环境灾难引导创新方向

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评论：这篇文章选取的角度和数据都十分有趣，尽管数据上存在一定的局限性，比如对侵蚀度的衡量是累积而非冲击导致、对杂交技术的衡量困难等。但是作者通过各种替代变量和额外分析弥补了数据上存在的问题。不仅仅是做了非常多的检验等来保证结果的稳健性，作者选取替代变量的思路也是值得学习的一个点，没有杂交技术方面的数据衡量使用非完全花作为替代，是一个本身就很有趣的选择。

1、引言

经济增长的历史中充满了通过技术进步应对新兴威胁的案例，当环境、公共卫生或是地缘政治危机冲击经济体，技术进步是经济体危机响应措施中的重要组成部分。一个存在的问题是：灾难冲击如何影响技术进步的方向，而当灾难摧毁了特定的地区、部门或人群时，新技术又能在多大程度上抑制或加剧原始冲击的影响。这个问题的回答对准确衡量危机造成的经济后果有着重要意义。文章研究区间为 1920-1960 年，通过聚焦于 1930 年代发生在美国的极端环境冲击“黑色风暴”（Dust Bowl），结合数字化土地侵蚀地图与美国农业普查数据，衡量作物特定黑色风暴暴露程度。并将其与美国农业部品种名称列表的新生物技术发布数据集以及专利、研究出版物和美国联邦实验站试验记录，从不同技术之间的创新转型、研究对上游科学的影响以及政府资助研究的作用三个方向揭示黑色风暴冲击如何影响新种子技术的开发。

文章的贡献有 3 点，首先文章扩展了大量研究适应环境冲击的文献，包括但不限于技术进步在环境适应中的作用、黑色风暴的经济影响。其次文章扩展了技术变革方向的研究，证明了创新会对环境危机做出显著反应，并在随后的几十年后持续反应，而这个过程是在没有政府直接支持的情况下发生的。最后文章的发行为创新者对环境压力做出显著反应的假说提供了经验性证据，并证明了 20 世纪早期的极端气候对农业创新产生了持久的影响。

2、数据

2.1 受黑色风暴影响程度

县级层面受黑色风暴影响程度的指标来自于 Hornbeck（2012）研究中的数字化的地图数据，该数据测量了 1930 年代中期的县级土壤侵蚀情况，并确定了连片且生态相似的大平原区域的县级样本。该地图将美国土地分为轻度侵蚀（表土流失低于 25%）、中度侵蚀（表土流失 25%-75%）和重度侵蚀（表土流失超过 75%）三类。该数据存在的问题是地图描绘的土壤侵蚀情况是累积的，而非单纯由于黑色风暴导致的侵蚀。

2.2 技术发展数据

数据来源于美国农业部品种名录数据统计的新品种发布数量，该名录收录了美国农业部已知的所有已发布作物品种及其发布年份，包括“品种发布通知、官方期刊、种子目录、种子贸易出版物，以及种子公司获准使用的品种名称”。在 1970 年之前，种子无法申请专利，从而无法通过知识产权数据衡量技术发展。

2.3 其他补充创新与技术发展的额外指标

2.3.1 作物专项专利数据

来自于 PatSnap 数据库，统计与各作物相关的合作专利分类中非畜牧农业（A01B-A01N），通过品种名录里的作物名称对专利进行匹配。优势在于通过多技术领域的创新探究跨技术

领域的发明转向；同时专利数据库拥有更严格的收录标准，用以验证基准结果的稳健性。但以专利衡量的创新与作物的关联不如品种数据直接。

2.3.2 农业研究数据

来自 Web of Science 数据库中所有农业科学领域的研究论文数据，通过检索论文标题中的作物名称将论文与作物做匹配

2.3.3 联邦实验站数据

Kantor 与 Whalley（2019）整理的 1910-1945 年美国联邦实验站作物专项实验数据，实验层级信息采集自各实验站发布的独立报告。

2.4 作物的黑色风暴暴露程度估计

估算 1930 年农业普查中列出的在研究期间至少发布了一个品种的作物的黑色风暴暴露程度，总共包括 43 种作物。暴露程度衡量黑色风暴对作物层面的整体损害，即 1930 年前种植作物的土地在黑色风暴期间遭受侵蚀的比例。为了弥补侵蚀数据是侵蚀积累而非黑色风暴直接导致的偏误，作物层面的衡量指标是每种作物种植土地同时满足①位于文章定义的平原区域；②在侵蚀调查时已遭受侵蚀。

$$\text{Exposure}_c = \sum_i \frac{L_{ic}}{\sum_{i'} L_{i'c}} \cdot \mathbb{I}\{\text{Plains}_i\} \cdot \text{High Erosion Share}_i$$

其中i代表县，c代表作物，L_{ic}是 1930 年农业普查测得的县i用于种植作物c的土地面积。$\mathbb{I}\{Plains_i\}$为指示函数，若县属于平原区域则取值为 1。$High\ Erosion\ Share_i$是县i中经历重度侵蚀（表土流失 75%）的土地比例

使用 1930 年前测定的作物种植模式来估计作物层面的黑色风暴暴露程度优势在于种植模式相对于环境冲击是预先确定的，即环境冲击是一个外生变量。劣势在于如果作物种植模式在随后发生重大改变则会错误估计作物的黑色风暴暴露程度。但是作物布局在整个样本其内表现出显著持续性，分县别的作物种植面积在 1930 年与 1960 年之间的相关性接近 1，且这种关系不受县级侵蚀或作物层面总体黑色风暴暴露程度的影响。

3、模型构建

3.1 基本模型

评估黑色风暴对创新方向的影响，方程如下：

$$y_{ct} = \alpha_c + \gamma_t + \beta \cdot \text{Exposure}_c \cdot \mathbb{I}_t^{\text{Post 1930}} + \Gamma X'_{ct} + \epsilon_{it}$$

其中c代表作物，t代表年份（1920-1960 年）。自变量为作物层面的黑色风暴暴露程度$Exposure_c$与指示变量（在 1930 年黑色风暴开始后的年份取值为 1）$\mathbb{I}_t\{Post\ 1930\}$的交互项。$\alpha_c$和$\gamma_t$分别是作物固定效应和年份固定效应，并控制了时变控制变量向量X'_{ct}，结果变量y_{ct}是衡量第t年作物c创新水平的指标。系数$\beta > 0$表明创新活动更多的指向受黑色风暴损害更严重的作物，原因可能是受黑色风暴影响地区对韧性技术的需求上升；若系数$\beta < 0$表明品种创新避开了受黑色风暴损害更严重的作物，可能转向于农业经济中根基更稳固的领域获取更大的利润机会。

3.2 动态模型

同时为了探究黑色风暴暴露程度与创新之间的动态关系，并检验结果变量是否存在预先趋势，使用如下方程：

$$y_{ct} = \alpha_c + \delta_t + \sum_{\tau \in \mathcal{T}^{pre}} \beta_\tau \cdot \text{Exposure}_c \cdot \delta_\tau + \sum_{\tau \in \mathcal{T}^{post}} \beta_\tau \cdot \text{Exposure}_c \cdot \delta_\tau + \epsilon_{ct}$$

若不同暴露程度的作物在黑色风暴发生前遵循相似的发展趋势，则当τ属于前置期T_{pre}时，系数β_τ在统计上应不显著异于零；而当τ属于前置期T_{post}时，系数β_τ可识别黑色风暴暴露对第τ年创新活动的因果效应。

3.3 模型假设与局限性

模型的前提假设是若黑色风暴未发生，暴露程度不同的作物在 1930 年后仍保持相似的发展趋势。模型可能存在的问题是：可能存在一些即使没有黑色风暴等环境变化，1930 年后也会有创新突破的作物。同时，由于作物样本有限，整个样本期（1920-1960）内的创新活动主要集中于有经济重要性的作物，所以结果可能是由少量作物样本创新趋势伪变化驱动。尽管作物层面的黑色风暴暴露在一系列特征变量上没有系统性差异（包括但不限于衡量作物市场规模（如前期总种植面积、品种发布数量）、环境变化敏感度（如最低降雨需求、最高温度耐受性）以及技术可行性（如杂交难易度）的指标。整个实证分析仍存在黑色风暴暴露与作物层面创新趋势的伪相关性可能。

