NATURAL DISASTERS, AGGREGATE TRADE RESILIENCE AND LOCAL DISRUPTIONS:

EVIDENCE FROM HURRICANE KATRINA*

Felix L. Friedt†

Macalester College

Abstract

What drives the resilience of international trade against increasingly destructive natural disasters? In this study, I investigate the dynamics and spatial distribution of Hurricane Katrina's trade effects across U.S. infrastructure and break new ground on the mechanisms underlying the static and dynamic trade resilience. Analyzing port-level data, I find that ports subject to this calamity experience significant and lasting trade reductions, while shipments handled by the adjacent ports increase by as much as 13,000%. Interestingly, the duration of this rerouting effect is persistent for eight years uncovering novel path dependencies and providing important policy insights in light of recent events.(*JEL* F14, F18, Q54, R40)

Key words: Trade; Trade Costs; Natural Disaster; Resilience; Infrastructure; Ports

*I am grateful for discussions with Bruce Blonigen, Anca Cristea, Michael Jerman, Taylor McKenzie, Jeremy Piger, Timothy Taylor, Sarah West and Wesley Wilson. Earlier versions of this paper were presented at the WEAI and AEA annual meetings 2017 and 2018. I am thankful for the comments received from Scott Baier, Anming Zhang and other TPUG participants.

†Department of Economics, Macalester College, 1600 Grand Avenue, Saint Paul, MN 55105; ffriedt@macalester.edu.

I INTRODUCTION

Natural disasters pose a constant threat to human life and economic activity. As recently evidenced by Hurricanes Florence and Michael, as well as the horrific hurricane season of 2017, the frequency and destructive force of these disasters continue to increase and adversely affect U.S. coastal regions and global value chains.[1] According to the Centre for Research on the Epidemiology of Disasters (CRED), the global community experiences an average of 384 natural disasters per year, impacting close to 200 million people and causing annual average damages around $162 billion (Centre for Research on Epidemiology of Disasters 2015).

A variety of case studies indicate that this devastation not only involves the tragic loss of human life, but also the impairment of entire regional economic structures.[2] As international trade has grown and gained economic significance (Blonigen and Wilson 2013), its global presence exposes it to the destruction and tragedy originating from natural disasters. The displacement of workers, destruction of product and capital, and impairment of infrastructure paramount to the facilitation of international trade can lead to substantial changes in the supply and demand of traded products, as well as delays or rerouteing of their respective shipping patterns (Grenzeback and Lukman 2008).[3] As such, natural disasters represent uncertain yet considerable barriers to trade that have remained largely unexplored at the disaggregated port level.[4]

How are local trade flows and global supply chains affected by natural disasters? Does the disruption of local economies alter the demand for trade? Do shippers and freight forwarders

[1]Disaster data published by the Centre for Research on the Epidemiology of Disasters (CRED) show that the period from 1960 to about 2000 saw a sharp ten-fold increase in the frequency of natural disasters. Moreover, research by Emanuel (2005) suggests that tropical cyclones are increasing in their destructive force.

[2]The main determinants of this impairment include, for example, the natural-disaster-induced effects on labour markets (Belasen and Polachek 2008) and supply chains (Altay and Ramirez 2010). The general findings of this strand of the literature provide evidence of large economic distortions that exhibit significant heterogeneity across economic agents and over time. This variation in economic impacts is a reoccurring theme throughout the natural disaster's literature (see, for example, a survery by Cavallo and Noy 2009) and applies to macroeconomic studies as well (see, for example, Noy 2009; Strobl 2011).

[3]Hurricane Florence, for example, has led to prolonged seaport closures in South and North Carolina and disrupted the global supply chains of several multinational corporations, such BMW or Volvo located in South Carolina.

[4]Within the international trade literature, research on the effects of trade costs has a long-standing history. Hummels (2001) or Anderson and van Wincoop (2004) offer excellent surveys on this topic. From these surveys, it is also clear, however, that the consequences of natural disasters on trade are not yet well understood.

respond to these unpredictable barriers? These are important questions central to this study. While related research suggests rather small and resilient responses in aggregate trade (see, for example, Parsons 2014), these global analyses may overshadow local trade disruptions. If so, a central point of interest to policy makers is whether these trade disruptions, resulting from the displacement of economic activity and destruction of infrastructure, are short-lived or lasting in nature. In this study, I address these critical issues and break new ground providing evidence on the short-run and long-run adjustments of local U.S. trade flows in response to a Hurricane Katrina.[5]

To begin, I develop a model of port-level trade to capture the dynamic and geographic variation of disaster-induced disruptions, while accounting for the spatial dependence present in the local trade flow data. Building on the theory, I derive a spatial econometric model of port-level trade and integrate a generalized difference-in-differences estimator to quantify the average treatment effects of natural disasters.[6] I apply this empirical specification to U.S. port-level containerized trade data and estimate the geographic spillovers caused by Hurricane Katrina over a time period from 2003 to 2013. The identification of the spatial heterogeneity in port-specific treatment effects is based on the quasi-experimental and exogenous shock caused by Hurricane Katrina. The resulting devastation of the ports of New Orleans and Gulfport provides a random increase in trade costs that allows me to identify the responses of carriers over the U.S. infrastructure network of major seaports and differentiate this rerouting effect from the adverse trade effects caused by the destruction of local economic activity and reduction in local demand and supply of traded products.

Matching the recent experiences due to Hurricanes Florence and Michael, my empirical analysis points to economically significant and highly concentrated disruptions at the port level. In

[5]These findings complement the work by Sytsma (2017, 2018), who investigates the implications of Hurricanes on U.S. port-level trade. While Sytsma's findings provide important insights on the implications across the broader U.S. port network and for global consumers, it encounters several limitations addressed in this study. Among others, my work provides a more close investigation of the trade effects of Hurricane Katrina, one of the most devastating hurricanes experienced by the U.S. that is more representative of the most recent events; it disentangles the rerouting effect from local devastations and differentiates the disaster-induced trade responses across industries.

[6]The spatial econometric techniques used in this study are most appropriate when the dependent variable of interest, such as port-level trade, is spatially correlated across panel units (LeSage and Pace 2009). Due to its relative novelty in the trade literature, however, I test the sensitivity of my results against alternative methods. Reassuringly, the results are quantitatively and qualitatively consistent when I estimate the model via the more traditional Poisson Pseudo-Maximum Likelihood (PPML) estimator (Santos Silva and Tenreyro 2006).

general, the trade disruptions are drastic within a 300 mile radius of the hurricane's epicenter, but evaporate exponentially past this threshold. Considering the short-run implications, I find that within this impact area the directly affected ports of New Orleans, Louisiana, and Gulfport, Mississippi, for example, experience statistically significant reductions in trade of around 95% one month post treatment, valued at around $300 million in monthly exports and $500 million in monthly imports. In contrast, I estimate that the port of Panama City, Florida, one of the closest neighboring ports to New Orleans and Gulfport, experiences substantial short-run increases in trade ranging from about 1500% in imports, valued at $100 million per month, to about 4,000% in exports, valued at nearly $20 million per month, one month after Katrina's landfall. Although these relative changes in trade are unparalleled across ports and the only consistently estimated increases in Gulf Coast port-level trade in the immediate aftermath of Hurricane Katrina, this short-run rerouting effect accounts for only 10%, of lost exports and about 20% of lost imports.

