U.S. Agricultural Exports and the 2022 Mississippi River Drought

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Abstract

This paper investigates the impact of the 2022 Mississippi River drought on agricultural trade using counterfactual evaluation methods and detailed trade data at the U.S. port level. The study examines how the drought disrupted agricultural shipments out of Louisiana ports and whether the disruption led to trade diversion to other ports. Our findings reveal that shipments out of Louisiana ports were 3.9 percent or $560 million below the counterfactual between July 2022 and January 2023. In addition, the dynamic treatment estimates provide evidence of immediate trade recovery after the drought receded in October 2022, indicating that the impact of the drought was short-lasting. Wheat exports were the most affected, experiencing a reduction in shipments from Louisiana ports of $150 million and being diverted to U.S. ports on the West coast. In contrast, corn and soybeans did not experience lasting trade destruction or diversion to other ports. Our analysis also reveals that export prices increased significantly above the counterfactual level at Louisiana ports, suggesting that the drought impacted the supply and export dynamics of agricultural commodities. In conclusion, this paper provides valuable insights into the short-run implications of natural disasters on agricultural trade.

JEL: F14, Q17

Keywords: 2022 Mississippi River drought, agricultural exports, dynamic trade effects, event studies, treatment heterogeneity

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1. Introduction

The Mississippi River system is the most critical waterborne transportation highway for U.S. agriculture. The river allows states on the Upper Mississippi to ship agricultural commodities southbound to the Gulf of Mexico ports for further exporting to foreign markets. In 2020, more than 56 percent of agricultural commodities traveled from the Midwest down the Mississippi river, accounting for 165.5 million tons of freight (Bureau of Transportation Statistics, 2022). In the Fall of 2022, scant rainfalls in the Midwest led to the drying up of the Mississippi River system, which constrained upbound and downbound barge shipments. Transportation via barges relies heavily on the water level. With lower water levels, barge operators must reduce the draft by restricting the load (Arita et al., 2022). In addition, a narrower river channel limits the number of barges operating simultaneously. In some cases, barges were grounded for weeks in the mud and sand, further disrupting barge traffic on the Mississippi River. As a result, U.S. agricultural suppliers faced long barge waiting times, forcing them to find alternative transportation means, such as rail and trucks, to ship agricultural commodities from the Midwest to foreign markets.

A growing empirical literature investigates the consequences of waterborne shipping disruptions for U.S. agriculture. For example, Carter et al. (2022) examined the trade implications of the 2021 supply chain bottlenecks on containerized agricultural exports from California ports. They found that port congestion and container shortages reduced agricultural exports by 22 percent. In line with that work, Ahn et al. (2023) assessed the maritime transportation disruptions caused by the Russia-Ukraine war. Their counterfactual findings indicate a 78.2 percent reduction in grain and oilseed exports from Ukraine in the early month after the Russian invasion of Ukraine. In contrast, research on the implications of climate change for the waterborne transportation of agricultural commodities is limited. The National Integrated Drought Information System (2019) assessed the economic implications of the 2012 Great Plains drought for agricultural production and trade in the Midwest states. More recently, Arita et al. (2022) conducted a descriptive assessment of the economic implications caused by the 2022 Mississippi River drought, focusing on how the low water levels affected agricultural output and input prices. Their study analyzed price differences between Gulf and inland counties. Notably, shipping disruptions caused by climate change can result in higher trade costs, which harm exporters and can cause food security issues in net-food-importing countries (Vermeulen et al., 2012; Janssens et al., 2020).

This paper assesses the trade implications of the 2022 Mississippi River drought for agricultural shipments from Louisiana ports. It also investigates whether the shipping disruption diverted trade to other U.S. ports. We utilize monthly export data at the port-destination-good level from the U.S. Census Bureau (2023). Our dataset contains trade data at the Harmonized System (HS) code heading (4-digit) level for all agricultural goods (HS chapters 0 to 24) and export destinations from January 2012 to January 2023. We rely on a counterfactual research design and use a non-linear panel event study centered around July 2022 to assess the treatment effects of the 2022 Mississippi River drought. Our empirical strategy identifies the treatment dynamics by comparing trade volumes from 2022 with those from earlier years (Freyaldenhoven et al., 2021; Roth & Sant'Anna, 2021; Schmidheiny & Siegloch, 2020). In combination with high-dimensional fixed effects at the port-destination-good-event-month and port-destination-good-event-year levels, which account for unobserved time-variant differences between ports at the destination-good level, this comparison group enables us to account for seasonality and other arbitrary (and unobserved) correlations to measure the average treatment effects of the 2022 Mississippi River drought (Carter et al., 2022a, 2022b). This empirical approach has been widely used to assess the trade implications of exogenous shocks, such as the Covid-19 pandemic, the 2021/22 maritime shipping disruptions, and the Russia-Ukraine war (Ahn et al., 2023; Carter et al., 2022a, 2022b, Steinbach, 2023). The baseline regression model is flexible, allowing the treatment effect to be dynamic before and after the 2022 Mississippi River shipping disruption amplified. The empirical framework allows us to assess the direct impact on Louisiana ports and quantify the trade diversion to other U.S. ports.

Our baseline findings provide evidence of considerable trade destruction for Louisiana ports due to the 2022 Mississippi River drought. On average, agricultural exports from those ports were 3.9 percent below the counterfactual level between July 2022 and January 2023. The trade disruptions were most pronounced in September when Louisiana ports shipped about 20.7 percent fewer agricultural goods to foreign markets. Starting in late October 2022, agricultural exports from those ports started to pick up again, returning to levels before the 2022 Mississippi River drought. At the same time, U.S. agricultural exports from East and West coast ports were 5.8 percent and 7.1 percent above the counterfactual between July 2022 and January 2023, implying that some agricultural suppliers diverted shipments to alternative U.S. ports. Among the top diverted agricultural goods were wheat and rice, which were mainly rerouted to U.S. ports on the West coast. We also observe lasting positive export price effects driven by rising truck, rail, and barge transportation costs. Our baseline results hold up to several robustness checks, including linear pre-trends, different control groups, and fixed effects. These findings shed light on the significant implications of climate-induced trade disruptions for U.S. agriculture.

Our paper provides three distinct contributions to the growing literature on the trade effects of climate-induced shipping disruptions. First, we show that the 2022 Mississippi River drought had considerable implications for agricultural shipments through Louisiana ports. In addition to disrupting trade at Louisiana ports, we find evidence for trade diversion to U.S. ports on the West coast. This research expands on earlier work concerned with the adverse trade effects of shipping disruptions for agricultural commodities and the implications of increased transportation costs (Ahn et al., 2023; Arita et al., 2022; Carter et al., 2022a, 2022b, Steinbach, 2023). Second, our paper speaks to the growing literature on how climate-induced trade disruptions impact U.S. agriculture. We show that the trade effects of the 2022 Mississippi River drought are heterogeneously distributed across commodity groups. These insights are essential considering the growing competition for market share in key export markets (Erenstein et al., 2022; Gale et al., 2019; Ridley & Devadoss, 2022). The trade uncertainty caused by climate-induced shipping disruptions could induce major trading partners to diversify their supply chains further and move away from the United States as their leading supplier of agricultural commodities. An example is the growing market share of Brazil in the Chinese corn market. Third, the paper speaks to the increasingly adverse role climate change plays in the international competitiveness of U.S. agriculture (Anderson, 2022; Dall'Erba et al., 2021; Nava et al., 2023). Under the new "normal of global warming," it is likely that such drought events are more frequently occurring, having considerable and lasting impacts on U.S. agriculture. Our research provides essential insights for policymakers regarding the resilience of agricultural trade to climate-induced disruptions at the key U.S. waterborne transportation highway, vital to the prosperity of the American farming economy.