4、结果（创新方向）

4.1 基准回归

表 1 为作者基于模型

$$y_{ct} = \alpha_c + \gamma_t + \beta \cdot \text{Exposure}_c \cdot \mathbb{I}_t^{\text{Post 1930}} + \Gamma X'_{ct} + \epsilon_{it}$$

的估计结果。第 1、2 列是 OLS 估计值，对结果变量（每年各作物新发布农业品种数量）进行取反双曲正弦值处理。第 1 列为未加权回归，第 2 列以 1929 年各作物总种植面积为权重进行回归，以确保研究发现不受在农业生产中占比较小的作物驱动。第 3、4 列沿用相同设定，但将结果变量转换为对数形式，第 5 列则采用泊松伪最大似然估计法以适配计数变量特征。各列估计结果均显示，核心系数显著为正，表明新品种研发方向显著偏向受黑色风暴影响更严重的作物。根据估计结果，黑色风暴暴露程度每增加一个标准差，新品种发布数量将分别增加 0.18 和 0.32 个标准差。

Table 1: Dust Bowl Exposure and New Crop Varieties

	(1)	(2)	(3)	(4)	(5)
Dependent Variable:	New Varieties (asinh)		New Varieties (log)		New Varieties (count)
Specification:	OLS	OLS	OLS	OLS	PPML
$\text{Exposure}_c \times \mathbb{1}_t^{\text{Post 1930}}$	0.0694***	0.114***	0.0680**	0.133***	0.0750***
	(0.0242)	(0.0272)	(0.0320)	(0.0356)	(0.0283)
Crop Fixed Effects	Yes	Yes	Yes	Yes	Yes
Year Fixed Effects	Yes	Yes	Yes	Yes	Yes
Weighting	None	Initial Area	None	Initial Area	None
Crops	43	43	43	43	43
Observations	1,720	1,720	799	799	1,720
R-squared	0.663	0.828	0.601	0.823	-

Notes: The unit of observation is a crop-year. All specifications include crop and year fixed effects. In columns 1-2 the outcome variable is the inverse hyperbolic sine of the number of new varieties in each crop-year, in columns 3-4 it is log of the number of new varieties, and in column 5 it is the number of new varieties in each crop-year. Columns 1-4 are estimated via OLS and column 5 is estimated via Poisson pseudo-maximum likelihood. Columns 2 and 4 are weighted by initial crop planted area. Standard errors, double clustered by crop and year, are reported in parentheses. *, **, and *** indicate significance at the 10%, 5%, and 1% levels.

4.2 动态估计

图 1a 展示了模型

$$y_{ct} = \alpha_c + \delta_t + \sum_{\tau \in \mathcal{T}^{pre}} \beta_\tau \cdot \text{Exposure}_c \cdot \delta_\tau + \sum_{\tau \in \mathcal{T}^{post}} \beta_\tau \cdot \text{Exposure}_c \cdot \delta_\tau + \epsilon_{ct}$$

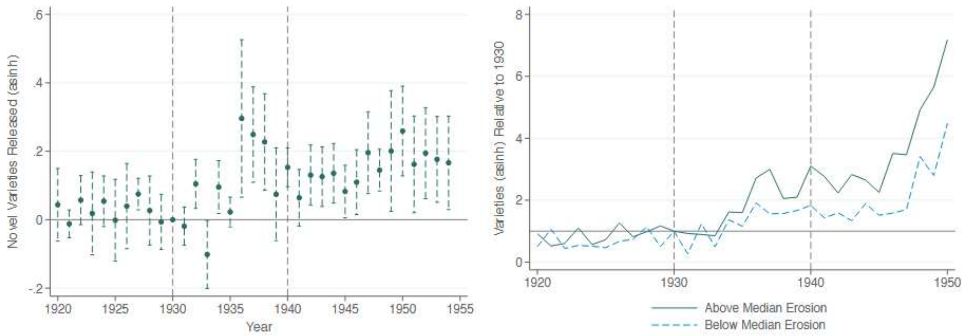
的系数估计结果并给出了每个系数的估计值与置信区间。可以在图中看到，在 1930 年前所有估计系数数值相似且均接近 0 值。在 1930 年代中期，估计系数转向显著为正并在随后几十年中持续保持这一趋势。

图 1b 使用原始数据展现暴露程度高于中位数的作物组与低于中位数的作物组以 1930 年为基准的每年新品种发布数量的变化轨迹，尽管所有作物在样本期内新品种发布数量均呈现上升趋势，但在黑色风暴最严重的年份，暴露程度不同的作物组之间出现了显著的创新分化。

暴露程度更高的作物的创新增长趋势从黑色风暴高峰期一直持续到样本期结束，可能存在以下解释：

1、由于黑色风暴导致的表土流失，土地质量长期难以恢复，对抗灾、适应力强的作物品种的需求长期存在。

2、黑色风暴期间启动的项目，投入的资金等持续运作，这与近年关于研发投资具有长期创新溢出效应的研究结论一致。



(a) Event Study (b) Raw Data Trend

Figure 1: **Dust Bowl Exposure and Innovation: Dynamics.** Figure 1a reports coefficient estimates from 4.2, and 95% confidence intervals are displayed. The dotted gray lines mark the decade during which the Dust Bowl took place. Standard errors are double-clustered by crop and year. Figure 1b displays new varieties (asinh) released, relative to 1930, for crops with above median (solid line) and below median (dotted line) Dust Bowl exposure.

4.3 敏感性和稳健性检验

4.3.1 作物地理安慰剂检验

由于黑色风暴主要集中于平原地区，需要检验黑色风暴暴露程度是否仅仅捕捉了在平原地区集中种植的作物而非真实的环境暴露。因此构建安慰剂指标如下：

$$\text{Low Exposure}_c = \sum_i \frac{L_{ic}}{\sum_{i'} L_{i'c}} \cdot \mathbb{I}\{\text{Plains}_i\} \cdot \text{Low Erosion}_i$$

如果主要捕捉的是来自于平原地区作物创新的变化趋势，那么$Low\ Exposure_c$在黑色风暴后也应当与创新呈正相关。结果如图 A2，从左往右分别是基准回归（高侵蚀度的平原县），低侵蚀度的平原县，中等侵蚀度的平原县，高侵蚀度的非平原县。图中可以看出，安慰剂度量指标（低侵蚀度平原县暴露）与作物品种创新之间没有关系。将其更改为中等侵蚀度平原县暴露后尽管影响是正向的，但远不及高侵蚀的影响。这进一步支持了环境破坏程度是作物创新技术发展原因的论点。

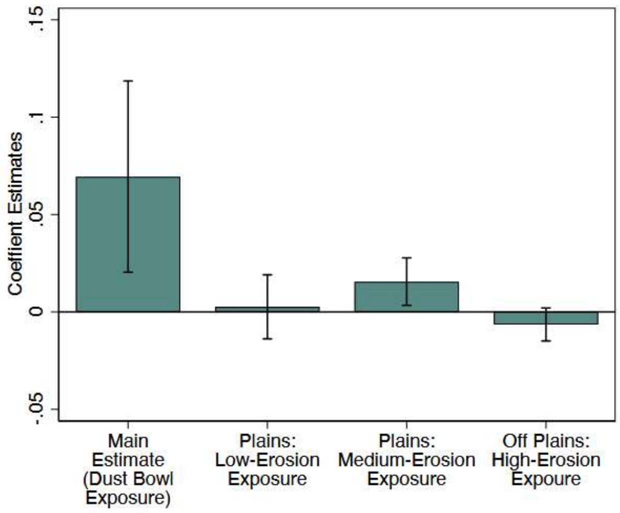


Figure A2: **Placebo Dust Bowl Exposure Estimates.** This figure reports estimates of Equation 4.1. The first bar reproduces the baseline estimate in which Dust Bowl exposure is computed as each crop's exposure to high levels of top soil erosion in Plains counties. The second bar reports the coefficient estimate using a measure of exposure computed as each crop's exposure to low levels of top soil erosion in Plains counties. The third bar reports the coefficient estimate using a measure of exposure computed as each crop's exposure to medium levels of top soil erosion in Plains counties. The fourth bar reports the coefficient estimate using a measure of exposure computed as each crop's exposure to high levels of top soil erosion *outside* of Plains counties. Standard errors are clustered by crop and 95% confidence intervals are reported.