To further investigate this issue, I consider the dynamic, long-run changes of these natural disaster-induced trade variations. Differentiating the monthly impacts across multiple Gulf Coast ports, I find that the duration of trade disruptions is largely port specific. While some ports recover fairly quickly, others exhibit persistent long-run changes in trade throughput. Trade facilitated through the port of New Orleans, for example, reveals a rapid recovery within the first six to twelve month post treatment defying the adverse consequences resulting from the lasting disruption of the local economy.[7] In contrast, U.S. trade transported through the severely damaged port of Gulfport only partially recovers and experiences permanent reductions relative to pre-Katrina levels valued at around $50 million in exports and $100 million in imports per month.[8] Directly adjacent ports reflect similarly heterogeneous dynamics. While the immediate increase in trade handled by the port of Panama City continues to be valued at around $15 million dollars in monthly exports and $50 million in monthly imports by August 2013, I find that the port of Mobile experiences a rather

[7]This rapid recovery can be explained by the port's strategic location at the mouth of the Mississippi, the main channel for exports of U.S. grain and other products.

[8]These long-run trade disruptions are attributable to substantial infra- and superstructure damages sustained by the port of Gulport, including damages to berths, cranes, and office buildings, in response to the 24-foot storm surge. As a legislative report states, officials still operated out of new locations nearly one year after Hurricane Katrina (PEER 2006) and complete reconstruction lasted over 11 years costing more than $450 million by 2016 (Bonney 2016).

gradual increase in trade in response to the disaster amounting to around $40 million in monthly exports and $100 million in monthly imports eight years after Hurricane Katrina.[9] Cumulatively, export and import rerouting effects across the ports of Panama City and Mobile account for nearly all of the Gulfport trade lost due to Hurricane Katrina and exemplify the considerable resilience of the U.S. network of critical infrastructure against such events.

In addition to these novel insights, I find that the response in exports is more sensitive to epicenter distance leading to a more pronounced rerouting effect in imports and that the speed and magnitude of export recovery exceeds that of imports. Intuitively, these findings are indicative of the fact that exports facilitated via truck, railroad or inland barge shipments command higher transportation costs per ton-mile traveled than imports, which are predominately shipped via container vessels. As such, my findings provide first evidence that the disaster-induced burden of the added transport cost disproportionately affects exports relative to imports and results in greater export elasticities with respect to added distance.[10] Lastly, I provide new evidence on the potentially preferential rerouting treatment of high-value containerized cargo, such as textiles.[11]

Overall, these findings are significant for several reasons. First, the empirical analysis on directly affected ports of entry and exit indicates that U.S. trade suffers from a combination of effects, including the destruction of local demand for traded products as well as the disruption of local transport infrastructure. Isolating this infrastructure effect, my results are the first to directly evidence the primary channels of resiliency of aggregate U.S. trade flows and show that it critically depends on the ability of international carriers to reroute cargo shipments across the unaffected seaport infrastructure network. Conclusions based on aggregate analyses misrepresent the tremendous disruptions experienced at local seaports of entry or exit and undervalue excess infrastructure

[9]The estimates suggest that trade handled by ports at greater distances is largely unaffected by Hurricane Katrina.

[10]While these results are indicative of the exaggerated vulnerability of exports relative to imports, a note of caution is warranted. Since my findings are based on the actual consequences of Hurricane Katrina, I cannot provide a counterfactual analysis to provide evidence that the resilience of U.S. trade would have been any different in the absence of nearby ports, such as Panama City.

[11]Early interviews with several Floridian port authorities indicated that the resilience of U.S. trade is not unique to containerized traffic, but also true for dry- and break bulk cargo. Nonetheless, this study focuses on containerized traffic and contributes to the literature by providing new evidence of economically and statistically significant trade disruptions at the port and port-industry level. The analysis across multiple modes of transportation goes beyond the scope of this study and is highlighted as an important area for future inquiry.

capacity in close proximity. In light of recent events, this finding is of particular significance to policy makers in developing countries, such as the Philippines, that are frequently subject to natural disasters and consider various strategies to improve their resiliency against these calamities.

Second, the documented disaster-induced rerouteing of international cargo points to important path dependencies concerning containerized shipments. My findings suggest that natural disasters create rare opportunities for local shipping patterns to adjust and can thereby change the competitive landscape across urban economies dependent on the rerouted transport services.[12]

Third, the considerable persistence in rerouteing can have important implications for global value chains that base location decisions on the availability of consistent and reliable transport services offered by international carriers. Permanently rerouteing international cargo through alternative seaports of entry and exit can create a comparative advantage for the positively affected seaport community and shift the distribution of economic activity across disaster-prone regions.

The literature concerning the linkages between trade and natural disasters is rather sparse. In a seminal study, Gassebner, Keck, and Teh (2010) analyze the effects of natural disasters on aggregate international trade. In general, the authors show that a country's governance and economic size matter to the degree of devastation on the import side, while exports experience a negative shock regardless of country characteristics. Additional research complementing these findings suggests that natural disasters cause heterogeneous responses across industries, firms, products, and seaports (Ando and Kimura 2012; Martincus and Blyde 2013; Sytsma 2017, 2018). Although this relatively small strand of the economic literature on natural disasters has provided substantial insights into the variation of natural-disaster-induced impacts on trade[13], little is known about the spatial heterogeneity of these trade effects.[14]

[12]For an in-depth analysis of the urban equilibrium consequences of the rerouting of international cargo induced by Hurricane Katrina see Friedt (2018).

[13]Oh and Reuveny (2010) find that political risk is an important factor in the determination of trade effects caused by natural disasters. Studies by Andrade da Silva and Cernat (2012), for example, distinguish between the trade effects of natural disasters on developing versus developed countries and show that the estimated trade effects vary by economic and geographical size of the affected country as well as across imports and exports. Further disaggregation of these trade effects has provided evidence that the resulting trade disruptions vary dynamically (Ando and Kimura 2012; Parsons 2014), across industries and firms (Ando and Kimura 2012; Martincus and Blyde 2013) as well as product groups (Martincus and Blyde 2013) and can lead to a change in trade composition (Ando and Kimura 2012).

[14]The study by Martincus and Blyde (2013) exploits geo-referenced data on Chile to estimate the short-run impact

A finding of particular interest to this study, emerges from the research by Parsons (2014), which shows that Hurricane Katrina caused relatively small and short-lived disruptions of aggregate U.S. trade. While this may be falsely interpreted as a negligible trade effect overall, my empirical analysis suggests that this insignificant aggregate trade shock masks the economically and statistically significant local trade disruptions. The primary results, in fact, produce strong evidence of the systematic spatial and dynamic heterogeneity in trade effects that is driven by port-specific recoveries as well as rerouting effects and consistent with the *static* and *dynamic* resilience of international trade as defined by Rose (2007).[15]

Based on these findings, my research contributes to the economic literature in several ways. To the best of my knowledge, this study is the first to identify and estimate the spatial heterogeneity of natural disaster-induced trade effects and consider their short-run and long-run geographic distribution. The empirical findings offer intuitive insights into the dynamic responses of the international transport sector and domestic infrastructure network to natural disasters and point to their importance in mitigating aggregate repercussions. Since many countries continue to be battered by severe natural disasters and often suffer significant reductions in output growth (Toya and Skidmore 2007; Strobl 2012), the specific resiliency channels identified in this research are of particular interest to international policy makers and offer insights on one of the important remaining gaps in the literature as established by Cavallo and Noy (2009).

The remaining parts of the paper are organized as follows: Section II provides detailed background information on Hurricane Katrina and its repercussions, whereas section III presents the theoretical framework and empirical specification I use to analyze the dynamic spatial variation in trade effects. In sections IV and V, I summarize the U.S. port-level trade data and discuss the empirical results. Section VI concludes and offers suggestions for further inquiry.

of local infrastructure disruptions on trade and, along with the work by Sytsma (2017, 2018), is perhaps most closely related to the present study. While Sytsma (2017) explores the port-level trade effects from U.S. Hurricanes between 2003-2015 identified via variation in wind-speeds, Sytsma (2018) considers the global welfare implications from the disaster-induced delays of indirectly affected U.S. exports.