2. Mississippi River Drought and Agricultural Exports

The Mississippi River basin is predominantly used to produce agricultural commodities. The resulting agribusiness industry has contributed significantly to agricultural exports in the United States, accounting for 92 percent of such shipments out of the United States and 78 percent of global exports in feed grains and soybeans (National Park Service, 2023). The Mississippi River is the largest drainage basin in the United States and the second-longest river in North America, providing a significant advantage for shipping agricultural goods to foreign markets due to the lower costs of river transportation as compared to planes, trains, and trucks. More than 60 percent of all grain exported from the US is transported via the Mississippi River and shipped through the Ports of New Orleans and South Louisiana. In 2022, the Mississippi River region experienced a historic drought resulting from a lack of rain and reduced water inflow from its tributaries. According to the Earth Observatory (2022), certain parts of the Mississippi River have not experienced such low water levels in over a decade.

Figure 1 illustrates the implications of the 2022 Mississippi River for water stages, barge transportation costs and shipments, and agricultural exports from Louisiana ports. Panel (a) shows the water stage above Tiptonville, Tennessee, typically highest in Spring and lowest in Winter due to precipitation, snowmelt, and evapotranspiration. In 2022, the river recorded considerably lower water stages between September and December. Water stages reached their lowest point in early October, recording below the minimum water stage on some days. The low water stages had major implications for the Mississippi River shipping industry. Barges were stuck on sandbars and forced to reduce their cargo, disrupting a critical shipping route for agricultural producers in the Midwest. Furthermore, barge rates for grain skyrocketed, as shown in panel (b), reaching as high as about $2.20 per metric ton, almost four times the rate in the same month in 2021. This increase in barge rates directly results from the challenges barge operators face due to lower water levels, resulting in reduced load capacities and limited barge operations. Panels (c) and (d) show barge grain movement by lock and commodity at the Mississippi River and its tributaries. Agricultural shipments through the Mississippi River lock are higher than for the locks on its tributaries, indicating the importance of the Mississippi River for agricultural shipments, which are predominately in corn, soybeans, and wheat. These insights underscore the vital link between the Mississippi River water and agricultural exports from Louisiana ports. The low water level has forced exporters to seek alternative means of transportation, driving up costs and affecting overall trade dynamics. Moreover, the declining barge grain movement reveals the vulnerability of the U.S. agricultural export sector to climate-related disruptions.

3. Empirical Strategy

Our empirical strategy relies on a non-linear panel regression model that assesses the impact of the Mississippi River drought on agricultural exports from Louisiana ports and evaluates the trade diversion to other U.S. ports. The regression specification includes dynamic lags and leads relative to the event of interest to account for treatment dynamics, which enables us to test for pre-trends and assess treatment dynamics in the post-event period in the following baseline regression specification (Freyaldenhoven et al., 2021):

$$X_{ijgt} = \exp\left(\alpha_{ijg,mo} + \alpha_{ijg,yr} + \sum\nolimits_{k=-6}^{k=6} \beta_k \, r_{ijg,t-k} \times LA_{it}\right) \eta_{ijgt} \, , \qquad (1)$$

where we use the subscript i for the U.S. port, j for the export destination, g for the good (commodity or product), and t for the month. The outcome of interest is defined by y_{ijgt}, and we study two outcomes: the export quantity (measured in kilograms) and the export price (defined as the value divided by the quantity). To account for unobserved factors, we include fixed effects at the port-destination-good-event-month $\alpha_{ijg,mo}$ and port-destination-goof-event-year $\alpha_{ijg,yr}$ levels. These fixed effects account for factors that likely vary over time and determine (unobserved) foreign demand, domestic supply, and trade costs. The term $\sum_{k=-6}^{k=6} \beta_k \, r_{ijg,t-k} \times LA_{it}$ measures the dynamic treatment effects of the Mississippi River drought on agricultural exports from Louisiana ports. The treatment effects are identified through the interaction terms. The baseline regression model is flexible and allows the treatment effect to be dynamic before and after the barge shipping disruptions intensified at the Louisiana ports due to the 2022 Mississippi River drought. Our baseline comparison group is agricultural exports from all U.S. ports. We center the event study around July 2022, when the barge transportation issues on the Mississippi River amplified. We use a symmetric event window of six lags and leads around the event month to account for pre-trends and test for leveling off treatment effects (Freyaldenhoven et al., 2021). Following earlier work by Carter et al. (2022a, 2022b) and Steinbach (2022), we use trade data from earlier years as the control group. More specifically, we resort to trade data from 2013 to 2020 to construct a control group unaffected by the 2022 Mississippi River drought.

Our estimation strategy relies on the Poisson Pseudo Maximum likelihood estimator to identify the relationship of interest (Silva & Tenreyro, 2006). The estimator is commonly used in the trade literature because it allows researchers to deal consistently with zero trade flows. At the same time, the estimator is superior because the scale of the dependent variable does not affect the parameter estimates. Furthermore, to account for the high-dimensional fixed effects, we use a modified version of the iteratively re-weighted least-squares algorithm (Correia et al., 2020). Lastly, following standard practice in the international trade literature, the standard errors are clustered at the port-destination-good level (Weidner & Zylkin, 2021).

We obtained monthly export data at the U.S. port level from the U.S. Census Bureau (2023), which includes information on transport mode (air, bulk, and containerized), export value, and shipping volume. Our analysis focused on bulk and containerized shipments of agricultural goods under HS chapters 0 to 24, which were further classified based on their relevance to Mississippi barge shipments.[1] To investigate the impact of the 2022 Mississippi River drought on trade response across different regions, we grouped the U.S. maritime ports into Louisiana, Gulf, Western, and Eastern categories according to the U.S. Census Bureau (2022) port division classification.[2] We constructed the event study panel dataset using this information, controlling for singleton observations following Correia et al. (2020). The final dataset covers the monthly export quantity and unit value of agricultural shipments from 122 U.S. ports to 222 export destinations. **Appendix Table A1** provides descriptive statistics for the four regions before and after the first event month in July 2022. The descriptive comparison reveals a 10.8 percent reduction in agricultural exports from Louisiana ports and a 24.1 percent reduction for other Gulf coast ports. However, there was also a 4.9 percent increase in agricultural exports from U.S. ports on the East Coast and a 0.5 percent increase for ports on the West Coast, indicating potential trade diversion to those regions.

4. Results and Discussion

4.1 Baseline Results

We present the baseline event study estimates for the impact of the 2022 Mississippi River drought on agricultural exports from Louisiana ports in **Figure 2**. Each subfigure shows the parameter estimates and 95 percent confidence intervals for the event-time of the outcome (Freyaldenhoven et al., 2021). Panels (a) and (b) reveal the treatment dynamics for Louisiana ports and compare

[1] We identified the four primary exported agricultural commodities at the HS-4 level based on their export value in the past three years. The primary agricultural commodities are soybeans (HS 1507), corn (HS 1005), wheat (HS 1001), and rice (HS 1006). They account for 85 percent of total agricultural exports from Louisiana ports.

[2] Louisiana ports include ports in the state of Louisiana, while Gulf port encompasses all other ports on the Gulf coast. East coast ports are defined as those in the South Atlantic and New England customs divisions, while the West coast ports are those in the Pacific customs divisions (U.S. Census Bureau, 2022).

them to the national average for the export quantity and unit value. We show the net treatment effects for Louisiana ports in panels (c) and (d). The sub-figure notes report Wald tests for pre-trends, average post-event treatment effects, and regression statistics. Apart from the unit value specification, there is no evidence for statistically significant pre-trends, indicating that the 2022 Mississippi River drought is exogenous to the outcomes of interest, which validates the research design (Freyaldenhoven et al., 2021; Roth, 2022; Sun & Abraham, 2021). Conditional on the port-destination-good-event-year and port-destination-good-event-month fixed effects, the treatment group exhibits similar trends in the pre-treatment period as the control groups.