4.3.2 创新的其他驱动因素

如图 A3，作者加入了一系列的控制变量来控制作物创新趋势是否由环境变化之外的因素驱动。从左往右分别为基准结果，品种发布趋势，农业调整法案（AAA），作物特性与重要性，重大历史时期影响，作物繁殖特性（不完全花，即作物是否有杂交可能），作物是否属于主要谷物类别，全控制变量。在所有情况下系数都保持相似，并且在包含所有控制变量时幅度会增大。

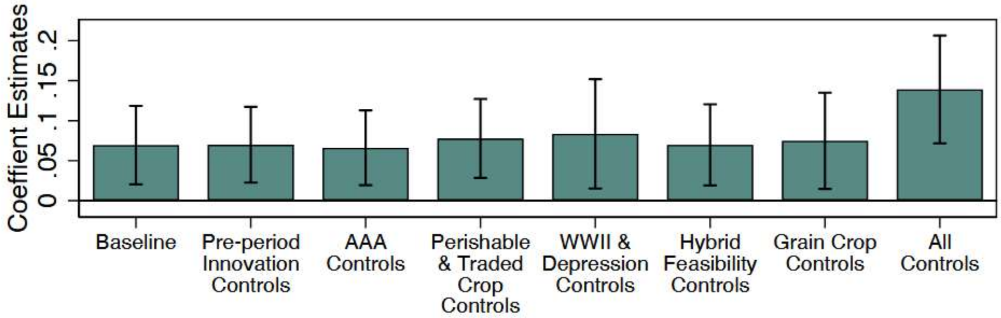


Figure A3: **Robustness to Controls.** This figure reports estimates of Equation 4.1 with additional controls added in each specification. The controls are pre-period crop-level variety releases interacted with year fixed effects (bar 2); an Agricultural Adjustment Act (AAA) inclusion indicator interacted with year fixed effects (bar 3); a perishable crop indicator interacted with year fixed effects as well as an indicator for inclusion in United States Department of Agriculture (1936) for years prior to the Dust Bowl interacted with year fixed effects (bar 4); indicators for the years of WWII (1941-1945) and the depression (1929-1939) interacted with crop fixed effects (bar 5); an indicator that equals one if a crop has imperfect flowers interacted with year fixed effects (bar 6); an indicator that equals one if a crop is a major grain (sorghum, corn, wheat, spelt, buckwheat, millet, rye, barley, oats, rice) interacted with year fixed effects (bar 7); and all previous controls combined (bar 8). Standard errors are clustered by crop and 95% confidence intervals are reported.

而图 A4 剔除了样本中那些可能本身就存在创新趋势的作物。从左往右分别为基准结果，排除前期土地面积最大的作物（1929 年前种植面积前 25%的作物）、排除所有谷物类作物，在排除谷物类的基础上排除贸易作物，排除土地种植面积最大、谷物、贸易作物（即前三者），在排除上述作物的基础上加入图 A3 中所有控制变量。得到的结果是相似的。

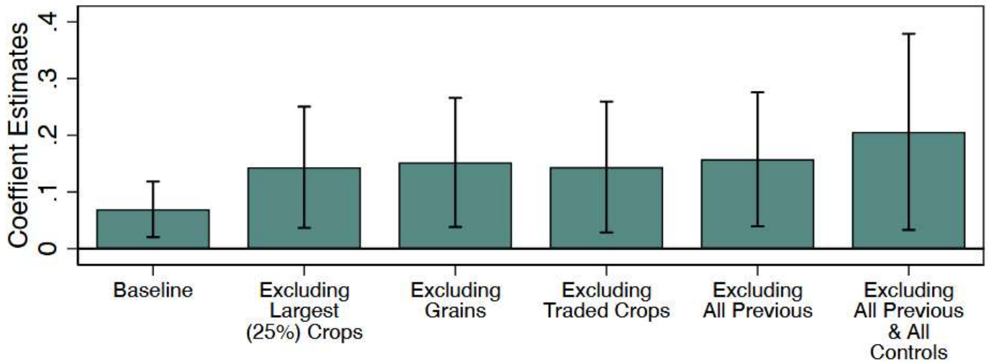
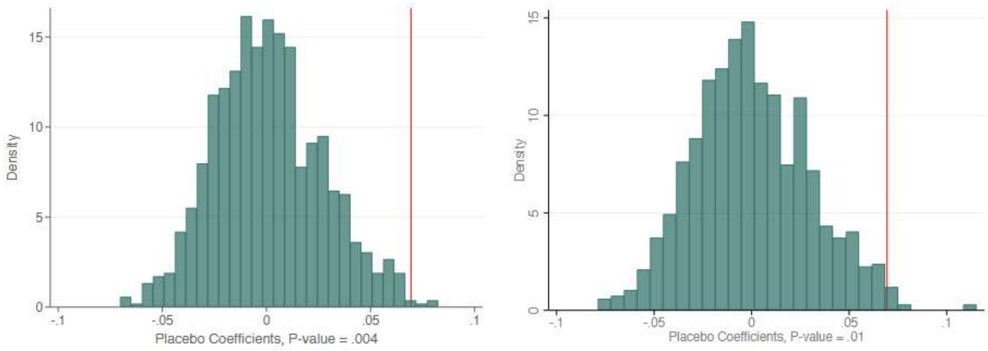


Figure A4: **Robustness to Sample Restrictions.** This figure reports estimates of Equation 4.1. The first bar repeats the baseline estimate. Bars 2-6 exclude from the sample the top 25% of crops by planted area in 1929 (bar 2); further exclude all grain crops (bar 3); further exclude all traded crops as recorded in United States Department of Agriculture (1936) for years prior to the Dust Bowl (bar 4); exclude all crops ever excluded in bars 2-4 (bar 5); and do the same while also controlling for all controls from Figure A3 (bar 6). Standard errors are clustered by crop and 95% confidence intervals are reported.

4.3.3 置换检验

作者将各作物的黑色风暴暴露度随机分配，并将其重新纳入基准回归方程，如果真实系数估计值在安慰剂系数估计值分布的右尾侧，则表明基准回归估计的精确度并非由少量作物

或随机因素驱动。如图 2，红线为真实系数估计量，图 2a 不包含任何控制变量，图 2b 包含所有控制变量。



(a) No Added Controls

(b) All Additional Controls

Figure 2: **Falsification Tests.** Histogram of placebo estimates of β from Equation 4.1 after Exposure_c was randomized across crops. The results from 1000 randomizations are reported as the green histogram and the true estimate of β is marked with a red line. Panel 2a reports results using the baseline difference-in-differences specification and Panel 2b reports estimates from a specification that also includes all additional controls listed in Figure A3. The implied randomization inference p-value is reported beneath each x-axis.

4.3.4 环境冲击的度量

前面提到过，黑色风暴暴露度的缺点在于地表侵蚀程度是累积导致（包含黑色风暴和黑色风暴之前）而非单纯由黑色风暴导致。表 A4 使用外生天气冲击（帕尔默干旱指数和气温标准差）构建工具变量，结果与原本相似。

Table A4: Dust Bowl Exposure and Biotechnology Development: Estimates using 1930s Weather

	(1)	(2)
Dependent Variable:	New Varieties (asinh)	
Estimator:	OLS (Reduced Form)	2SLS
$\text{Exposure}_c \times \mathbb{1}_t^{\text{Post 1930}}$		0.0829**
		(0.0403)
$\text{Palmer Drought Index}_c \times \mathbb{1}_t^{\text{Post 1930}}$	0.0961***	
	(0.0285)	
$\text{Temperature Standard Deviation}_c \times \mathbb{1}_t^{\text{Post 1930}}$	0.433**	
	(0.184)	
Excluded Instuments:		Palmer drought index; Temp. SD
K-P F-Statistic		10.335
Crop Fixed Effects	Yes	Yes
Year Fixed Effects	Yes	Yes
Crop x Year Fixed Effects	-	-
Crop x Technology Class Fixed Effects	-	-
Year x Technology Class Fixed Effects	-	-
Crops	43	43
Observations	1,720	1,720

Notes: The unit of observation is a crop-year and both columns include crop and year fixed effects. In column 2, the excluded instruments are the average standard deviation in temperature and the average Palmer drought index , interacted with the post-period indicator. Standard errors, clustered by crop and year, are reported in parentheses. *, **, and *** indicate significance at the 10%, 5%, and 1% levels.