[15] In his study, the author describes *static* resilience as the ability of the economic system to maximize output based on the remaining after-shock resources and *dynamic* resilience as the speed of recovery of the economy post natural disasters. In a later study, Rose and Wei (2013) develop an input-output model to simulate the effects of a hypothetical port shut-down and illustrate that rerouting of international cargo is the key mechanisms of resiliency.

II INSTITUTIONAL BACKGROUND

While some empirical studies consider the average effect of natural disaster on aggregate trade, this study identifies the dynamic and spatially heterogeneous trade effects at a more disaggregated local level via the variation caused by a single event, Hurricane Katrina. Hurricane Katrina is widely recognized for its immense devastation that caused tremendous hardship in human life and economic outcomes. At the time, Katrina was the costliest and most destructive natural disaster ever experienced by the U.S. causing over 1,800 deaths and an estimated $75 billion in damage.

As depicted in Figure 1, Hurricane Katrina originated as a tropical storm around the Bahamas and made its initial landfall as a Category 1 hurricane in Florida on August 25, 2005. After causing modest disruptions in Florida, the wind storm moved into the Gulf of Mexico, where it rapidly intensified and developed into a Category 5 hurricane at its peak. Its second landfall occurred in the state of Louisiana on August 29, 2005, with sustained winds of 125 mph. Upon this second landfall, the havoc caused by Hurricane Katrina was felt along the majority of the U.S. Gulf Coast with the most severe effects along the coastal regions of Louisiana and Mississippi.

In addition to causing substantial loss of human life, Hurricane Katrina's impact extended across the regional economic structure and even to the national level. Based on early estimates, Holtz-Eakin (2005) argues that the effects of Hurricane Katrina were expected to lower U.S. output growth by 0.5 percentage points in the short run, whereas recovery efforts were expected to reverse this effect by 2006. The underlying causes for this initial decline in the growth of aggregate income range from extensive reductions in employment and housing due to the flooding of New Orleans[16], to the destruction of physical capital[17], and trade disruptions caused by the severe impairment of the regional infrastructure. According to Grenzeback and Lukman (2008), the infrastructure of the U.S. coastal region of Alabama, Louisiana, and Mississippi experienced substantial ruination encompassing damages to road, rail and port networks. Taking account of the specific damages,

[16]Studies by Dolfman, Wasser, and Bergman (2007) and Vigdor (2008) show that Hurricane Katrina resulted in significant reductions of employers and employment (between 70,000 and 95,000 lost jobs) and the long-term displacement of over 150,000 people. In addition to these labor market effects, Vigdor (2008) reports that the New Orleans' availability of housing declined from 215,000 units in 2000 to 106,000 units by 2006.

[17]Holtz-Eakin (2005) estimates physical capital damages to total between $70 billion and $130 billion.

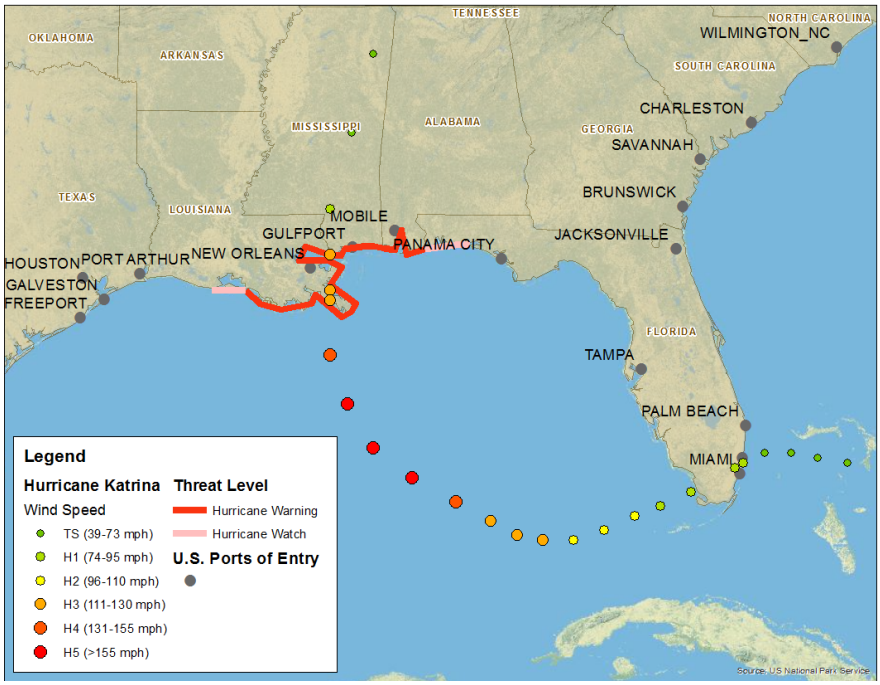


Figure 1: Geography of Hurricane Katrina

the authors point to the destruction of bridges, railways, the ports of New Orleans and Gulfport and Interstate 10, as well as the loss of electricity and closing of major waterways as the main factors determining this wreckage of the coastal infrastructure.

Considering the impact on the port of Gulfport more carefully, a 2006 Mississippi legislative report by the Joint Legislative Committee on Performance Evaluation and Expenditure Review (PEER) reveals significant damage to infra- and superstructures, including berths, docks, storage areas, cranes, terminals, and office buildings (PEER 2006) that led to a complete shutdown of the port of around five weeks (Grenzeback and Lukman 2008). The reconstruction of this state-level infrastructure took more than 11 years to complete and cost of $450 million procured from local and federal sources (PEER 2006; Bonney 2016). In contrast, the port of New Orleans, which also suffered severe damages, was deemed a strategically important port of exit for U.S. exports and was prioritized in terms of the reconstruction efforts. As a result, the port of New Orleans, projected to stay closed for up to six month after the storm, remained shutdown for only two weeks and reached more than 70% of its original capacity by January, 2006 (Grenzeback and Lukman 2008).

III MODEL

Intuitively, the primary channels through which a natural disaster, such as a hurricane, can impact port-level trade flows are threefold. First, climate and weather extremes can lead to the ruination of physical infrastructure, which prohibits or limits the movement of goods through a particular seaport of entry or exit. Second, natural disasters can have significant implications on local economies and alter the supply and demand for internationally traded products handled by a given seaport of entry or exit. For any given disaster, one would expect the directly and adversely-affected ports to experience trade disruptions caused by a combination of these two mechanisms. That is, we expect the port of New Orleans, for example, to experience a reduction in trade due to the tragic and unparalleled ruination of New Orleans and displacement of half of the city's population, as well as the seaport's two week closure and infra- as well as superstructure damages sustained due to the flooding caused by Hurricane Katrina. The rerouting of international cargo through the otherwise unaffected seaport network is the third mechanism, through which disasters can influence port-level trade flows. I label this third mechanism as the *rerouting effect* that serves to mitigate the adverse disruptions and shapes the resilience of international trade against such calamities.

There are, of course, a few obvious concerns regarding identification of this third mechanism. First, one may be concerned about a nontrivial share of locally originating or destined shipments that are simultaneously subject to all three of these mechanisms and limit the opportunity for rerouting of international cargo. Based on the U.S. Census Foreign Trade Database, which tracks the state of origin and port of exit for U.S. exports prior to 2007, local (originating within state) exports handled by the ports of New Orleans and Gulfport account for about 39% and 13% of total seaport exports, while the majority of this trade, particularly for the port of Gulfport, originated outside of the states of Louisiana and Mississippi. Albeit the potential displacement of local economic activity and reduction in supply of local exports, the respective shares of local trade increase to 42% and 15% of total annual exports by 2006 suggestive of the anticipated rerouting of otherwise unaffected cargo. Further evidence of the rerouting effect is provided through the local export shares observed for the port of Panama City, FL. In 2004, around 60% of this seaport's exports

originated within Florida, while around 40% originated outside of the port's home state. By 2006, more than 80% of the port of Panama City's exports originated outside of the Florida.

