measure by 2.3 percent.

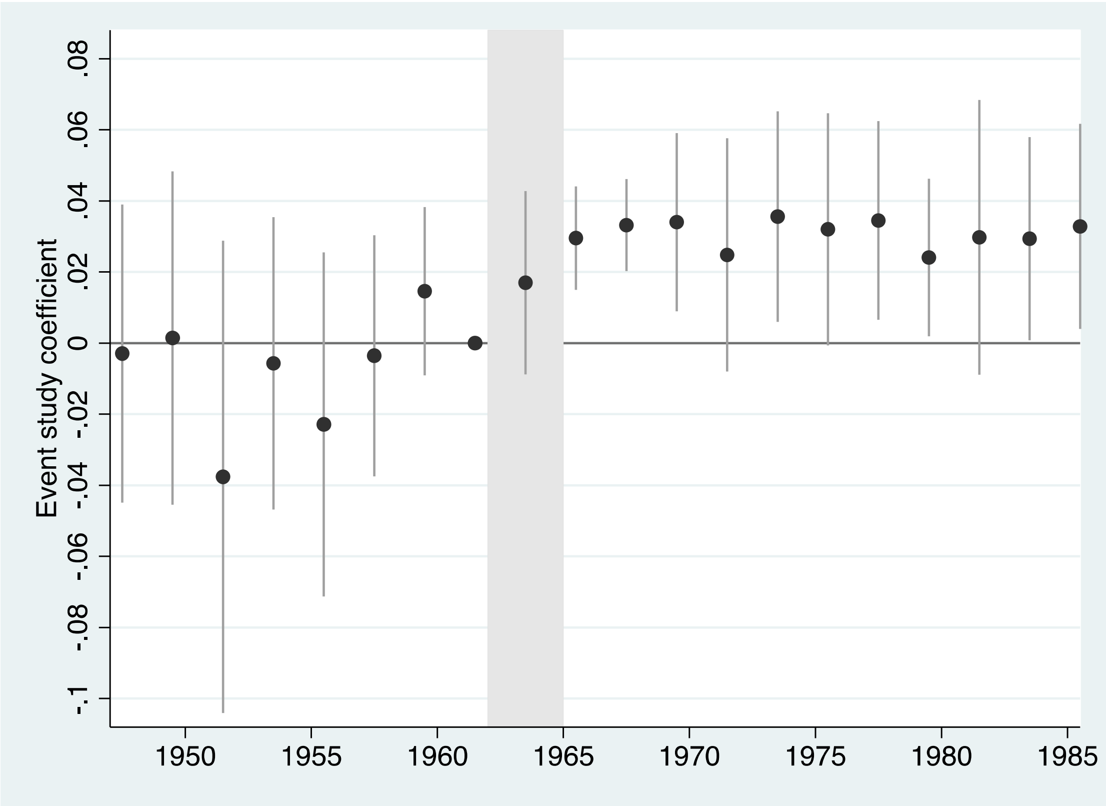
I also explore the dynamics of the effects uncovered in Table 1 by estimating a specification in which the treatment effect interacts with a set of indicator variables corresponding to a particular calendar year. Following the end of the *bracero* program, the treatment effect rises monotonically, arriving at its pick three to four years after *bracero* exclusion, and remains at the same level (see Figure 1). Two aspects of this result are worthy of note. First, I find no evidence of recovery—the effect of *bracero* exclusion persisted for at least 15-20 years. This result suggests that the labor scarcity did not induce only the patenting of off-the-shelf technologies, but mostly induced the invention of new technologies. Second, the event study coefficients fluctuate around zero and are not significantly different from zero for periods before 1965, showing no evidence for a pretreatment trend.

Effects by Type of Technology

To study the heterogeneous effect of labor supply on different types of technology, I use information on the labor intensity of different tasks as a proxy for the probability of a technological innovation related to these tasks to be labor saving. The underline assumption is that everything else is equal, the incentive to develop new labor-saving technology for a particular task is higher the greater the labor intensity in that task.