4.4 技术与创新类型

4.4.1 杂交品种

杂交品种在极端灾害侵蚀时有更强的韧性。为了验证作物创新是否由杂交品种驱动，作者将不完全花（即雌花雄花在植株的不同部位，这样的植株拥有更低的成本和更高的可行性开发新品种）作为杂交品种的衡量。图 A5 是将黑色风暴暴露与不完全花指标的交互项纳入基准回归的结果。尽管对于不可杂交的作物系数同样为正且显著，但对于可杂交的作物，系数更大且同样显著。这表明杂交品种的发展在黑色风暴导致的作物创新响应中扮演了重要的角色。

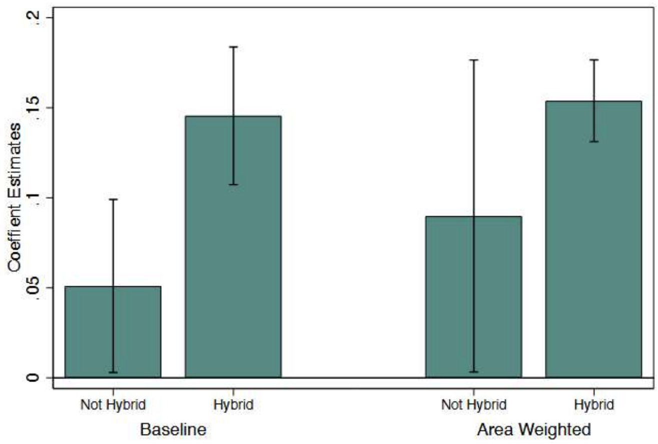


Figure A5: **Heterogeneity by Hybrid Feasibility.** This figure reports estimates of Equation 4.1 in which the main treatment variable is interacted with indicators for whether or not the crop is hybrid compatible (i.e., whether or not it has imperfect flowers). Crop fixed effects and year fixed effects interacted with the imperfect flower indicator are included in all specifications. Each pair of bars corresponds to a single regression estimate; the first set of bars is from an un-weighted regression and the second set of bars is from a regression weighted by pre-period crop area. In both cases, the difference between the bars is statistically significant ($p < 0.05$). Standard errors are clustered by crop and 95% confidence intervals are reported.

4.4.2 专利与非品种技术

技术发展重点除了在不同种类作物之间转移外，也可能重新定向至那些对是环境适应能力最有用的技术。作者通过将农业专利分为机械技术（收割机等），收获后与加工技术，以及土壤改良与化学技术（化肥、农药等）三类。表 A5 是黑色风暴暴露对每个技术类别专利申请的影响。其中，黑色风暴对于机械或收获后技术没有影响，而对土壤改良以及生物、化学技术有正向影响。并且黑色风暴对于生物和化学技术尤其有影响。这组估计结果能表明基准回归的结果可能并非由于作物层面的创新的总体趋势所驱动，反而集中于那些可能与环境适应相关的技术上。由此，作者拓展了基准模型如下：

$$y_{xct} = \alpha_{cx} + \delta_{tx} + \gamma_{ct} + \psi \cdot \text{Exposure}_c \cdot \mathbb{I}_t^{\text{Post 1930}} \cdot \mathbb{I}_x^{\text{Adapt}} + \epsilon_{kct}$$

这是一个基于“作物-年份-技术”的三重差分模型，其中x是对农业专利技术的分类，$\mathbb{I}_x^{Adapt}$当技术属于土壤改良和化学技术（CPC 类别 A01B, A01C, A01H 和 A01N）取值为 1。γ_{ct}吸收作物特定趋势以及作物层面的价格变化。结果于表 A5 中第四列，表明在受黑色风暴影响更严重的作物中，与适应相关的技术发展显著增强。这一结果证明基准模型结果中的趋势并非作物间的虚假差异趋势或者作物层面的价格变化导致，而是由特定技术需求的增加驱动的。

Table A5: Dust Bowl Exposure and Patented Technologies

	(1)	(2)	(3)	(4)
	Outcome is log citation-weighted patents related to:			Outcome is log citation-weighted patents
	Mechanical and Post-Harvest Tech	Soil Modification and Bio / Chemical Tech	Only Bio / Chemical Tech	
$\text{Exposure}_c \times \mathbb{1}_t^{\text{Post 1930}}$	0.0163	0.0391**	0.149**	
	(0.0164)	(0.0165)	(0.0697)	
$\text{Exposure}_c \times \mathbb{1}_t^{\text{Post 1930}} \times \mathbb{1}_k^{S}$				0.292***
				(0.0592)
Crop Fixed Effects	Yes	Yes	Yes	-
Year Fixed Effects	Yes	Yes	Yes	-
Crop x Year Fixed Effects	-	-	-	Yes
Crop x Technology Class Fixed Effects	-	-	-	Yes
Year x Technology Class Fixed Effects	-	-	-	Yes
Observations	356	441	296	330
R-squared	0.643	0.434	0.475	0.863

Notes: The unit of observation is a crop-year (columns 1-3) or crop-year-technology class (column 4). Columns 1-3 include crop and year fixed effects and column 4 includes all possible two-way fixed effects. In column 1, the outcome is log of the number of mechanical and post-harvest technologies (A01D,F,G), in column 2 it is log of the number of soil modification and bio-chemical technologies (A01B,C,H,N) and in column 3, it is log of the number of bio-chemical technologies (A01H,N). In column 4, the outcome is log of the number of articles in the relevant technology class. $\mathbb{1}(k,S)$ is an indicator that equals onw for classes A01B,C,H,N. Standard errors, clustered by crop, are reported in parentheses. *, **, and *** indicate significance at the 10%, 5%, and 1% levels.

4.4.3 联邦实验站

为了验证政府资助的育种项目是否对黑色风暴做出系统性的反应，通过美国联邦实验站进行的试验数据，识别出每个实验重点关注的作物类别。表 A7 因变量捕捉了与每种作物相关的联邦实验站实验数量。A 组是所有联邦实验站，B 组仅包含黑色风暴影响各州的实验站。所有的估计值都很小，且无法在统计上与 0 值区分。一个可能的解释为，研究人员更多被指示于专注基础研究而非应用研究。

Table A7: Dust Bowl Exposure and US Station Experiments

	(1)	(2)	(3)	(4)
	Experiments (asinh)		Any Experiment (0/1)	
	Panel A: All Experiment Stations			
High Exposure$_c$ x $\mathbb{1}_t^{Post\ 1930}$	-0.00775	-0.000547	0.000127	-0.00134
	(0.00869)	(0.00917)	(0.00386)	(0.00787)
R-squared	0.705	0.736	0.533	0.571
	Panel B: Experiment Stations in Dust Bowl States			
High Exposure$_c$ x $\mathbb{1}_t^{Post\ 1930}$	-0.0146	-0.0148*	-0.00422	-0.00928
	(0.0105)	(0.00745)	(0.00534)	(0.00623)
R-squared	0.630	0.714	0.548	0.608
Crop and Year Fixed Effects	Yes	Yes	Yes	Yes
All Additional Controls	No	Yes	No	Yes
Observations	1,548	1,118	1,548	1,118

Notes: The unit of observation is a crop-year. All specifications include crop and year fixed effects, and columns 2 and 4 also include all baseline controls. In columns 1-2, the outcome variable is the inverse hyperbolic sine of the number of experiments and in columns 3-4, it is an indicator that equals one if at least one experiment was conducted. Standard errors, clustered by crop, are reported in parentheses. *, **, and *** indicate significance at the 10%, 5%, and 1% levels.