The dynamic treatment estimates in panel (c) indicate that agricultural exports through Louisiana ports were 3.9 percent below the counterfactual level between July 2022 and January 2023. The adverse trade effects translate into reduced agricultural exports of 1.2 million tons or $560 million during the study period.[3] Notably, the adverse trade effects caused by the 2022 Mississippi River drought vary over time. Louisiana ports began experiencing trade losses in August 2022, with the most pronounced negative trade effects materializing in September 2022 (-20.7 percent). The recovery started in late October 2022, as the adverse trade effects decreased to -16.5 percent in that month. This trend persisted until January, when the observed trade changes exceeded the counterfactual level, indicating a strong recovery after the initial shipping disruptions caused by the 2022 Mississippi River drought. Notably, panel (d) provides evidence of positive unit value effects, indicating higher export prices for agricultural commodities shipped through Louisiana ports between July 2022 and January 2023.

4.2 Robustness Checks

Extrapolated Linear Pre-Trends — A potential concern regarding our identification strategy relates to pre-trends that could bias the parameter estimates (Freyaldenhoven et al., 2021). Following the approach developed by Dobkin et al. (2018), we estimate Equation (1) under the alternative assumption that the linear pre-trends of the treated units would have continued linearly along their pre-event paths. The results of this exercise are presented in **Appendix Figure A1.** We find an insignificant linear trend coefficient for the quantity specification, which allows us to reject the null hypothesis that pre-trends drive the observed trade effects. However, we find evidence for a

[3] We transformed the parameter estimates to trade effects using the formula $(\exp(\beta_k) - 1) * 100$. The aggregated the trade effects were calculated based on corresponding agricultural value and quantity for June 2022.

significant linear pre-trend for the unit value specification. Therefore, we focus on the export quantity as the main outcome of interest for further analysis.

Different Control Groups — An additional concern regarding our identification strategy relates to the choice of the control group. To better understand how robust the baseline results are to this choice, we use a set of alternative control groups in **Appendix Table A2**. The average post-event treatment effects are like those for our baseline regression in terms of magnitude using the alternative control groups. However, the statistical power decreases when limiting the control groups to different windows between 2012 and 2020. As for the unit value specification, we find that the average post-event treatment effects are all statistically significant. At the same time, the coefficients are more prominent in terms of magnitude for Louisiana ports than for non-Louisiana ports.

Choice of Fixed Effects — The baseline model in Equation (1) employs port-destination-good-event-month and port-destination-good-event-year fixed effects, which may raise concerns about a lack of flexibility and theoretical foundations compared to more traditional economic models such as the gravity model of trade (Grant et al., 2021). The set of fixed effects used in our baseline analysis is more restrictive than that used in gravity estimations. To see how sensitive our identification strategy is to the choice of those fixed effects, we use alternative combinations of fixed effects in the estimations presented in **Appendix Table A3**. The average post-event treatment effects are consistent in magnitude and statistical significance to those obtained for the baseline model. Accordingly, the estimated trade effects are robust to different fixed effect combinations.

4.3 Heterogeneity Analysis

To better understand how agricultural producers responded to the shipping disruptions at the Louisiana ports caused by the 2022 Mississippi River drought, we conducted two additional analyses, focusing on trade diversion to other U.S. ports and differences in the trade response according to major agricultural commodities. **Figure 3** shows the average post-event treatment effects of the 2022 Mississippi River drought by U.S. port regions. While Louisiana ports account for over 86 percent of agricultural export shipped through Gulf ports, non-Louisiana Gulf ports exhibit more pronounced trade disruptions (-15.1 percent). On average, the adverse trade effects are almost four times larger than those observed for Louisiana ports (-3.9 percent). Furthermore, we find evidence for considerable trade diversion, with positive trade effects for the East coast (5.8 percent) and West coast ports (7.1 percent). These estimates imply that some agricultural suppliers opted for alternative transportation modes to facilitate foreign shipments via U.S. ports on the West and East coasts. Notably, the average unit value effects do not align with the quantity effect across different export regions. The average unit value of agricultural goods exported in Louisiana ports rose 1.4 percent. This export price increase for Louisiana ports is approximately ten times higher than for the other Gulf (0.13 percent) and East coast ports (0.16 percent). At the same time, the average export price for the West coast ports dropped by 0.4 percent. The export price decrease at Western ports is likely due to the relief from supply chain bottlenecks, driven by the sharp decline in shipping freight rates in 2022 and infrastructure programs like the Commodity Container Assistant Program (Steinbach & Zhuang, 2023).

We examine the trade effects of the 2022 Mississippi River drought for top agricultural commodities in **Figure 4**. Rice exports from Louisiana ports fell more between July and October 2022 than between November 2022 and January 2023. We find no statistically significant evidence of trade destruction and diversion for soybeans and corn, while we observe significant trade destruction for wheat shipped through Louisiana ports. Notably, the trade destruction for wheat is more pronounced from November 2022 to January 2023, while overall agricultural exports recovered after October 2022, as shown in **Figure 2**. During the same period, East and West coast ports experienced significant trade diversion for wheat.

We summarize the trade gains and losses by major agricultural commodities in **Table 1**. The results indicate wheat exports through Louisiana and other Gulf coast ports were about 435 million kilograms below the counterfactual. East and West coast ports experienced trade gains of 2 and 167 million kilograms, respectively. Even though we do not find statistically significant evidence of trade destructions for soybeans and corn, we observe notable differences in trade effects for these agricultural commodities. Between July and October 2022, we find evidence for trade diversion in soybeans and corn but some evidence for additional rice exports through Western ports. In contrast, we observe a significant trade recovery for soybeans and corn at Louisiana ports between November 2022 and January 2023. We also find evidence for considerable heterogeneity across port regions and commodity groups regarding the export unit value effects. Notably, most agricultural commodities experienced positive price effects at the Louisiana and Gulf coasts ports. In contrast, the export price effects of the 2022 Mississippi River drought for East and West coast ports are mixed.

5. Conclusion

The 2022 Mississippi River drought disrupted barge transportation of agricultural commodities from the Midwest to U.S. ports on the Gulf of Mexico between July and October 2022. This paper assessed the trade destruction effects of these shipping disruptions at the Louisiana ports, measured the trade recovery after the water stage returned to normal, and investigated trade diversion to other U.S. ports using detailed trade data and counterfactual evaluation methods. Our findings indicate that the drought led to a 3.9 percent reduction in agricultural exports from Louisiana ports, resulting in agricultural trade losses of $563.9 million between July 2022 and January 2023. The drought also led to a 1.4 percent increase in agricultural export unit values, while they dropped by 0.1 percent for Gulf and 0.2 percent for East coast ports during the same period. Wheat exports were the most affected, with a considerable decrease in export volume of 350 million kilograms at the Louisiana ports. In contrast, there is limited statistical support for adverse trade effects for soybeans and corn. While we find some evidence for adverse treatment dynamics at the beginning of the 2022 Mississippi River drought, there is also considerable support for strong trade recovery once the barge transportation disruptions at the Mississippi River dissolved. As a result, there was limited trade diversion for those commodities, while the dynamic treatment estimates provide evidence of trade diversion to East and West coast ports for wheat. These findings shed light on the significant implications of climate-induced trade disruptions for U.S. agriculture.

Our paper highlights the urgent need to mitigate the impact of natural disasters and supply chain disruptions on U.S. agricultural exports, especially regarding barge transportation on the Mississippi River. With the ongoing warming of the global climate, chronic and prolonged hydrological droughts are predicted to increase significantly by the end of this century (Wehner et al., 2017). While various federal and state agencies offer direct relief and recovery support for drought impacts, a more comprehensive plan may be necessary to address this potential long-term issue at the Mississippi River (National Integrated Drought Information System, 2019). In a climate and trade environment that is becoming increasingly volatile, it is essential to implement food policies that ensure food security and access to foreign markets (Anderson, 2022). The lack of tools to deal with similar supply chain disruptions can limit the production capacity of agricultural farmers and their access to foreign markets (Deconinck & Toyama, 2022; Nava et al., 2023). While the Bipartisan Infrastructure Law has authorized up to $108 billion to support federal public transportation programs, including barge transportation on the Mississippi River, it may take time for these solutions to take effect, and the federal funding allocation for barge transportation remains unclear (U.S. Department of Transportation, 2022). Moreover, it is crucial to enhance the availability and efficiency of alternative transportation options, such as rail, truck, and intermodal transport solutions, to supplement barge transportation of agricultural commodities from the Midwest to foreign markets, as these additional modes can provide more flexibility and resilience to the U.S. agricultural supply chain.