For each class-crop pair, I calculate the share of labor requirements for this technological class over the total labor requirements of that crop. I use two versions of these labor-intensity measures, one using man-hours and the second using the monetary cost. The second measure takes into account potential

Figure 2: Continuous DID, Event-Study Analysis. Treatments: Share of Foreign Seasonal Workers in 1964. Dependent Variable: Number of Patents.



Notes: This graph plots the Poisson quasi-maximum likelihood estimators of $ln[\mathbb{E}(y_{it}|X_{it})] = \beta_t \cdot \%Foreign_i \cdot post_t + \gamma_i + \delta_t$. Standard errors clustered at the crop level.

differences in skills or efficiency units of the labor inputs. I also estimate a specification where the labor-intensity measure equals one for Harvesting tasks, which is the most labor-intensive category on average, and zero for the other categories.

Using those measures, I estimate the following continuous triple-difference regression:

$$ln\left[\mathbb{E}(patents_{ijt}|X_{ijt})\right] = \beta \cdot \%Foreign_i \cdot Intensity_{ij} \cdot post_t + \gamma_{ij} + \delta_{it} + \epsilon_{jt} \quad (2)$$

where y_{ijt} is the number of US patents/citations in crop i, technological class j, and year t. $\%Foreign_i$ is the foreign percentage of seasonal workers in crop i in 1964. $Intensity_{ij}$ is a measure of labor inputs required to perform task j in crop i. $post_t$ indicates years after 1964. γ_{ij}, δ_{it}, and ϵ_{jt} are crop-task, crop-year, and task-year fixed effects, respectively.

Poisson quasi-maximum likelihood estimates of equation 2 imply a substantial higher effect of bracero exclusion after 1964 in more labor-intensive tasks relative to less labor-intensive tasks (table 2).

The results indicate that the effect of labor scarcity on technological progress is greater in labor-intensive tasks. Under the assumption that labor-saving technologies are more likely to be developed for labor-intensive tasks, the results suggested that labor scarcity concurrence the invention of labor-saving technologies more than other technologies, in accord with the theory.

The Winners and the Losers: The Impact on Farm Value

This section explores who are the winners and the losers from the abrogation of the *bracero* program. In a recent study, Clemens et al. (2018) show that US workers did not gain from the change. Although the policy change aimed to increase the wages and the employment rate of local US workers, both employment and wages were not affected by the termination of the program.

An open question is whether the farmers win or lose from the policy change. To investigate it, I use the land value as a measure of the welfare of the farmers. The value of a farm would increase if following the end of the program it became more profitable to be a farmer in farms that were more exposed to the program.

Table 2: Effects of Bracero Exclusion on Invention in Labor Intensive Tasks: Triple-differences Estimates

	patents	citations	patents	citations	patents	citations
	(1)	(2)	(3)	(4)	(5)	(6)
%Foreign x labor-class x post	0.032***	0.022***				
	(0.012)	(0.010)				
%Foreign x cost-class x post			0.031***	0.021***		
			(0.011)	(0.009)		
%Foreign x class x post					0.025***	0.018***
					(0.010)	(0.007)
N (crops x classes x years)	1,447	1,447	1,447	1,447	2,096	2,096
Mean patents/citations before 1965	2.19	14.14	2.19	14.14	1.89	12.72
Crop-class FE	Yes	Yes	Yes	Yes	Yes	Yes
Crop-year FE	Yes	Yes	Yes	Yes	Yes	Yes
Crop-year FE	Yes	Yes	Yes	Yes	Yes	Yes

Notes: This table reports the Poisson quasi-maximum likelihood estimators of equation 2. Standard errors clustered at the crop-class level.