4.4.4 科学研究

文章先前的研究一直停留在技术发展上，而上游的科学研究重点是否因为黑色风暴而转移是本节所关注的问题。通过 Web of Science 的数据库，将 1925-1960 年所有发表在农业科学研究类别中的文章标题与具体作物做匹配，额外加入提及环境相关关键词的文章。结果如表 A6 所示，黑色风暴增加了科学研究，尤其是对于环境相关的研究。这种情况可能是导致前文提到的黑色风暴对创新长期影响的驱动力之一。

Table A6: Dust Bowl Exposure and Scientific Articles

	(1)	(2)	(3)	(4)
	Total Articles		Any Articles (0/1)	
	PPML	PPML	OLS	OLS
	All Articles	Environment-Related Articles	All Articles	Environment-Related Articles
Exposure$_c$ x $\mathbb{1}_t^{Post\ 1930}$	0.136***	0.457***	0.0145***	0.0186*
	(0.0451)	(0.103)	(0.00432)	(0.00928)
Crop and Year Fixed Effects	Yes	Yes	Yes	Yes
Pre-period articles x Year Fixed Effects	Yes	Yes	Yes	Yes
Observations	1,296	609	1,548	1,548
R-squared			0.494	0.246

Notes: The unit of observation is a crop-year. All specifications include crop and year fixed effects, as well as pre-period article counts interacted with year fixed effects. In columns 1-2, the outcome variable is the total article count and PPML specifications are reported. In columns 3-4, the outcome is an indicator that equals one if at least one article was published and OLS specifications are reported. In columns 2 and 4, the outcome consists only of environment-related articles, as determined by a keyword search using all article titles for the following words or word segments: drought, erosion, climate, temperature, rain, dust, wind. Standard errors, clustered by crop, are reported in parentheses. *, **, and *** indicate significance at the 10%, 5%, and 1% levels.

5、结果（适应）

此节研究因黑色风暴导致的新技术发展转向是否影响了黑风暴带来的经济后果。

5.1 衡量

此节的两个关键要素是地方对黑色风暴的暴露以及地方对黑色风暴所致创新的暴露。其中，地方对黑色风暴的暴露采用的是县级层面暴露于高水平表土侵蚀的土地比例。地方对黑色风暴所致创新的暴露为每个县所种植的作物，在所有县中平均暴露于黑色风暴的程度。由于在第 4 节已经证明了创新方向会转向更容易受到黑色风暴影响的作物，即种植了更易受黑色风暴影响作物的县，是更多引致创新的受益者。遵循这一逻辑，创新暴露定义如下：

$$\text{InnovationExposure}_i = \sum_c \left(\frac{L_{ic}}{L_i} \cdot \frac{\sum_{j \neq i} \text{ErodedLand}_{jc}}{\sum_{j \neq i} \text{Area}_{jc}} \right)$$

其中：L_{ic}是 1929 年县i用于种植作物c的土地面积，L_i是县i在 1929 年的总耕种面积，$ErodedLand_{jc}$是县j中种植作物c且遭受高度侵蚀的土地面积，$Area_{jc}$是县j中种植作物c的总土地面积。与前文的度量相比，$InnovationExposure_i$排除了所关注的县本身，捕捉了县i中所种植的作物在所有其他的平原县中受损的程度，从而反应了该县对于黑色风暴所致创新的暴露程度。

5.2 模型估计

模型如下：

$$\begin{aligned} y_{it} = &\alpha_i + \delta_{st} + \beta \cdot \left(\text{Erosion}_i \cdot \mathbb{I}_t^{\text{Post 1930}} \right) + \gamma \cdot \left(\text{InnovationExposure}_i \cdot \mathbb{I}_t^{\text{Post 1930}} \right) + \\ &\phi \cdot \left(\text{Erosion}_i \cdot \mathbb{I}_t^{\text{Post 1930}} \cdot \text{InnovationExposure}_i \right) + X_{it}'\Gamma + \epsilon_{it} \end{aligned}$$

其中i是县的索引，t是农业普查轮次索引，s代表州。主要的因变量是每英亩农业用地的价格，该价格来源于每年t对县i的农业普查，捕捉了农业生产利润的净现值。控制了县固定效应α_i和州乘普查轮次固定效应δ_{st}。系数β代表黑色风暴侵蚀对县级土地价值及其生产其他特征的直接效应，在假设中$\beta < 0$。系数φ捕捉了黑色风暴侵蚀的经济影响在多大程度上受到对黑色风暴引致创新暴露程度的调节。如果$\varphi > 0$则意味着更多暴露于创新的县受到黑色风暴侵蚀的边际影响会减弱。

5.3 结果

表 2 的 A 组展示了模型

$$y_{it} = \alpha_i + \delta_{st} + \beta \cdot \left(\text{Erosion}_i \cdot \mathbb{I}_t^{\text{Post 1930}}\right) + \gamma \cdot \left(\text{InnovationExposure}_i \cdot \mathbb{I}_t^{\text{Post 1930}}\right) + \phi \cdot \left(\text{Erosion}_i \cdot \mathbb{I}_t^{\text{Post 1930}} \cdot \text{InnovationExposure}_i\right) + X_{it}'\Gamma + \epsilon_{it}$$

的长期差分估计结果，该估计中只包含每个结果变量被记录的首次和最后一次普查轮次的数据。在第一列中，结果变量是经过对数处理的每英亩土地和建筑物价值，尽管β 为负且显著，但 φ>0，这与技术发展减轻了黑色风暴对土地和建筑物价值的负面效应的结论一致。将结果变量改为：对数处理的每英亩土地价值（2），对数处理的样本内农业总收入（3）或对数处理的每英亩农业收入（4），结果相似。

表 2 的 B 组表明在创新暴露与县级层面结果之间的关系中，似乎不存在任何预先存在的趋势。每一列报告了 A 组中感兴趣的自变量〖Erosion〗_i×〖InnovationExposure〗_i 与每个结果变量在 1910 年至 1930 年间变化之间的关系。在所有情况下，系数估计值的幅度与 A 组相比都很小，并且在统计上与零无法区分。

Table 2: Innovation and Adaptation to the Dust Bowl: County-Level Estimates

Dependent Variable:	(1) log Value of Land and Buildings per Acre	(2) log Value of Land per Acre	(3) log Total Revenue	(4) log Total Revenue per Acre
	Panel A: Effects of Dust Bowl and Innovation Exposure			
$\text{Erosion}_i \times \mathbb{1}_t^{\text{Post 1930}}$	-1.416***	-0.964***	-1.660***	-1.265***
	(0.441)	(0.317)	(0.530)	(0.474)
$\text{Erosion}_i \times \mathbb{1}_t^{\text{Post 1930}} \times \text{InnovationExposure}_i$	11.99**	7.931**	15.25**	11.42**
	(5.160)	(3.745)	(6.231)	(5.555)
County Fixed Effects	Yes	Yes	Yes	Yes
Census Round x State Fixed Effects	Yes	Yes	Yes	Yes
Observations	1,592	1,592	1,592	1,592
R-squared	0.949	0.974	0.881	0.922
	Panel B: Pre-trends for Innovation Exposure			
$\text{Erosion}_i \times \text{InnovationExposure}_i$	0.0925	1.035	1.189	2.287
	(3.649)	(3.881)	(6.111)	(4.579)
State Fixed Effects	Yes	Yes	Yes	Yes
Observations	796	796	796	796
R-squared	0.469	0.488	0.269	0.365

Notes: The unit of observation is a county-year in Panel A and a county in Panel B. All estimates are from long differences specifications. In Panel A, the starting year is either 1920 or 1925 and ending year either 1940 or 1959, depending on data availability. In Panel B, the dependent variable is the change in each outcome variable between 1910 and 1930. The sample of counties was selected as in Hornbeck (2012). All specifications include county fixed effects and census round-by-state fixed effects. The dependent variable is listed at the top of each column. Standard errors, clustered by county, are reported in parentheses. *, **, and *** indicate significance at the 10%, 5%, and 1% levels.