Second, one may be concerned about the potentially confounding impact of the displacement of economic activity. Evacuees from New Orleans, for example, may shift the local demand and supply of internationally traded products towards otherwise unaffected port communities, such as the Floridian port of Panama City, and convolute the estimated rerouting effect. Estimates regarding Katrina evacuees, indeed, indicate that Florida experienced a marginal inflow of about 15,000 refugees primarily relocating to the major Metropolitan areas of Miami and Tampa-St. Petersburg (BBC News 2005). In relative terms, however, these evacuees represented less than a tenth of a percent (0.084%) of Florida's entire population during the third quarter of 2005 and are comparably small to the number evacuees headed to Arkansas and Texas.[18] Given that the estimated labor market effects are relatively mild[19] and that the number of Texas-bound evacuees far exceeded those headed to Florida in response to Hurricane Katrina, the concern over the confounding influence of evacuees on rerouted trade flows through adjacent ports seems rather unsubstantiated.

To quantify the rerouting effect and resilience of U.S. trade against natural disasters, such as Hurricane Katrina[20], I develop a simple model of port throughput that allows me to identify the port-specific local trade disruptions resulting from natural disasters, while accounting for the potential spatial correlations arising from the cross-port interactions and dependencies. Following common practice, I assume that U.S. trade (X_t) at time (t) is a function of exogenously given U.S. income (Y_t) and national trade cost factors (τ_t). That is, aggregate U.S. trade is given by $X_t = X(Y_t, \tau_t)$. Based on aggregated international carrier port choices, each U.S. port of entry and

[18]These states welcomed about 70,000 and 240,000 refugees, respectively (BBC News 2005).

[19]The literature on the labor market effects from this disaster-induced migration has focused on the Houston and suggests marginal repercussions. McIntosh (2008), for example, finds that native Houstonians experience a 1.8% reduction in wages and 0.5% decrease in employment probability in response to the 240,000 Texas-bound evacuees.

[20]A final concern in regards to this identification strategy may arise due to the extreme qualities of Hurricane Katrina. While it is true that Hurricane Katrina was an unusually destructive disaster compared to previous events, more recent experiences in 2017 and 2018, along with research indicating the increasing destructive force of tropical cyclones (Emanuel 2005), suggest that it may be more representative of future events than initially expected. In the absence of more definitive predictions about future U.S. hurricanes, however, the trade disruptions caused by Hurricane Katrina and resulting test of the resilience of the U.S. seaport network may be interpreted as an upper bound. That is, if the empirical analysis yields evidence of the anticipated rerouting effect and resilience of U.S. trade, less damaging climate and weather extremes should produce barriers to trade no greater than those created by Hurricane Katrina.

exit (p) facilitates a share (α_{pt}), of these trade flows, where each port-specific share is independent of aggregate trade and the sum of shares across all seaports (S) must equal one, $\sum_{p=1}^{S} \alpha_{ipt} = 1 \ \forall t$. Naturally, each port's share in aggregate trade is assumed to depend on port-specific characteristics (c_p), such as a port's location, and port-specific trade costs (f_{pt}). In addition, each port's trade share may depend on the degree of port-to-port competition and/or port-to-port integration resulting from the emergence of national and international supply chains. To integrate this feature into the theoretical framework, I expand the function of each port's trade share and incorporate the strategic consideration of every other ports' trade share ($\alpha_{t,-p}$). Each port's throughput of U.S. trade (x_{pt}) is therefore given by the following expression:

$$x_{pt} = \alpha(c_p, f_{pt}, \alpha_{t,-p}) X(Y_t, \tau_t). \tag{1}$$

Unlike previous studies (see, for example, Gassebner et al. 2010), this specification relaxes the assumption that natural disasters represent a national trade cost component that is uniformly distributed across the entire infrastructure network. Instead, I assume that natural disasters have heterogeneous effects on trade at the seaport level and therefore, represent a port-specific cost factor that varies with the geo-spatial location of a given port in reference to the disaster's epicenter.

Since the exact geography of this potential resilience, however, is unknown a priori, I develop a spatially disaggregated specification to allow for geophysical heterogeneity in the disaster-induced trade effects. Based on the identification strategy, port-specific trade costs reflect the timing of Hurricane Katrina's second landfall for each of the given sample ports at various distances to its epicenter. This variable captures the resulting port-specific trade effects and gives insights into their dynamic geographic distribution.

While this theoretical framework is fairly abstract, it lends itself well to the derivation of more complex stochastic models of port-specific trade flows and captures all of the essential elements to evaluate the disaster-induced local trade effects. To this end, I develop two empirical models to differentiate the static and dynamic resilience of trade. The first specification aims to identify

the static resilience of trade and estimates the port-specific short-run (six month) average treatment effects, captured by the vector of coefficients (γ_p) in response to Hurricane Katrina. For this model, port-level trade costs (f_{pt}), represent a matrix of port-specific indicator variables that turn equal to one for a specific port during and after the month of Katrina's landfall, August 2005.

I specify the model in log-linear form and control for unobservable port characteristics, such as location, entry restrictions, and harbor type, and national trends, such as U.S. income, via port (α_p) and time fixed effects (α_t).[21] The resulting empirical model is given by Equation (2).

$$\ln(x_{pt}) = \beta_0 + \gamma_p f_{pt} + a_p + a_t + \lambda W u_{pt} + \epsilon_{pt}. \tag{2}$$

Given the potential for unobserved spatial correlations across ports, I assume an error term structure that represents the Spatial Error Model (SEM) discussed by LeSage and Pace (2009). In this stochastic model, the random error is comprised of two important components, including the spatial component consisting of the spatial correlation coefficient (λ) and the spatial weight matrix (W), which govern the nature of cross-port correlations[22], and the identically and independently distributed random error (ϵ_{pt}).[23] The parameters of interest, capturing the static and spatially distributed average treatment effects caused by Hurricane Katrina, are given by the coefficient vector γ_p. Once transformed ($[exp(\gamma_p) - 1] * 100$), these coefficient estimates capture the six-month av-

[21] Given the sample of aggregate U.S. port-level trade, the inclusion of time fixed effects captures not only macroeconomic trends in income, but also the multilateral resistance to trade coined by Anderson and van Wincoop (2003).

[22] Intuitively, trade handled by the port of Long Beach, CA, for example, may strongly depend on unobservable shocks to its closest neighbor, the port of Los Angeles, CA, and to lesser degree on unobservable factors influencing trade through the ports of San Francisco, Seattle or even Houston. The literature on these types of spatial error correlations suggests that there are several weight matrices available when considering the final spatial econometric specification (see, for example, Ord 1975; LeSage and Pace 2009). Since the distribution of U.S. seaports is non-uniform across space and competition between these infrastructures arguably depends on port-to-port proximity, a natural choice for the spatial weights is inverse distance suggesting that the spatial correlation across ports declines exponentially with the distance between a pair of ports (Cliff and Ord 1968; Griffith 1996; Getis 2009). A commonly used alternative is a row normalized contiguity or nearest neighbor matrix indicating each port's neighboring facilities (LeSage and Pace 2009). Grounded in the theoretical considerations, I base the primary empirical findings on a symmetric inverse port-to-port distance matrix, the lower triangle of which is presented in Table 6 in the Appendix. Reassuringly, my findings are robust to alternative weight matrix specifications. The results are available upon request.