References

Ahn, S., Kim, D., & Steinbach, S. (2023). The impact of the Russian invasion of Ukraine on grain and oilseed trade. *Agribusiness*, 39(1), 291–299.

Anderson, K. (2022). Trade-related food policies in a more volatile climate and trade environment. *Food Policy*, 109, 102253.

Arita, S., Breneman, V., Meyer, S., & Rippey, B. (2022). Low Mississippi River Barge Disruptions: Effects on Grain Barge Movement, Basis, and Fertilizer Prices. *Farmdoc Daily*, 12(164), Department of Agricultural and Consumer Economics, University of Illinois at Urbana-Champaign.

Bureau of Transportation Statistics. (2022). *Low Water on the Mississippi Slows Critical Freight Flows*. https://www.bts.gov/data-spotlight/low-water-mississippi-slows-critical-freight-flows./

Carter, C. A., & Steinbach, S. (2022). California Almond Industry Harmed by International Trade Issues. *ARE Update*, 26(1), 1–4.

Carter, C. A., Steinbach, S., & Zhuang, X. (2022a). Global Shipping Container Disruptions and US Agricultural Exports. *IATRC Working Paper Series* 22-01.

Carter, C. A., Steinbach, S., & Zhuang, X. (2022b). Supply chain disruptions and containerized agricultural exports from California ports. *Applied Economic Perspectives and Policy.*

Correia, S., Guimarães, P., & Zylkin, T. (2020). Fast Poisson estimation with high-dimensional fixed effects. *The Stata Journal*, 20(1), 95–115.

de Chaisemartin, C., & d'Haultfoeuille, X. (2020). Two-way fixed effects estimators with heterogeneous treatment effects. *American Economic Review*, 110(9), 2964–96.

Deconinck, K., & Toyama, L. (2022). Environmental impacts along food supply chains: Methods, findings, and evidence gaps. *OECD Working Paper*. https://www.oecd-ilibrary.org/agriculture-and-food/environmental-impacts-along-food-supply-chains_48232173-en

Dall'Erba, S., Chen, Z., & Nava, N. J. (2021). US interstate trade will mitigate the negative impact of climate change on crop profit. *American Journal of Agricultural Economics*, 103(5), 1720-1741.

Dobkin, C., Finkelstein, A., Kluender, R., & Notowidigdo, M. J. (2018). The economic consequences of hospital admissions. *American Economic Review*, 108(2), 308–52.

Earth Observatory. (2022). *Drought and Barge Backups on the Mississippi*. https://earthobservatory.nasa.gov/images/150504/drought-and-barge-backups-on-the-mississippi

Erenstein, O., Jaleta, M., Sonder, K., Mottaleb, K., & Prasanna, B. M. (2022). Global maize production, consumption and trade: trends and R&D implications. *Food Security*, 14(5), 1295-1319.

Freyaldenhoven, S., Hansen, C., Pérez, J. P., & Shapiro, J. M. (2021). Visualization, identification, and estimation in the linear panel event-study design. *National Bureau of Economic Research.* https://www.nber.org/system/files/working_papers/w29170/w29170.pdf

Gale, F., Valdes, C., & Ash, M. (2019). Interdependence of China, United States, and Brazil in soybean trade. *USDA ERS*. https://www.ers.usda.gov/webdocs/outlooks/93390/ocs-19f-01.pdf?v=226.2

Grant, J. H., Arita, S., Emlinger, C., Johansson, R., & Xie, C. (2021). Agricultural exports and retaliatory trade actions: An empirical assessment of the 2018/2019 trade conflict. *Applied Economic Perspectives and Policy*, 43(2), 619-640.

Janssens, C., Havlík, P., Krisztin, T., Baker, J., Frank, S., Hasegawa, T., Leclère, D., Ohrel, S., Ragnauth, S., Schmid, E., Valin, H., Lipzig, N. V., & Maertens, M. (2020). Global hunger and climate change adaptation through international trade. *Nature Climate Change*, 10(9), 829-835.

National Integrated Drought Information System. (2019). Drought Trade Footprint Study of the Mississippi River. https://www.drought.gov/documents/drought-trade-footprint-study-mississippi-river.

National Park Service. (2023). River Facts - Mississippi National River and Recreation Area. https://www.nps.gov/miss/riverfacts.htm.

Nava, N. J., Ridley, W., & Dall'erba, S. (2023). A model of the US food system: What are the determinants of the state vulnerabilities to production shocks and supply chain disruptions? *Agricultural Economics,* 54(1), 95-109.

Ridley, W., & Devadoss, S. (2022). Competition and trade policy in the world cotton market: Implications for US cotton exports. *American Journal of Agricultural Economics*.

Rivergates. (2023). *Water Levels of Rivers and Lakers*. https://rivergages.mvr.usace.army.mil/WaterControl/new/layout.cfm/.

Roth, Jonathan, and Sant'Anna, Pedro HC. 2021. Efficient estimation for staggered rollout designs. arXiv preprint arXiv:2102.01291.

Roth, J. (2022). Pretest with Caution: Event-Study Estimates after Testing for Parallel Trends. *American Economic Review: Insights*, 4(3), 305–22.

Schmidheiny, Kurt and Siegloch, Sebastian. 2020. On event studies and distributed-lags in two-way fixed effects models: Identification, equivalence, and generalization. ZEW-Leibniz Centre for European Economic Research. https://ftp.zew.de/pub/zew- docs/dp/dp20017.pdf.

Silva, J. S., & Tenreyro, S. (2006). The log of gravity. *The Review of Economics and Statistics*, 88(4), 641–658.

Steinbach, S., (2022). Port congestion, container shortages, and US foreign trade. *Economics Letters*, 213, 110392.

Steinbach, S. (2023). The Russia–Ukraine war and global trade reallocations. *Economics Letters*, 226, 111075.

Steinbach, S., & Zhuang, X. (2023). Global Container Shipping Disruptions, Pop-Up Ports, and US Agricultural Exports. *AAEA Annual Meeting*, January, Vol. 6.

Sun, L., & Abraham, S. (2021). Estimating dynamic treatment effects in event studies with heterogeneous treatment effects. *Journal of Econometrics*, 225(2), 175-199.

U.S. Census Bureau. (2022). *Geographic Levels*. https://www.census.gov/programs-surveys/economic-census/guidance-geographies/levels.html#par_textimage_34.

U.S. Census Bureau. (2023). *USA Trade Online.* https://www.census.gov/foreign-trade/reference/products/catalog/usatradeonline.html.

USDA Agricultural Marketing Service. (2023). *Grain Transportation Report Datasets*. https://www.ams.usda.gov/services/transportation-analysis/gtr-datasets.

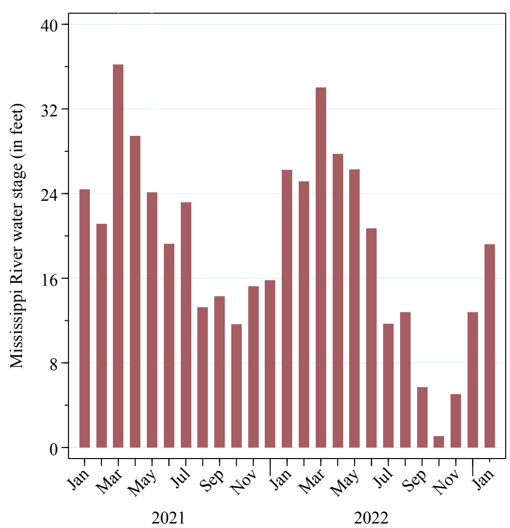
U.S. Department of Transportation. (2022). *Transportation Planning*. https://www.transit.dot.gov/regulations-and-guidance/transportation-planning/transportation-planning

Vermeulen, S. J., Campbell, B. M., & Ingram, J. S. (2012). Climate change and food systems. *Annual Review of Environment and Resources*, 37, 195-222.