图 3 使用表 2A 组的第 1 列设定，说明了创新效应的幅度。纵轴是黑色风暴暴露（即土地侵蚀程度）对农业土地价值的边际影响，横轴是县的“创新暴露”程度的分位数。对于一个处于创新暴露分布中位数的县，其土地侵蚀的边际影响不到处于创新暴露分布底端县的一半。此外，处于创新暴露分布最高部分的县，其土地价值并未因黑色风暴而出现可辨识的长期下降（右上角）。因此，定向技术导致了黑色风暴下游经济影响的显著异质性。

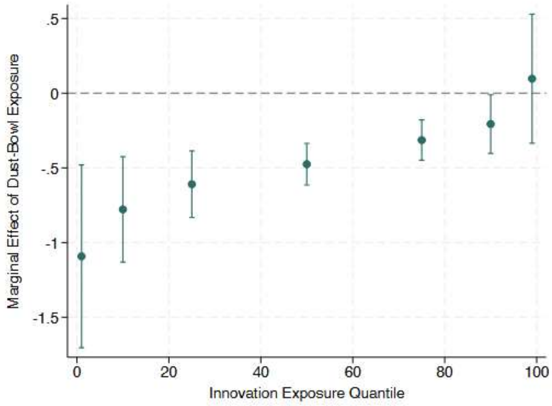


Figure 3: **Quantitative Impact of Innovation Exposure.** The points display the marginal impact of Dust Bowl exposure (y-axis) by innovation exposure quantile (x-axis). Marginal effects are estimated using Equation 5.2, evaluated at various percentiles of the innovation exposure distribution. Innovation exposure is defined in Equation 5.1 and the reported coefficients correspond to the 1st, 10th, 25th, 50th, 75th, 90th and 99th percentile effects. 95% confidence intervals are reported.

作者针对这一估计的敏感性做了多种其他结果：

表 A10 是使用完整的普查轮次面板数据（而非长期差分估计）来复现的研究结果

Table A10: Innovation and Adaptation: Panel Estimates

	(1)	(2)	(3)	(4)
Dependent Variable:	log Value of Land and Buildings per Acre	log Value of Land per Acre	log Total Revenue	log Total Revenue per Acre
$\text{Erosion}_i \times \mathbb{1}_t^{\text{Post 1930}}$	-0.736***	-0.678***	-1.068***	-0.764**
	(0.214)	(0.217)	(0.393)	(0.316)
$\text{Erosion}_i \times \mathbb{1}_t^{\text{Post 1930}} \times \text{InnovationExposure}_i$	5.224**	4.759*	8.663*	5.596
	(2.498)	(2.525)	(4.593)	(3.664)
County Fixed Effects	Yes	Yes	Yes	Yes
Census Round x State Fixed Effects	Yes	Yes	Yes	Yes
Observations	7,959	3,184	7,164	7,164
R-squared	0.960	0.960	0.892	0.923

Notes: The unit of observation is a county-year. All estimates are from panel regressions including all census rounds for which each dependent varaible was recorded. The sample of counties was selected as in Hornbeck (2012). All specifications include county fixed effects and census round-by-state fixed effects. The dependent variable is listed at the top of each column. Standard errors, clustered by county, are reported in parentheses. *, **, and *** indicate significance at the 10%, 5%, and 1% levels.

表 A11 为在不包含州乘以时间固定效应的情况下重新生成所有估计值

Table A11: Innovation and Adaptation: Excluding State × Round Fixed Effects

	(1)	(2)	(3)	(4)
Dependent Variable:	log Value of Land and Buildings per Acre	log Value of Land per Acre	log Total Revenue	log Total Revenue per Acre
$\text{Erosion}_i \times \mathbb{1}_t^{Post1930}$	-2.390***	-1.588***	-2.448***	-1.852***
	(0.531)	(0.451)	(0.568)	(0.527)
$\text{Erosion}_i \times \mathbb{1}_t^{Post1930} \times \text{InnovationExposure}_i$	22.49***	16.05***	21.85***	16.11***
	(6.301)	(5.285)	(6.558)	(5.978)
County Fixed Effects	Yes	Yes	Yes	Yes
Census Round Fixed Effects	Yes	Yes	Yes	Yes
Observations	1,592	1,592	1,592	1,592
R-squared	0.900	0.926	0.865	0.909

Notes: The unit of observation is a county-year. All estimates are from long differences specifications; the starting year is either 1920 or 1925 and ending year either 1940 or 1959, depending on data availability. The sample of counties was selected as in Hornbeck (2012). All specifications include county fixed effects and census round fixed effects. The dependent variable is listed at the top of each column. Standard errors, clustered by county are reported in parentheses. *, **, and *** indicate significance at the 10%, 5%, and 1% levels.

表 A12 是排除了同一州内其他县作物受灾情况的版本，用以剔除本地溢出效应的影响。

Table A12: Innovation and Adaptation: "Leave-State-Out" Estimates

	(1)	(2)	(3)	(4)
Dependent Variable:	log Value of Land and Buildings per Acre	log Value of Land per Acre	log Total Revenue	log Total Revenue per Acre
$\text{Erosion}_i \times \mathbb{1}_t^{Post1930}$	-1.412***	-0.956***	-1.694***	-1.286***
	(0.450)	(0.324)	(0.536)	(0.480)
$\text{Erosion}_i \times \mathbb{1}_t^{Post1930} \times \text{InnovationExposure}_i$	12.21**	8.011**	15.97**	11.97**
	(5.321)	(3.864)	(6.361)	(5.672)
County Fixed Effects	Yes	Yes	Yes	Yes
Census Round x State Fixed Effects	Yes	Yes	Yes	Yes
Observations	1,592	1,592	1,592	1,592
R-squared	0.953	0.975	0.885	0.924

Notes: The unit of observation is a county-year. All estimates are from long differences specifications; the starting year is either 1920 or 1925 and ending year either 1940 or 1959, depending on data availability. The sample of counties was selected as in Hornbeck (2012). All specifications include county fixed effects and census round-by-state fixed effects. Innovation exposure is estimated excluding crop-level damage in the county's state. The dependent variable is listed at the top of each column. Standard errors, clustered by county, are reported in parentheses. *, **, and *** indicate significance at the 10%, 5%, and 1% levels.

表 A13 比较了暴露于中等水平侵蚀与高水平侵蚀的边际效应，以及相应的创新暴露度量。

Table A13: Innovation and Adaptation: High vs. Medium Levels of Local and Aggregate Exposure

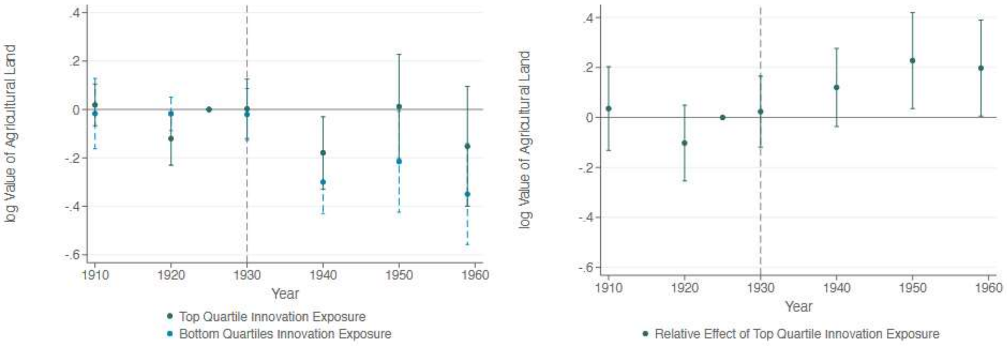
	(1)	(2)	(3)	(4)
Dependent Variable (Long Difference Estimates):	log Value of Land and Buildings per Acre	log Value of Land per Acre	log Total Revenue	log Total Revenue per Acre
High Erosion$_i$ x $\mathbb{1}_t^{Post\,1930}$	-1.344***	-0.909***	-1.590***	-1.163**
	(0.427)	(0.308)	(0.538)	(0.472)
High Erosion$_i$ x $\mathbb{1}_t^{Post\,1930}$ x High CropMixDamage$_i$	9.743**	6.470*	12.69**	9.257*
	(4.961)	(3.644)	(6.232)	(5.464)
Medium Erosion$_i$ x $\mathbb{1}_t^{Post\,1930}$	0.140	0.104	0.357	0.446
	(0.288)	(0.219)	(0.353)	(0.333)
Medium Erosion$_i$ x $\mathbb{1}_t^{Post\,1930}$ x Medium CropMixDamage$_i$	-1.760	-1.133	-2.778**	-2.619*
	(1.125)	(0.851)	(1.398)	(1.346)
t-statistic of difference between φ and φ^{med}	*2.261*	*2.032*	*2.422*	*2.110*
County Fixed Effects	Yes	Yes	Yes	Yes
Census Round x State Fixed Effects	Yes	Yes	Yes	Yes
Observations	1,592	1,592	1,592	1,592
R-squared	0.953	0.975	0.888	0.925

Notes: The unit of observation is a county-year. All specifications are long differences estimates between 1920 or 1925 and 1940 or 1959 depending on data availability. The sample of counties was selected as in Hornbeck (2012). All specifications include county fixed effects and census round-by-state fixed effects. The dependent variable is listed at the top of each column. Standard errors, clustered by county are reported in parentheses. *, **, and *** indicate significance at the 10%, 5%, and 1% levels.