[23] In the absence of spatial considerations ($\lambda = 0$), the resulting empirical specification, given by Equation (2), resembles the standard stochastic trade models used to identify the impact of various barriers to international transactions. Traditionally, these trade relations are estimated using the PPML estimator developed by Santos Silva and Tenreyro (2006), which I employ as a robustness check for my primary results.

erage treatment effect measured as the percentage change in monthly port-level exports or imports triggered by Hurricane Katrina.[24] Given the nature of this difference-in-differences (DiD) estimator, the static port-specific average treatment effects must be interpreted in reference to the excluded sample ports. Based on the aggregate resilience of trade and slight disruptions experienced at the regional level (see, for example, Figure 1), I estimate the trade effects for U.S. Gulf Coast ports (including all Floridian ports) and contrast these treatment effects to the excluded sample ports located at greater nautical distances from Hurricane Katrina's epicenter.[25]

To investigate the dynamic resilience of trade, I develop a second empirical model, given by Equation (3). In this case, I integrate a dynamic trade cost component that includes a set of interacted dummy variables ($f_{p,t^*\pm k}$), each indicating a specific month before or after Hurricane Katrina for a given port of entry or exit. The reference month (t^*) is set for July, 2005, one month prior to Hurricane Katrina's landfall. Intuitively, $f_{p,t=t^*+1}$ captures the disaster-induced trade disruption at port (p), in August, 2005, the month of Hurricane Katrina's landfall. Tracing out these port-specific month-to-month treatment effects allows for the identification of the immediate rerouteing effect on U.S. trade and the long-term adjustments in shipping patterns, both of which are crucial mechanisms underlying the dynamic resilience of international trade. Combining this dynamic trade cost component with all of the previously discussed elements yields the following specification

$$\ln(x_{pt}) = \beta_0 + \sum_{k=-23, k\neq 0}^{K} \gamma_{p,t^*+k} f_{p,t^*+k} + a_p + a_t + \lambda W u_{pt} + \epsilon_{pt}, \tag{3}$$

where the parameters of interest, capturing the dynamic and spatially distributed pre-treatment ($k = -23$)[26] and port-specific post treatment ($K = 97$) trade effects caused by Hurricane Katrina, are given by the coefficient vector γ_{p,t^*+k}. The interpretation of each of the point estimates con-

[24]Following the spatial econometric literature, alternative specifications include, for example, the Spatial Autoregressive Model (SAR) and the Spatial Autocorrelation Model (SAC), which integrate an additional term that controls for spatial trade spillovers across ports. When estimating these models, proper interpretation of the coefficient estimates relies on their transformation into direct and indirect spatial effects given by $(I - \rho W)^{-1}\gamma_p$ (LeSage and Pace 2009), and produces quantitatively and qualitatively consistent results.

[25]The port-specific treatment effects are robust to various alternative definitions of treatment and control groups.

[26]Naturally, these pre-treatment trade effect estimates should be insignificant and provide a natural placebo test for the identification strategy.

tained in this vector slightly changes in comparison to equation (2). Here, the transformed version of γ_{p,t^*+2}, for example, reflects the percentage change in trade of a given Gulf Coast port (p) in September 2005 with respect to July 2005 relative to the average percentage changes in trade for all control ports over the same time period. Grounded in the static analysis, the dynamic specification evaluates the port-specific recovery and persistence of trade effects across the six Gulf Coast ports located closest to Hurricane Katrina's epicenter, including the port of Gulfport, New Orleans, Mobile, Panama City, Tampa and Port Arthur.[27]

IV DATA

To estimate the empirical specifications, given by Equations (2) and (3), I obtain data from various sources. The main variable of interest is given by U.S. containerized trade at the seaport of entry and exit level. These data involve aggregate international cargo shipments between the U.S. and the rest of the world and are available through the *USA Trade Online* database published by the *U.S. Census Bureau*. The data are reported at monthly frequency and the sample period under consideration covers two years prior to and eight years after Hurricane Katrina's landfall extending from August, 2003 to July, 2013. While *USA Trade Online* includes the universe of U.S. seaport of entry and exit with vastly different trade volumes, the selection of ports included in this analysis is based on economic significance. That is, I include only the largest forty ports of entry and exit in the sample. At the time of Hurricane Katrina's landfall, these forty ports account for roughly 98% and 96% of total U.S. containerised imports and exports, respectively.

The key variables distinguishing the systematic variation in trade disruptions caused by Hurricane Katrina are based on longitudinal and latitudinal coordinates obtained from the World Port Index (WPI) compiled by the *National Geospatial-Intelligence Agency* and nautical port-to-port distances published by the *U.S. Department of Commerce* in collaboration with the *National Oceanic and Atmospheric Administration (NOAA)* and the *National Ocean Service*.[28] The distinction in

[27]The results are robust against the expansion of this treatment group.

[28]The lower triangle of the symmetric port-to-port nautical distance matrix is presented in Table 6 in the Appendix.

local treatment effects is based on the spatial distribution of U.S. ports and their nautical distances from the epicentre of Hurricane Katrina's landfall, as depicted in Figure 1. Based on the selection of ports under consideration and their geographic locations, the ports of New Orleans, LA, and Gulfport, MS, are those closest to the epicentre in the western and eastern directions, respectively, while the port of Mobile, AL is the only other sample port still within the hurricane warning zone. All other sample ports are located at greater distances in Gulf Coast states, such as Florida and Texas, or more remote U.S. East Coast, West Coast, and Great Lakes' regions.

To gain preliminary insights into the geographic and dynamic distribution of trade disruptions caused by Hurricane Katrina, I provide a summary detailing the cross-sectional, spatial and time dimensions of these data. Figure 2, for example, maps the relative changes in port-level containerised trade from July, 2005 to September, 2005 across the U.S. Lower Atlantic and Gulf Coast regions.[29] The charted spatial distribution of port-level trade disruptions in reference to Hurricane Katrina clearly indicates that ports closest to the disaster experience the largest relative changes in overall trade flows. Trade facilitated by the port of Panama City, for example, experiences a substantial relative increase one month after Hurricane Katrina, while the ports of Gulfport and New Orleans exhibit the largest losses in international cargo shipments. In contrast, the geo-referenced ports at greater distances appear to experience relatively smaller relative short run changes in trade.

In terms of absolute gains and losses, Table 1 expands the selection of ports and offers complementary evidence of the spatially concentrated disruptions from Hurricane Katrina. In this table, I present the port-specific disaster-induced deviations in exports and imports averaged over one year prior to Hurricane Katrina (August, 2004 - July, 2005) to average trade one year after the disaster (September, 2005 - August, 2006). While columns (4) and (5) present the absolute and relative short-run deviations for port-level exports, columns (8) and (9) offer these respective insights for port-level imports. The individual ports are arranged by nautical distance Katrina's epicenter, presented in column (1). The changes in trade echo the clear spatial pattern of disaster-induced deviations in trade suggested by Figure 2. While the statistics indicate that all U.S. seaports are

[29]I gratefully acknowledge the excellent cartographic support provided by Ashley Nepp, who created Figure 2.