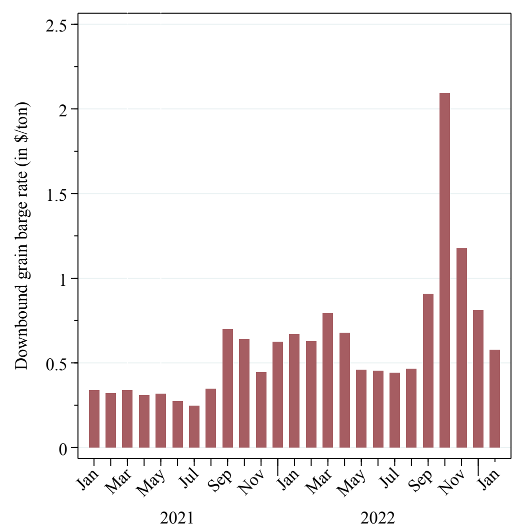
Wehner, M. F., Arnold, J. R., Knutson, T., Kunkel, K. E., & LeGrande, A. N. (2017). Droughts, floods, and wildfires. Climate science special report: fourth national climate assessment, 1(GSFC-E-DAA-TN49033).

Weidner, M. & Zylkin, T., (2021). Bias and consistency in three-way gravity models. *Journal of International Economics,* 132, 103513.

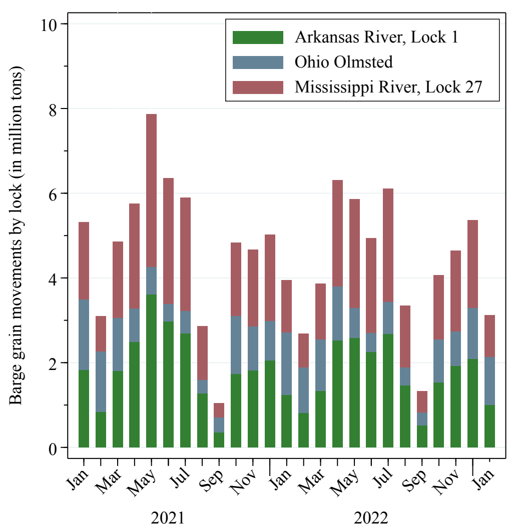
Tables and Figures



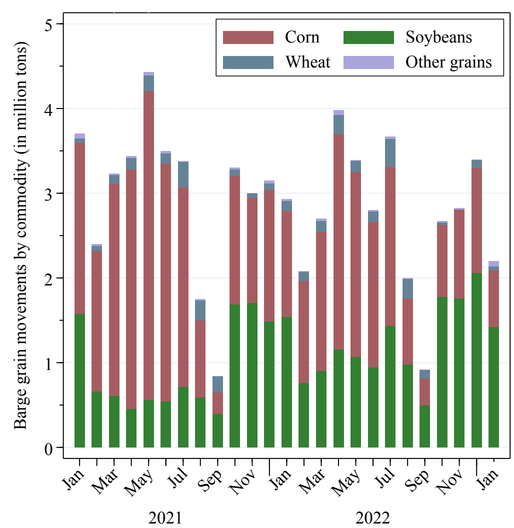
Panel (a): Mississippi River Water Stage.



Panel (b): Grain Barge Rates.



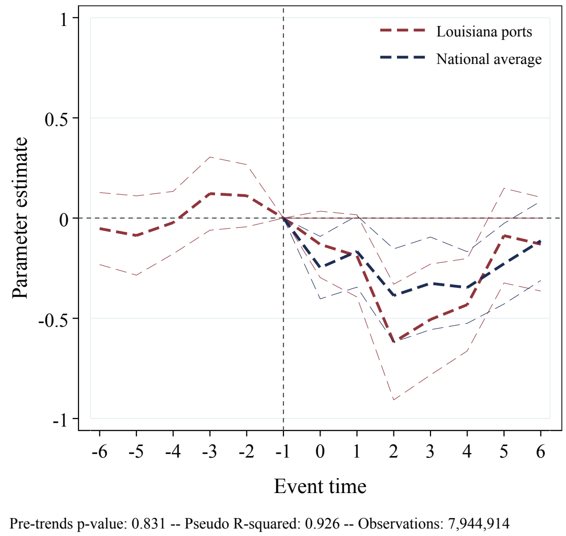
Panel (c): Barge Movement by Lock.



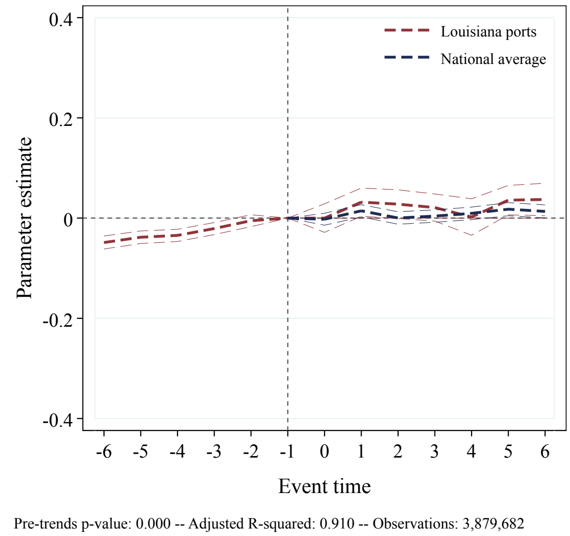
Panel (d): Barge Movement by Commodity.

Figure 1: The 2022 Mississippi River Drought and Barge Shipments.

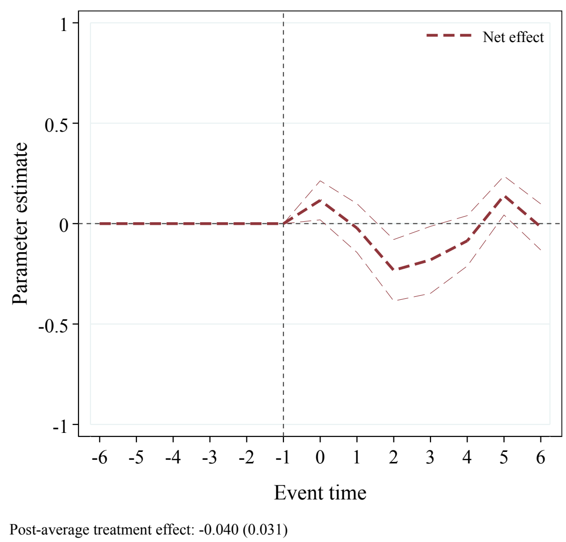
Note. The figure provides stylized facts regarding the 2022 Mississippi River drought and barge shipments. Panel (a) displays the water level of the Mississippi River at Tiptonville, TN. Data for this analysis come from RiverGages (2023). Panel (b) shows the downbound barge rates, panel (c) downbound barge grain movement for selected locks, and panel (d) downbound barge grain movement for major agricultural commodities passing through Mississippi River Lock 27, Arkansas River Lock 1, and Ohio Olmsted. The data for panels (b), (c), and (d) are from the USDA Agricultural Marketing Service (2023).