5.4 动态估计

图 4a 展示了黑色风暴暴露随时间变化的影响，并分别展示了处于创新暴露前四分之一的县（高创新暴露组）和四分之三后的县（低创新暴露组）在 1930 年前两组有相似的趋势，在 1940 年，即黑色风暴开始 10 年后出现分化，在 1950 和 1960 年进一步的扩大。黑色风暴在高创新暴露组的县的影响程度随时间推移而减弱，并在 1950 年代影响与 0 已经没有统计学上的显著差别。而黑色风暴对低创新暴露的县的影响在样本期内持续存在。

图 4b 可以看出差异系数于 1930 年在 0 附近且不显著，在 1940 年后变成了显著的正值并不断扩大。同样说明与低创新暴露县相比，高创新暴露县受沙尘暴的负面影响显著更小。



(a) Top and Bottom Quartiles Innovation Exposure　　(b) Relative Effect of Top Quartile Innovation Exposure

Figure 4: **Innovation Exposure and Land Values: Dynamic Effects.** Figure 4a reports the effects of Dust Bowl exposure in each decade separately for counties in the top quartile and bottom three quartiles of innovation exposure. Figure 4b reports the differential effect of Dust Bowl exposure between these two sets of counties. That is, it reports coefficient estimates on the interaction between Dust Bowl exposure, an indicator for being in the top quartile of the innovation exposure distribution, and decade indicators. 95% confidence intervals are reported for all coefficients.

5.5 潜在威胁

对创新暴露的估计来说，一个潜在的混淆因子是农业生产者价格的变化（即与创新暴露相关，又与土地价值相关），为了解决这一威胁，作者使用美国农业部的作物特定生产者价格数据，估算县i在年份t的产出价格组合：

$$\text{Output Price}_{it} = \sum_{c} \frac{L_{ic}}{L_i} \cdot \log(\text{Producer Price}_{ct})$$

其中，$Produce\ Price_{ct}$是作物c在年份t的全国生产者价格。控制了县级层面产出价格变化，以及产出价格变化与黑色风暴暴露的交互项后，结果如表 A15。

Table A15: Innovation and Adaptation: Flexible Output Price Controls

Dependent Variable:	(1) log Value of Land and Buildings per Acre	(2) log Value of Land per Acre	(3) log Total Revenue	(4) log Total Revenue per Acre
$Erosion_i \times \mathbb{1}_t^{Post 1930}$	-1.330***	-1.006***	-1.735***	-1.301***
	(0.415)	(0.328)	(0.521)	(0.466)
$Erosion_i \times \mathbb{1}_t^{Post 1930} \times InnovationExposure_i$	13.43***	9.058**	16.86***	12.67**
	(5.034)	(3.839)	(6.047)	(5.439)
County Fixed Effects	Yes	Yes	Yes	Yes
Census Round x State Fixed Effects	Yes	Yes	Yes	Yes
Output Price Aggregate	Yes	Yes	Yes	Yes
$Erosion_i \times \mathbb{1}_t^{Post 1930}$ x Output Price Aggregate	Yes	Yes	Yes	Yes
Observations	1,592	1,592	1,592	1,592
R-squared	0.953	0.975	0.885	0.924

Notes: The unit of observation is a county-year. All estimates are from long differences specifications; the starting year is either 1920 or 1925 and ending year either 1940 or 1959, depending on data availability. The sample of counties was selected as in Hornbeck (2012). All specifications include county fixed effects and census round-by-state fixed effects. Each specification also includes the county-by-year level agricultural output price measure and this measure interacted with Dust Bowl exposure. The dependent variable is listed at the top of each column. Standard errors, clustered by county are reported in parentheses. *, **, and *** indicate significance at the 10%, 5%, and 1% levels.

因为只有当价格变化对利润的影响在黑色风暴暴露程度更高的县更大时，它才对解读构成威胁，可能出现这种情况的原因是信贷约束限制了受黑色风暴影响的农场去适应环境损害，而更高的产出价格则缓解了部分约束并促进了生产调整。这种情况下，对于受约束最严重的农场或信贷获取潜力最有限的县，φ的估计值将会最大。为了验证这种可能性，作者使用了两种办法。

首先，作者基于前期平均农场规模研究了异质性效应如表 A14。如果研究结果是由规模较小也就是更可能受信贷约束的农场所在的县所驱动，则可能表明价格效应正在驱动创新暴露与农业结果之间的关系。但是对于表 A14 中的所有结果变量，拥有较大农场的县的估计值更大，并且在一半的列中，这种差异在统计上是显著的。这些结果与价格效应驱动该结果的假设不一致，因为它们表明研究结果是由受约束最小的农场驱动的。此外，它们与引致创新假说一致，因为规模较大的农场通常更能获得改良技术。

Table A14: Innovation and Adaptation to the Dust Bowl: Heterogeneity by Farm Size

	(1)	(2)	(3)	(4)
Dependent Variable:	log Value of Land and Buildings per Acre	log Value of Land per Acre	log Total Revenue	log Total Revenue per Acre
$Erosion_i \times \mathbb{1}_t^{Post\,1930} \times InnovationExposure_i \times Above\ Med.\ Size_i$	34.23**	22.38**	10.80	11.19
	(13.41)	(11.11)	(15.84)	(15.14)
County Fixed Effects	Yes	Yes	Yes	Yes
Round x State Fixed Effects	Yes	Yes	Yes	Yes
Relief Controls x Round FE	Yes	Yes	Yes	Yes
Observations	1,584	1,584	1,584	1,584
R-squared	0.952	0.977	0.889	0.927

Notes: The unit of observation is a county-year. All estimates are from long differences specifications; the starting year is either 1920 or 1925 and ending year either 1940 or 1959, depending on data availability. The sample of counties was selected as in Hornbeck (2012). Above Med. Farm is an indicator that equals one if the average farm size in a county in 1930 (measured as total county revenue divided by the number of farms) is above the within-sample median. Standard errors, clustered by county, are reported in parentheses. *, **, and *** indicate significance at the 10%, 5%, and 1% levels.

其次，作者使用联邦存款保险公司（1992）的数据直接测量了当地银行的可及性和银行停业情况，并在将样本限制在银行暴露或银行停业暴露高于或低于中位数的县后，重复估计。如图 A7，结果并没有显示出任何证据表明该效应是由银行可及性更有限的县所驱动，在所有信贷可及性代理指标上，两组县的效应大小几乎相同。因此，价格效应及其与异质性信贷约束的潜在相互作用，似乎并非主要发现的基础。

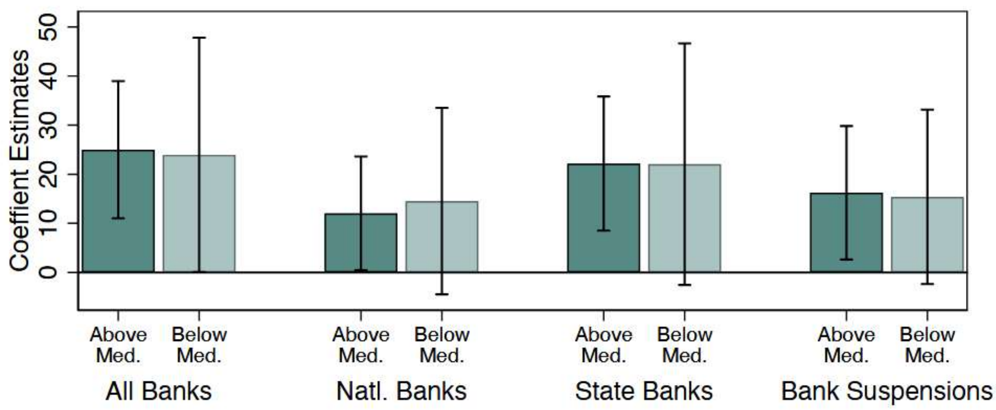


Figure A7: **Bank Access Sample Restrictions.** This figure reports estimates of ϕ from Equation 5.2. Each bar reports estimates from a restricted sample based on local bank access using data from Federal Deposit Insurance Corporation (1992). Bars 1-2 report estimates from specifications for counties with above versus below median total banks per capita; bars 3-4 report estimates from specifications for counties with above versus below median active national banks per capita; bars 5-6 report estimates from specifications for counties with above versus below median active state banks per capita; and bars 7-8 report estimates from specifications for counties with above versus below median bank suspensions per capita. Each measure is computed as the average over the decade prior to the Dust Bowl. Standard errors are clustered by county and 95% confidence intervals are reported.