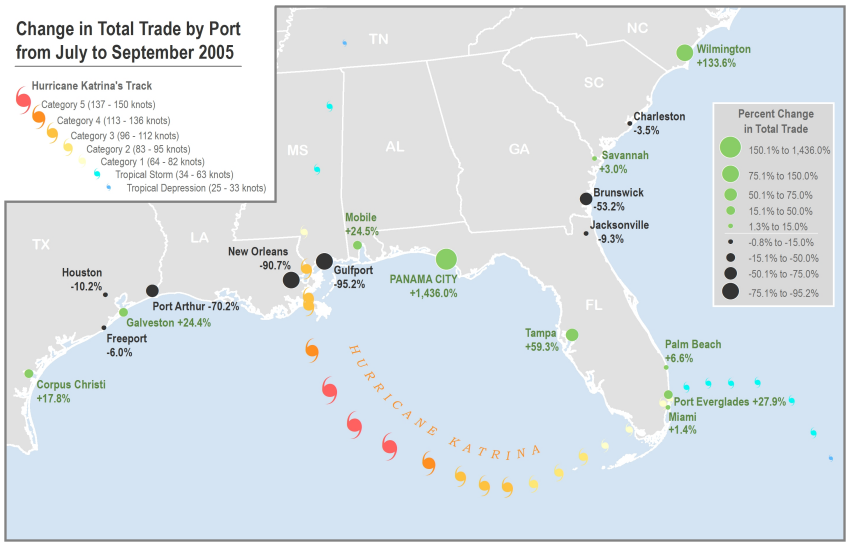


Figure 2: Port-level trade changes

subject to significant month-to-month trade variations, the magnitude of the deviations experienced by those ports closest to Hurricane Katrina's epicenter are uncharacteristic and non-coincidental. While the port of New Orleans, for example, reflects reductions of exports and imports of 10% and 35%, valued at around $20 million and $100 million, respectively, the port of Gulfport continues to experience significant reductions in trade one year after the disaster ranging 40% for exports to 47% for imports, valued at around $40 million and $100 million respectively.

The prolonged disruption experienced at the port of Gulfport poses the important questions if and how the affected carriers adjust international shipping routes. As previously suggested by Figure 2, the observed deviations experienced by the port of Panama City are most remarkable and provide evidence of immediate and intentional rerouteing decisions that clearly dependent on distance from the adversely affected ports. Table 1, in fact, suggests that exports and imports handled by the port of Panama City, FL one year after the disaster increased by around 62,400% and 1,500%, valued at around $30 million and $95 million respectively, relative to pre Hurricane Katrina levels. This extraordinary increase in trade at a favorably located port provides preliminary evidence of the static resilience of U.S. trade in response to natural disasters.

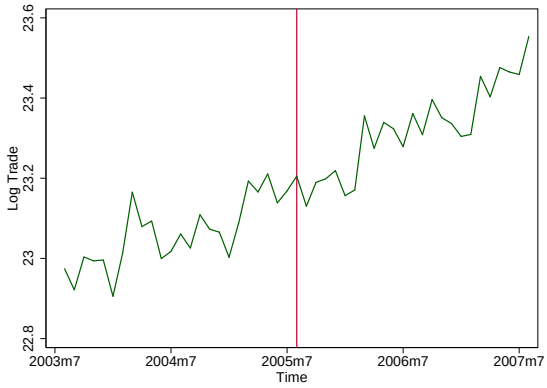
To shed further light on the dynamics of these trade effects in response to Hurricane Kat-

Table 1: U.S. seaport exports and imports

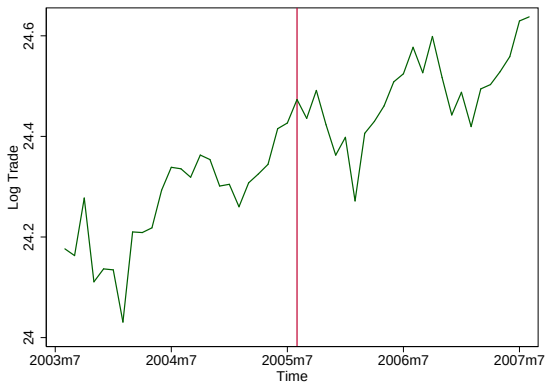
Ports	Distance to Epicenter (1)	**Exports** (mil. $) Pre-Avg. (2)	Post-Avg (3)	**Deviation in Exp.** (mil. $) (4)	(%) (5)	**Imports**(mil. $) Pre-Avg. (6)	Post-Avg (7)	**Deviation in Imp.** (mil. $) (8)	(%) (9)
Gulfport, MS	15.7	86.9	46.3	-40.7	-46.8	203.0	106.8	-96.2	-47.4
New Orleans, LA	40.4	213.4	190.4	-23.0	-10.8	270.0	173.7	-96.3	-35.7
Mobile, AL	113.7	8.2	13.0	4.8	58.5	37.5	61.2	23.6	63.0
Panama City, FL	237.7	0.1	31.9	31.8	62416.5	6.1	100.1	94.0	1532.5
Tampa, FL	428.7	5.7	7.2	1.5	25.7	13.1	11.7	-1.4	-10.7
Port Arthur, TX	481.4	1.8	2.7	0.9	49.1	2.7	6.1	3.4	127.0
Galveston, TX	486.4	8.4	9.5	1.0	12.3	26.6	28.3	1.7	6.5
Freeport, TX	529.4	17.2	19.4	2.2	12.5	20.9	11.3	-9.6	-46.0
Houston, TX	530.4	1015.9	1261.0	245.1	24.1	1136.6	1383.9	247.4	21.8
Corpus Christi, TX	595.4	1.3	1.6	0.3	22.8	1.6	3.4	1.8	108.8
Miami, FL	703.0	480.7	476.7	-4.0	-0.8	872.2	874.8	2.5	0.3
Port Everglades, FL	718.0	271.7	339.9	68.2	25.1	434.9	524.7	89.8	20.7
West Palm Beach, FL	759.0	69.0	80.8	11.8	17.0	63.0	49.4	-13.7	-21.7
Jacksonville, FL	1015.0	133.3	165.0	31.7	23.8	68.7	92.6	23.9	34.8
Brunswick, GA	1041.0	2.0	1.9	-0.1	-6.4	146.5	126.9	-19.6	-13.4
Savannah, GA	1096.0	594.9	728.6	133.6	22.5	1262.8	1511.7	248.9	19.7
Charleston, SC	1125.0	833.9	856.3	22.4	2.7	2217.9	2468.8	250.9	11.3
Wilmington, NC	1220.0	35.1	60.3	25.2	71.8	93.3	111.3	17.9	19.2
Newport News, VA	1458.0	816.1	960.2	144.1	17.7	1830.7	2083.2	252.6	13.8
Baltimore, MD	1584.0	228.1	261.0	32.9	14.4	892.8	958.5	65.8	7.4
Chester, PA	1624.0	67.1	92.6	25.6	38.1	152.1	166.3	14.1	9.3
Philadelphia, PA	1639.0	85.6	104.7	19.1	22.3	292.5	358.5	66.0	22.6
Perth Amboy, NJ	1642.0	1.7	1.6	-0.1	-5.2	0.8	1.5	0.7	82.0
Newark, NJ	1650.0	257.6	336.3	78.7	30.5	4878.0	5282.9	404.9	8.3
New York, NY	1662.0	1181.6	1436.2	254.6	21.5	667.6	662.5	-5.1	-0.8
Boston, MA	1900.0	56.5	72.3	15.8	27.9	161.6	195.7	34.0	21.1
Portland, ME	1940.0	2.7	3.6	1.0	35.5	2.7	5.4	2.8	103.8
Detroit, MI	3645.0	206.1	219.2	13.1	6.4	12.5	18.5	6.0	47.7
Port Huron, MI	3707.0	20.3	16.0	-4.3	-21.1	5.8	5.8	0.1	1.0
Chicago, IL	4278.0	25.1	32.7	7.6	30.1	21.3	15.2	-6.1	-28.8
San Diego, CA	4309.0	12.5	2.7	-9.8	-78.5	79.8	162.1	82.4	103.3
Long Beach, CA	4381.0	1122.8	1345.9	223.1	19.9	3657.3	4086.2	428.9	11.7
Los Angeles, CA	4382.0	1252.2	1501.2	249.0	19.9	11098.3	12697.6	1599.4	14.4
Port Hueneme, CA	4456.0	3.5	3.4	-0.1	-2.1	62.2	30.2	-32.0	-51.5
San Francisco, CA	4712.0	3.1	8.2	5.1	165.7	30.6	21.6	-9.0	-29.4
Richmond, CA	4723.0	1.4	1.1	-0.3	-22.9	21.1	9.6	-11.5	-54.4
Oakland, CA	4767.0	588.4	617.5	29.1	5.0	1678.7	1867.2	188.5	11.2
Portland, OR	5330.0	59.5	56.8	-2.7	-4.5	130.0	215.7	85.7	65.9
Seattle, WA	5486.0	492.3	505.5	13.2	2.7	2268.1	2204.8	-63.3	-2.8
Tacoma, WA	5511.0	230.0	246.4	16.5	7.2	1748.6	1876.5	127.9	7.3