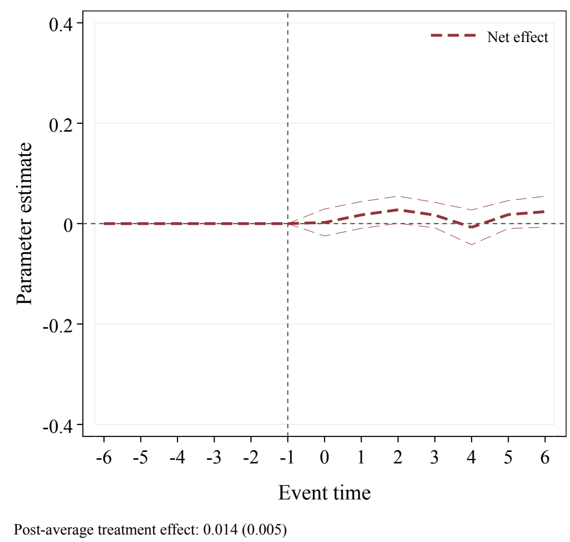
Panel (a): Quantity.



Panel (b): Unit Value.



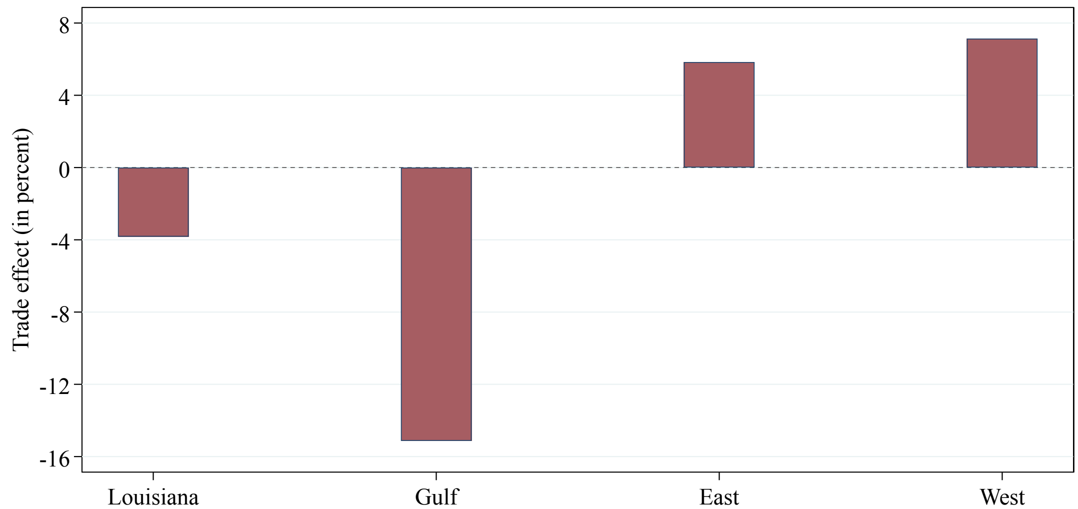
Panel (c): Net Quantity Effect.



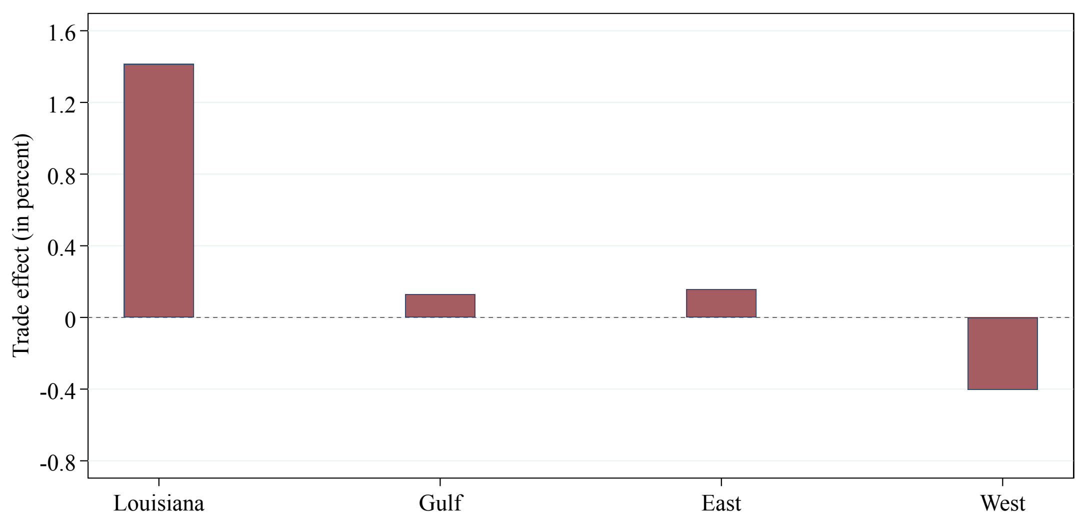
Panel (d): Net Unit Value Effect.

Figure 2: Event Studies for Agricultural Exports from Louisiana Ports.

Note. The figure shows event study estimates for the agricultural quantity and unit value effects of the 2022 Mississippi River drought for Louisiana ports. All regressions include port-destination-good-event-year and port-destination-good-event-month fixed effects. The standard errors are adjusted for within-cluster correlation at the port-destination-good level. We plot the dynamic treatment parameters and 95 percent confidence intervals for the event-time coefficients. We report Wald tests for the linear pre-trends, the average post-event treatment effects, the pseudo/adjusted R-squared, and the panel size in the sub-figure notes. The event time is measured in months relative to June 2022.



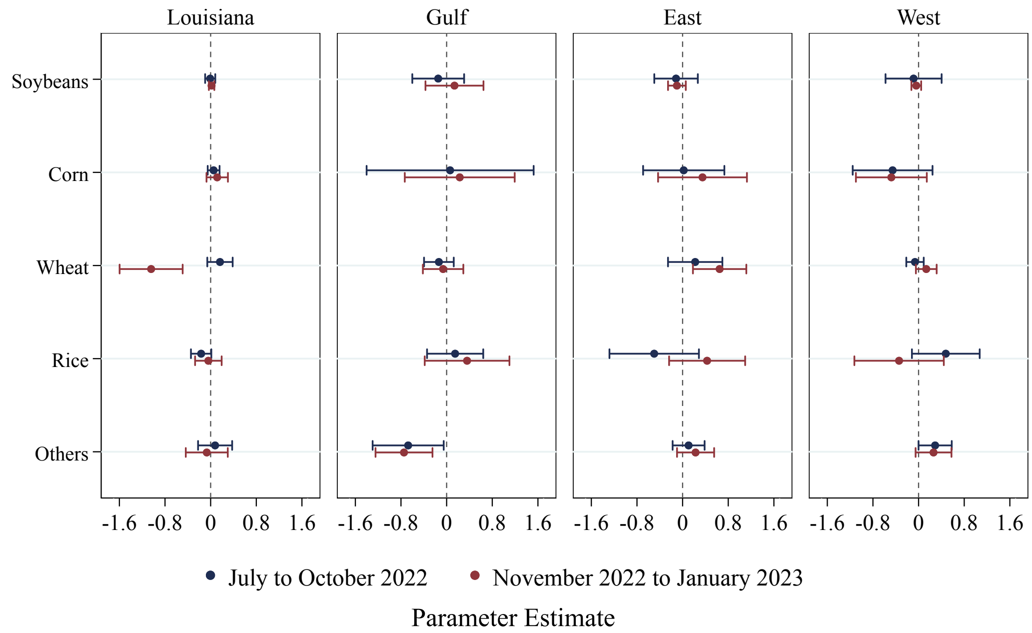
Panel (a): Quantity.