还有一个可能存在的威胁是创新暴露度量与应对黑色风暴所制定的政策存在虚假相关。在控制了地方政府支出以及 Fishback 等人 2005 年研究中的一系列“新政”项目后结果如表 A16，与基准结果相似。即新政并不是基准结果的中介机制。

Table A16: Innovation and Adaptation: Controlling for Policy

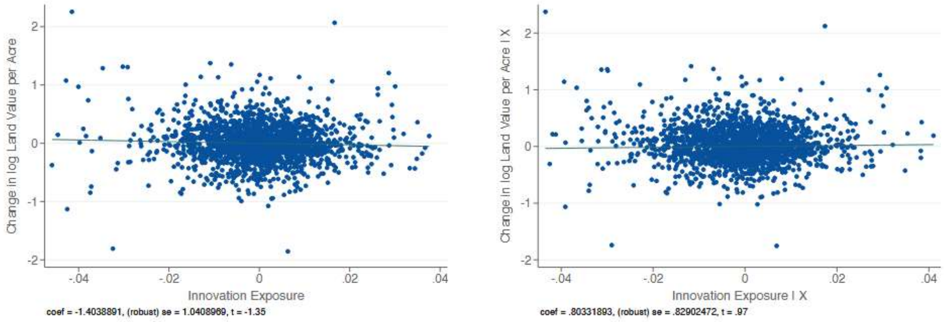
Dependent Variable:	(1) log Value of Land and Buildings per Acre	(2) log Value of Land per Acre	(3) log Total Revenue	(4) log Total Revenue per Acre
$\text{Erosion}_i \times 1_t^{\text{Post 1930}}$	-1.398***	-0.947***	-1.505***	-1.159**
	(0.450)	(0.322)	(0.529)	(0.479)
$\text{Erosion}_i \times 1_t^{\text{Post 1930}} \times \text{InnovationExposure}_i$	11.70**	7.740**	13.51**	10.25*
	(5.235)	(3.787)	(6.211)	(5.592)
County Fixed Effects	Yes	Yes	Yes	Yes
Census Round Fixed Effects	Yes	Yes	Yes	Yes
AAA Payments x Round Fixed Effects	Yes	Yes	Yes	Yes
Relief Spending x Round Fixed Effects	Yes	Yes	Yes	Yes
New Deal Loans x Round Fixed Effects	Yes	Yes	Yes	Yes
Observations	1,584	1,584	1,584	1,584
R-squared	0.950	0.975	0.885	0.924

Notes: The unit of observation is a county-year. All estimates are from long differences specifications; the starting year is either 1920 or 1925 and ending year either 1940 or 1959, depending on data availability. The sample of counties was selected as in Hornbeck (2012). All specifications include county fixed effects and census round fixed effects. All specifications also include AAA payments, relief spending, and new deal loans, interacted with a full set of census round fixed effects. The dependent variable is listed at the top of each column. Standard errors, clustered by county are reported in parentheses. *, **, and *** indicate significance at the 10%, 5%, and 1% levels.

5.6 机制：受损土地的恢复力与特定情境技术

这些由于黑色风暴所致的新技术可能对国家其他地方的农民有益（技术可能有普适性），也可能只会集中在受到黑色风暴影响的县。如果黑色风暴所致的新技术只是提升了对受侵蚀平原县土地的适应，那么上文衡量的创新暴露与国家其他地区的生产率提升的关系要弱得多。

图 5 是非平原县的县级创新暴露与县级土地价值变化之间的偏相关图。在图 5a 中估计未加权，图 5b 中按初始农场面积加权以避免结果由非农业县驱动。在两种情况下系数估计值小且不显著。即在非平原县中并没有产生足够的影响。此外，对于平原县内部，创新的效应也主要集中于高侵蚀水平的县。



(a) Unweighted

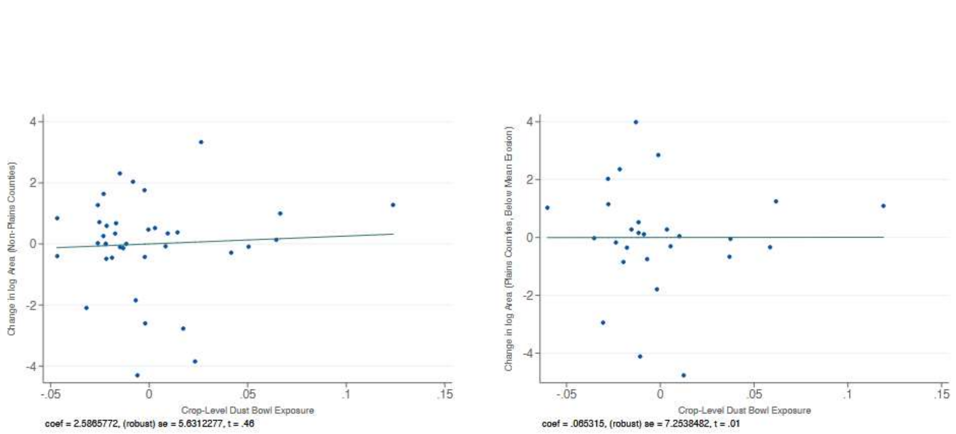
(b) Weighted by Initial Farm Area

Figure 5: **InnovationExposure$_i$ vs. Δ log Land Value per Acre: Non-Plains Counties.** The unit of observation is the county and each graph reports a partial correlation plot with state fixed effects. The sample includes all non-Plains counties. Coefficient estimates, standard errors, and t-statistics are reported at the bottom of each graph.

另一种可能是新技术扩大受损作物可种植的土地面积，而且即使没有创新，对黑色风暴的一种适应性反应也可能是将生产重新分配到更健康的土地上。作者结合 1929 年和 1959 年农业普查中按县、按作物的种植面积数据，估算了黑色风暴暴露与非黑色风暴地区耕种面积之间的关系。

图 A8 显示了作物层面上，受到黑色风暴损害程度与非平原县（图 A8a）以及土地侵蚀低于中位数的平原县（图 A8b）中用于该作物种植的土地面积变化在 1929-1959 年期间的关系。同样的，两种情况下系数估计值幅度都很小且无法与 0 区分，表明作物生产再分配的作用也有限。

基于本节以上内容，这些结果表明技术发展是对于特定技术需求的增长所驱动的，这些技术能提高困境中平原土地的恢复力。但并没有证据表明创新暴露提高了国家其他地区的生产率，或者促进了生产的重新分配。



(a) Δ log Area in Non-Plains Counties

(b) Δ log Area in Low-Exposure Counties

Figure A8: **Crop-Level Damage vs. Δ Area Planted Outside Dust Bowl.** This figure displays partial correlation plots at the crop-level. The dependent variable is the change in log total area harvested (1929-1959) in (a) non-Plains counties or (b) Plains counties with below-mean land erosion. Coefficient estimates, standard errors, and t-statistics are reported at the bottom of each graph.

6 结论

本文通过对黑色风暴时期及之后，美国农业创新发展重定向的研究，提供证据证明了在此情形下，技术发展转向了更容易受环境困境影响的作物，以及对环境适应最有用的技术。而这些创新使本因其作物构成最会被黑色风暴影响的县的土地价值和农业收入下降幅度更为缓和，即创新显著减轻了环境困境的经济影响。