Source: U.S. Census Bureau, USA Trade Online data.

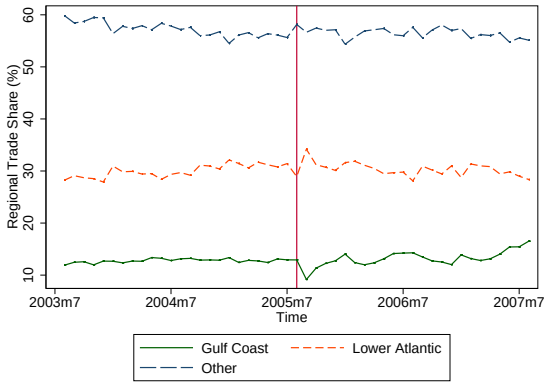
Notes: Column (1) presents the nautical distance of each port with respect to Hurricane Katrina's epicenter measured in nautical miles. Columns (2), (3), (6) and (7) present the port-level exports and imports averaged over one year prior to (August, 2004 - July, 2005) and after Hurricane Katrina (September, 2005 - August, 2006). Each of these average trade values are expressed in millions of U.S. $. Columns (4) and (8) depict the absolute change in average pre- and post-treatment exports and imports, respectively, measured in millions of U.S. ($). Lastly columns (5) and (9) present the relative change in trade measured in percentages of the pre-Katrina average trade levels.



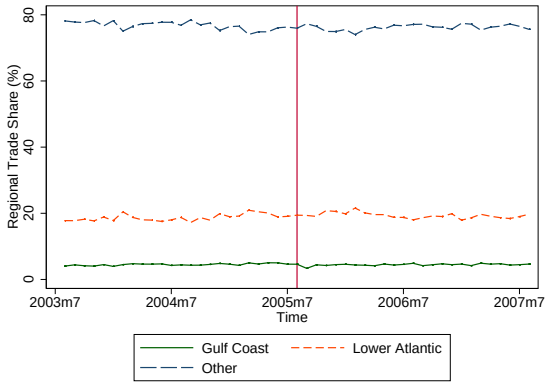
3.1: National Exports



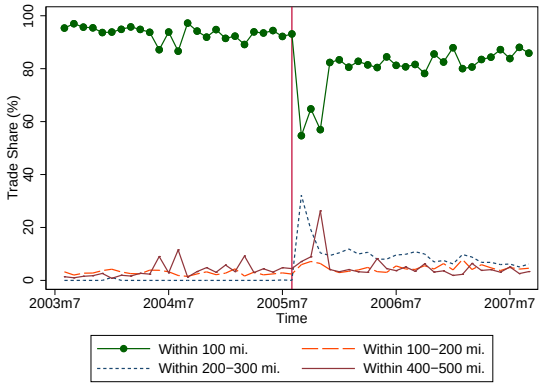
3.2: National Imports



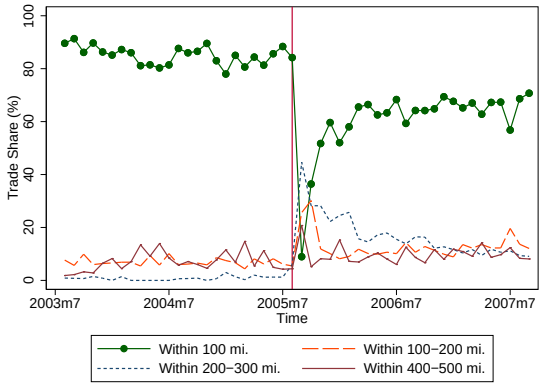
3.3: Regional Export Shares



3.4: Regional Import Shares



3.5: Local Export Shares (within 500 nautical mi. of Katrina's epicenter)



3.6: Local Import Shares (within 500 nautical mi. of Katrina's epicenter)

Figure 3: Trends in Aggregate, Regional and Local US Exports and Imports

rina, I present time plots of U.S. trade at various levels of aggregation. Figures 3.1 and 3.2, for example, exhibit the logged value of aggregate U.S. exports and imports. The figures illustrate positive overall growth and significant seasonal variation. The vertical line indicates Hurricane Katrina's landfall in August, 2005, and both figures demonstrate that, compared to common seasonal variation, the aggregate trade effects of Hurricane Katrina appear negligible in the short and long run. To explore the apparent disconnect between these aggregate observations and significant trade disruptions indicated in Figure 2 and Table 1, I consider the disaster impact on regional trade shares instead. Figures 3.3 and 3.4 reveal slight variations from the aggregate conclusions. U.S. Gulf Coast exports (including Alabama, Louisiana, Mississippi and Texas), for example, face a sharp, but temporary decline, while exports through the adjacent Lower Atlantic region (including Florida, Georgia, North Carolina, South Carolina and Virginia) experienced an apparent increase.[30] In addition to that, Figure 3.3 reveals that the share of exports held by the remaining U.S. regions remains rather stable during this period. In contrast, Figure 3.4 presents a much less noticeable impact of Hurricane Katrina on regional U.S. imports, where we observe very slight reductions in the U.S. Gulf Coast and no visible effects on the import shares of the Lower Atlantic region.

Given these mixed findings at the regional level, I offer a visual representation of the disaster-induced trade disruptions at the local level, defined as total seaport containerized trade within 500 miles of Hurricane Katrina's epicenter, in Figures 3.5 and 3.6. Again, the timing of Hurricane Katrina is given by the vertical line, but now marks a point of significant disruptions regarding local export and import trade shares across the more narrowly defined impact area spliced into four intervals of 100 miles at increasing distance from the disaster's epicenter.[31] Indeed, Figures 3.5 and 3.6 provide supporting evidence that natural disasters cause negative trade disruptions at the immediately affected ports (within 100 miles) whereas positive trade effects are encountered by ports within close proximity, within 100 to 300 miles for imports and within 200 to 500 miles for

[30] These regional definitions follow the categorization by the *U.S. Energy Information Administration*.