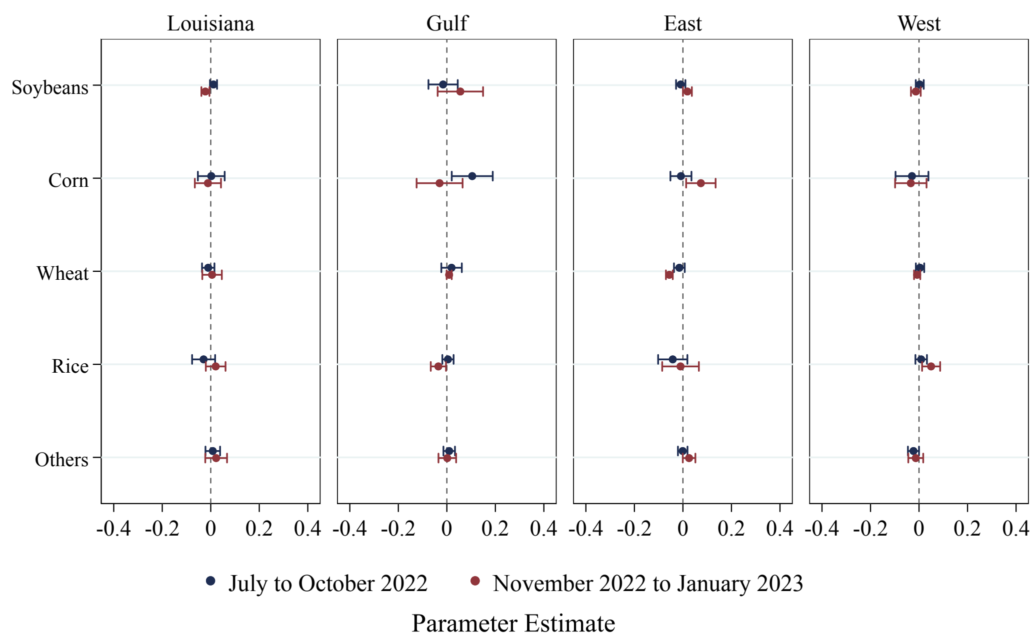
Panel (b): Unit Value.

Figure 3: Average Post-Event Trade Effects by U.S. Port Region.

Note. The figure shows the average post-event trade effects for export volume and unit value by U.S. port region. We followed Chaisemartin and D'Haultfœuille (2020) to calculate the average post-event trade effects. The "Louisiana" label denotes ports within the state of Louisiana, while "Gulf" encompasses Gulf ports, excluding those in Louisiana. The "East" category includes ports in the South Atlantic and New England customs divisions, and the "West" category includes those ports from the Pacific customs divisions (U.S. Census Bureau, 2022).



Panel (a): Quantity.



Panel (b): Unit Value.

Figure 4: Average Post-Event Treatment Effects by Commodity Group and U.S. Port Region.

Note. The figure shows the average post-event treatment effects corresponding confidence intervals of the 2022 Mississippi River drought for the four main commodity groups by the U.S. port region. The commodity sub-group "others" includes all commodities from those listed. The average post-event treatment effects were calculated following Chaisemartin and D'Haultfœuille (2020).

Table 1. Counterfactual Changes in Export Volumes and Unit Values by Commodity Group and U.S. Port Region.

		Louisiana ports		Gulf coast ports		East coast ports		West coast ports	
		Jul-Oct	Nov-Jan	Jul-Oct	Nov-Jan	Jul-Oct	Nov-Jan	Jul-Oct	Nov-Jan
Quantity (in million kg)	Soybeans	-3.30	71.84	-10.26	31.96	-66.63	-75.99	-24.22	-20.06
	Corn	613.64	1,047.47	21.94	25.05	37.39	105.73	-1,532.96	-1,144.44
	Wheat	311.38	-661.54	-91.26	6.06	0.54	1.56	-169.12	336.13
	Rice	-69.54	-12.56	28.15	69.45	-0.71	1.08	179.02	-53.37
	Others	200.47	0.30	-137.01	-109.43	82.98	139.83	1,177.99	822.28
Unit Value (in USD per ton)	Soybeans	7.70	-14.13	-17.05	77.14	-6.29	13.04	2.14	-9.11
	Corn	1.00	-3.73	203.48	-36.48	-10.52	108.15	-21.61	-28.13
	Wheat	-4.34	2.47	7.04	3.43	-5.91	-20.93	1.98	-3.49
	Rice	-24.24	18.61	11.37	-79.70	-64.79	-14.56	12.89	72.75
	Others	5.67	14.58	61.91	13.45	-2.17	94.45	-58.90	-33.17

Note. The table shows the counterfactual trade volume and unit value changes from July 2022 and January 2023 by commodity group and U.S. port region. We calculated the trade effects using the counterfactual dynamic treatment estimates at the port-commodity level.

Supplementary Materials

U.S. Agricultural Exports and the 2022 Mississippi River Drought

Sandro Steinbach and Xiting Zhuang

Table A1: Descriptive Statistics.

	Sum	Mean	SD	Min	Max	Obs.	Sum	Mean	SD	Min	Max	Obs.
	Panel (a): Louisiana ports.						Panel (b): Other Gulf ports.					
Value (Pre)	1,846,402.00	912.70	2,781.11	<1	52,139	2,023	673,567.30	17.1	161.04	<1	9,334	39,382
Value (Post)	1,995,029.00	1,167.37	5,633.01	<1	88,038	1,709	594,667.90	15.14	134.34	<1	9,820	39,269
Quantity (Pre)	4,301,351.00	2,126.22	7,019.96	<1	98,189	2,023	760,227.90	19.3	374.61	<1	28,288	39,382
Quantity (Post)	3,835,359.00	2,244.21	10,077.77	<1	162,511	1,709	577,057.70	14.69	259.39	<1	24,297	39,269
Unit Value (Pre)	15.25	0.01	0.99	-3	5	2,023	51,658.61	1.31	1	-4	8	39,382
Unit Value (Post)	227.69	0.13	1	-2	4	1,709	53,602.17	1.37	0.98	-6	7	39,269
	Panel (c): East coast ports.						Panel (d): West coast ports.					
Value (Pre)	748,765.90	37.63	200.66	<1	12,085	19,896	2,885,349.00	96.43	621.27	<1	53,314	29,922
Value (Post)	805,719.10	42.41	369.24	<1	24,464	18,998	2,959,248.00	103.31	1,042.75	<1	87,831	28,645
Quantity (Pre)	652,304.30	32.79	276.47	<1	18,383	19,896	3,101,797.00	103.66	1,157.77	<1	93,911	29,922
Quantity (Post)	684,304.30	36.02	526.96	<1	37,982	18,998	3,116,846.00	108.81	1,791.74	<1	160,124	28,645
Unit Value (Pre)	19,794.47	0.99	1.03	-6	9	19,896	31,538.69	1.05	1.05	-4	6	29,922
Unit Value (Post)	20,419.32	1.07	1.01	-3	8	18,998	31,419.33	1.1	1.04	-4	8	28,645

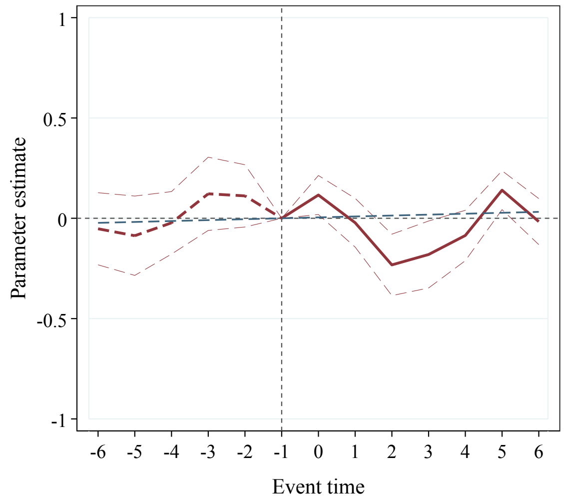
Note. This table shows the descriptive statistics by U.S. port region. We present the sum, mean, standard deviation (SD), minimum (Min), maximum (Max) and observation numbers (Obs.) for six months before and after July 2022.