I use the United States census of agriculture for the years 1950-1987 to build a panel data of land-value per acre by county and year. Additionally, using the same datasets and the exposure measures by crop, I build a measure of the exposure of a county c to the *bracero* program in the following way:

$$Exposure_c = \sum_i \%Foreign_i \cdot \%Acreage_{ic} \quad (3)$$

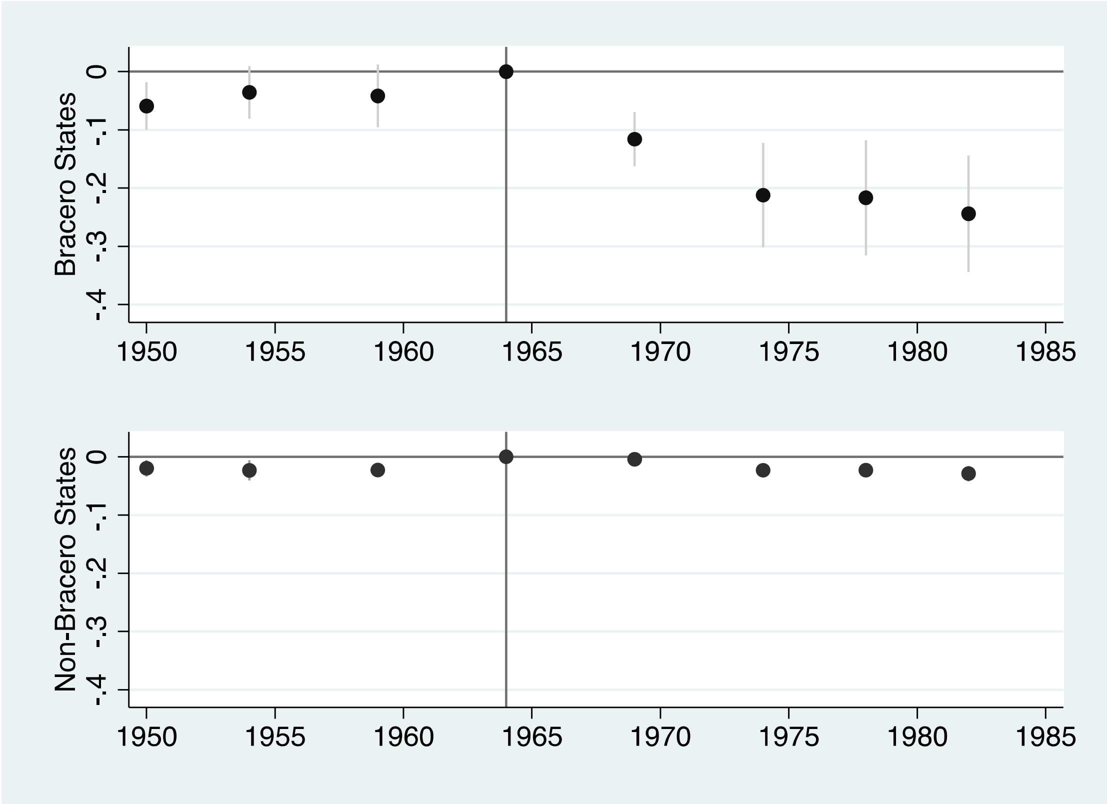
where $\%Foreign_i$ is the foreign percentage of seasonal workers in crop i and $\%Acreage_{ic}$ is the share of crop i in the total acreage of county c in the 1964 census. The regression equation is:

$$ln(Value_{ct}) = \sum_{\tau=1950}^{1987} \beta_\tau \cdot \mathbb{I}(t = \tau) \cdot Exposure_c + \gamma_c + \delta_t + \epsilon_{ct} \quad (4)$$

where γ_c and δ_t are county and year fixed effects, respectively. I run the regressions separately for *bracero* and non-*bracero* states. Figure 3 show a permanent decrease in farm values of counties that are relatively more exposed to the shock. These results are true only for states that participate in the *bracero* program.

Two aspects of this result are worthy of note. First, the results support the assumption that the shock was unexpected. If the termination of the *bracero* program was expected before 1964, one should not see this decline in the farm values. Second, farmers who employed *bracero* workers were adversely affected by the termination of the program. This fact is consistent with historical documentation about the farmers' opposition to the program's abrogation.

Figure 3: Continuous Diff-in-Diff, Event-Study Analysis. Treatments: Exposure Foreign Seasonal Workers in 1964. Dependent Variable: Farm Value per Acre.



Notes: This graph plots the Poisson quasi-maximum likelihood estimators of β_t in equation 4 and the 95 percent confidence interval of these coefficients. Standard errors clustered at the county level.

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