Table A2. Robustness Checks for Alternative Control Groups.				
	Louisiana ports		Non-Louisiana ports	
	Quantity	Unit value	Quantity	Unit value
Panel (a): 2013 to 2020				
Average post-event	-0.040	0.014***	0.034	0.000***
	(0.031)	(0.005)	(0.025)	(0.000)
Observations	7,944,914	3,879,682	7,944,914	3,879,682
Pseudo/Adjusted R-squared	0.926	0.910	0.926	0.910
Panel (b): 2013 to 2019				
Average post-event	-0.041	0.015***	0.035	0.000***
	(0.032)	(0.005)	(0.026)	(0.000)
Observations	6,720,344	3,381,832	6,720,344	3,381,832
Pseudo/Adjusted R-squared	0.930	0.913	0.930	0.913
Panel (c): 2013 to 2022				
Average post-event	-0.044	0.011*	0.036	0.000**
	(0.029)	(0.006)	(0.024)	(0.000)
Observations	10367696	4,795,584	10367696	4,795,584
Pseudo/Adjusted R-squared	0.923	0.905	0.923	0.905
Panel (d): 2015 to 2019				
Average post-event	-0.041	0.015***	0.035	0.000***
	(0.032)	(0.005)	(0.026)	(0.000)
Observations	6,720,344	3,381,832	6,720,344	3,381,832
Pseudo/Adjusted R-squared	0.930	0.913	0.930	0.913

Note. The table shows robustness checks for the treatment effects of the 2022 Mississippi River drought using alternative control groups. All regressions include port-destination-good-event-month and port-destination-good-event-year fixed effects. The average post-event treatment effects were calculated following de Chaisemartin and D'Haultfœuille (2020). The standard errors are adjusted for within-cluster correlation at the port-destination-good level. ***, **, and * indicate statistical significance at the 1, 5, and 10 percent confidence levels, respectively.

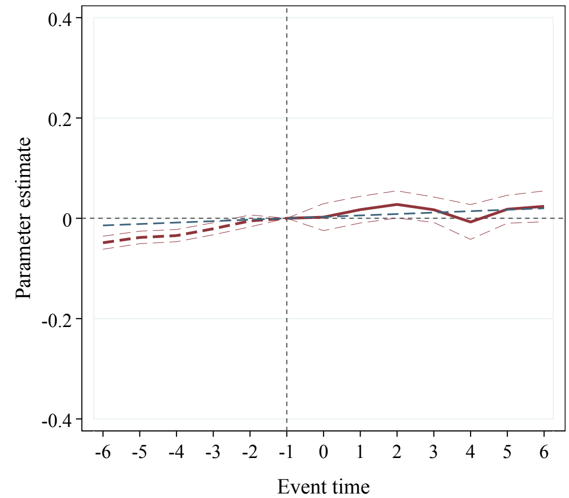
Table A3. Robustness Checks for Alternative Fixed Effects.				
	Louisiana ports		Non-Louisiana ports	
	Quantity	Unit value	Quantity	Unit value
Panel (a) ijs#yr,ijs#mo				
Average post-event	-0.040	0.014***	0.034	0.000***
	(0.031)	(0.005)	(0.025)	(0.000)
Observations	7,944,914	3,879,682	7,944,914	3,879,682
Pseudo/Adjusted R-squared	0.926	0.910	0.926	0.910
Panel (b): ijs, js#mo, is#mo, js#yr, is#yr				
Average post-event	-0.035	0.024***	0.030	0.000***
	(0.030)	(0.007)	(0.022)	(0.000)
Observations	15,327,482	3,879,682	15,327,482	3,879,682
Pseudo/Adjusted R-squared	0.896	0.836	0.896	0.836
Panel (c): ij#mo, is#mo, js#mo, ij#yr, is#yr, js#yr				
Average post-event	-0.038	0.020***	0.031	0.000***
	(0.031)	(0.006)	(0.023)	(0.000)
Observations	18,091,231	3.879,682	18,091,231	3,879,682
Pseudo/Adjusted R-squared	0.887	0.862	0.887	0.862
Panel (d): ij, i#mo, j#mo, s#mo, i#yr, j#yr, s#yr				
Average post-event	-0.053*	0.033***	0.043	-0.001***
	(0.032)	(0.009)	(0.028)	(0.000)
Observations	24,147,106	3,879,682	24,147,106	3,879,682
Pseudo/Adjusted R-squared	0.745	0.677	0.745	0.677

Note. The table shows robustness checks for the treatment effects of the 2022 Mississippi River drought using alternative fixed effects. All regressions include port-destination-good-event-month and port-destination-good-event-year fixed effects. The average post-event treatment effects were calculated following de Chaisemartin and D'Haultfœuille (2020). The standard errors are adjusted for within-cluster correlation at the port-destination-good level. ***, **, and * indicate statistical significance at the 1, 5, and 10 percent confidence levels, respectively.



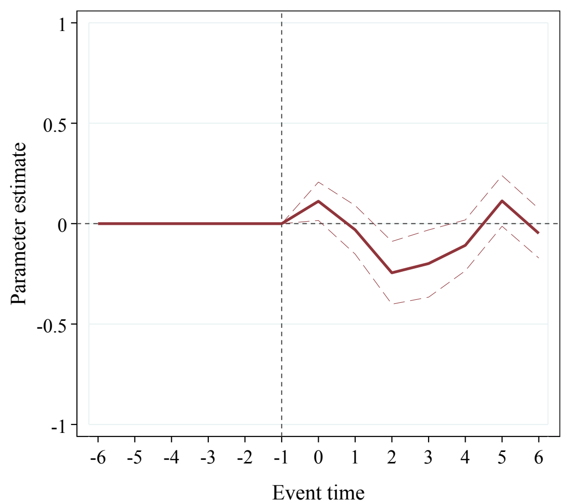
Linear trend: 0.005 (0.006) -- Pseudo R-squared: 0.926 -- Observations: 7,944,914

Panel (a): Overlaid Trend for Quantity.



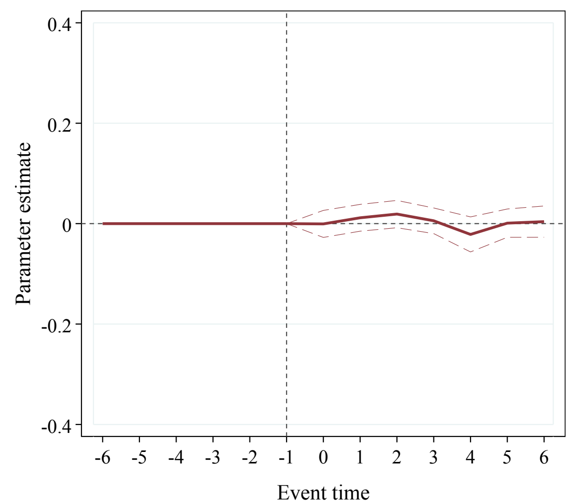
Linear trend: 0.003 (0.000) -- Adjusted R-squared: 0.910 -- Observations: 3,879,682

Panel (b): Overlaid Trend for Unit Value.



Post-average: -0.075 (0.034) -- Pseudo R-squared: 0.926 -- Observations: 7,944,914

Panel (c): Subtracted Trend for Quantity.



Post-average: 0.002 (0.006) -- Adjusted R-squared: 0.910 -- Observations: 3,879,682

Panel (d): Subtracted Trend for Unit Value.

Figure A1: Robustness Checks for Linear Pre-Trends.

Note. The figure shows pre-trend adjusted event studies for the impact of the 2022 Mississippi River Drought on U.S. agricultural exports. We overlaid the predicted linear pre-trends in panels (a) and (b) and subtracted them from the estimated net treatment effects in panels (c) to (d) following the approach outlined by Dobkin et al. (2018) and Freyaldenhoven et al. (2021). All regressions include port-destination-good-event-year and port-destination-good-event-month fixed effects. The standard errors are adjusted for within-cluster correlation at the port-destination-good level. We plot the dynamic treatment parameters and 95 percent confidence intervals for the event-time coefficients. We report Wald tests for the linear pre-trends, the average post-event treatment effects, the pseudo/adjusted R-squared, and the panel size in the sub-figure notes. The event time is measured in months relative to June 2022.