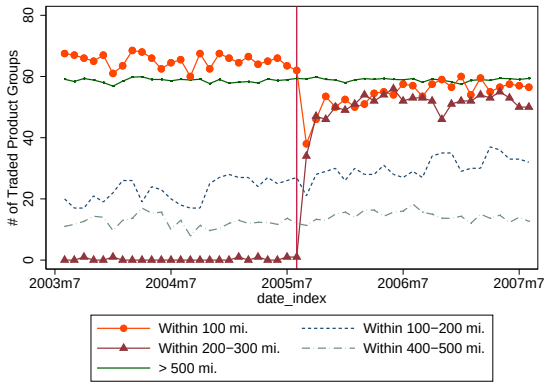
[31] According to Table 1, there are no sample ports located within the 300 to 400 miles of Hurricane Katrina and so this category is excluded. Ports within 100 miles include Gulfport and New Orleans, within 100 to 200 miles include Mobile, within 200 to 300 miles include Panama City and within 400 to 500 miles include Tampa, Port Arthur, and Galveston.

exports. Interestingly, the port-specific recovery of local trade appears much slower than indicated by regional or national comparisons. While exports seem to recover within the first two years, import trade shares exhibit more pronounced long-run positive and negative trade disruptions.

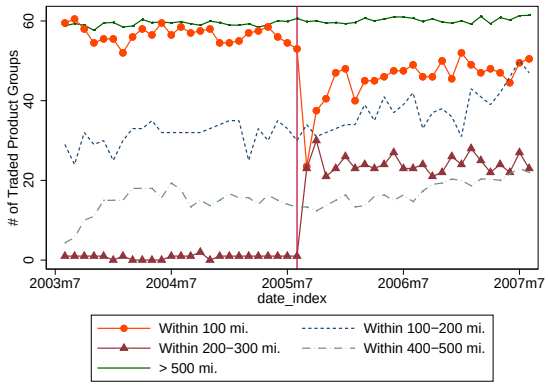
Uncovering this initial evidence concerning the static and dynamic resilience of trade raises the question of the specific mechanisms driving the prolonged recovery and persistent rerouteing of local trade. To shed some light on this issue, I also investigate the average number of two-digit HS traded product groups across ports of varying nautical distance with respect to Hurricane Katrina' epicenter. Similar to Figures 3.5 and 3.6, I bin ports in 100 mile intervals up to 500 miles from the disaster plus one additional group including all sample seaports outside of this 500 mile radius and calculate the average number of traded products for each of these distance intervals. The time plots depicted in Figures 4.1 and 4.2 reveal dramatic and long-lasting reductions in the average number of imported and exported products for ports within 100 miles of Hurricane Katrina's epicentre (Gulfport and New Orleans) that coincide with a significant and permanent increase in the number of exported and imported products for ports located 200 to 300 miles from ground zero (Panama City). Complementing the spatial heterogeneity in trade effects, ports located within 100 to 200 miles from Hurricane Katrina's second landfall reveal no visible treatment effects concerning the average number of traded products. In line with the negligible aggregate trade effects, ports at distances greater than 400 miles exhibit no change concerning their average trade composition in response to this natural disaster.

V RESULTS

In this section, I present the empirical findings based on the estimations of Equations (2) and (3). The analysis builds on the preliminary evidence established via the data summary and provides robust results detailing the dynamics of port-specific trade effects in response to Hurricane Katrina. Exploiting the spatial variation in treatment effects, I illustrate that nautical distance is a key determinant underlying the rerouteing effect on internationally traded products. The estimations



4.1: Exports



4.2: Imports

Figure 4: Local trends in the Number of Traded Products

naturally proceed from a preliminary analysis on aggregate trade to estimations of the static disruptions and dynamic treatment effects at the disaggregated port level. The analysis culminates in a heterogeneity analysis at the port-product level and dissects the resilience of trade across several broadly defined sectors. While the traditional average treatment effects serve to uncover the static resilience of U.S. trade over the first six months after the disaster (see Table 2), I estimate the month-to-month treatment effects to shed light on the dynamic resilience of trade and long-term effects of Hurricane Katrina. While the results of this dynamic analysis are presented in Figures 6.1 through 9.2, the heterogeneity analysis highlighting the disaster-induced response in the number of traded products is presented in Tables 4 and 5.

Given that the disaggregated port-level analysis necessitates the relatively novel application of spatial econometric techniques to a trade framework, I frequently test the sensitivity of my findings against more traditional estimators and alternative spatial econometric specifications. Following the trade literature, these traditional estimation techniques include a fixed effects model and the PPML estimator. In terms of alternative spatial empirical specifications, I test the sensitivity of my findings against the presence of spatial spillovers estimating the Spatial Autoregressive (SAR) and Spatial Autocorrelation (SAC) models.[32] Reassuringly, my findings are largely robust across all of

[32]While the SAR model solely accommodates spatial spillovers and ignores the potential presence of spatially correlated unobservables, the SAC model accommodates both types of spatial correlations.

these estimation techniques.[33] Inference is grounded in heteroskedasticity robust standard errors. For the spatial estimators these robust standard errors are based on Driscoll and Kraay (1998).

The preliminary aggregate trade analysis confirms some of the findings of the previous literature and produces evidence of the resilience of aggregate U.S. trade. Treating Hurricane Katrina as a uniform shock across the entire infrastructure network (see Equation (5) in the Appendix), the results, presented in Table 7 in the Appendix, suggest that the disaster caused largely insignificant disruptions in aggregate U.S. containerized exports and had mixed effects on seaport imports. The lack of significance of these average treatment effects, with exception of the SEM, SAR and SAC estimators in the import case[34], is consistent with the previous literature (Parsons 2014).

Refining the analysis, I consider the regional trade effects and differentiate the impact of Hurricane Katrina across the U.S. Gulf Coast and Lower Atlantic regions. The results, given in columns (1) through (5) of Table 8, paint a very different picture concerning the disaster-induced trade effects. Controlling for port and time fixed effects, the average response in Gulf Coast exports is found to be negative, yet statistically indistinguishable from zero, while exports facilitated through ports located in the Lower Atlantic appear to experience a significant average increase of around 50% over six month post Hurricane Katrina relative to pre-treatment levels and relative to the average change in exports experienced by ports located in all other U.S. regions. The indirect treatment effect estimates for regional exports are largely insignificant. On the import side, Hurricane Katrina appears to have caused considerable disruptions at the regional level resulting in a statistically significant reduction in average Gulf Coast imports six month after the hurricane ranging from 13% to 37% depending on the estimator. Similar to exports, all coefficient estimates, but those based

[33] A note of caution pertains to the interpretation of the resulting coefficient estimates. Unlike the OLS, PPML, SEM specifications, the SAR and SAC models produce parameter estimates that require a break down of the total impact into the direct and indirect treatment effects. Following the discussion by LeSage and Pace (2014), the direct treatment effects can be interpreted as the direct impact of Hurricane Katrina port-specific containerized trade. In contrast, the indirect effects measure the secondary response of all other ports to Hurricane Katrina's direct impact on a given port and can be seen as the feedback effect across ports arising from their spatial integration. Figures 12.1 through 15.2 in the Appendix report the dynamic direct effects of the SAC and SAR model estimations and compare those estimates to the PPML coefficients as well as the 95% confidence interval of the primary SEM estimates. In general, the PPML, SAR, and SAC estimates fall within the SEM confidence band.

[34] The point estimates of the statistically significant SEM, SAR and SAC treatment effects suggest that Hurricane Katrina caused a 8% reduction in average U.S. containerized imports over a six month period after the disaster.

on the PPML estimator, suggest a statistically significant positive treatment effect on imports of around 20% that suggests rerouting of U.S.-bound cargo shipments through ports located in the Lower Atlantic region. Lastly, Table 8 suggests that the indirect treatment effects on imports are statistically significant and lead inversely related spillover effects across port regions.

A. The static resilience of trade

Based on the previous summary of the data, the mixed aggregate and regional findings come at no surprise. Instead, these results speak to the intraregional resilience of international trade offsetting local trade reductions through immediate rerouteing of traded goods to nearby seaports with available capacity. To better understand the cross-sectional dependencies across U.S. ports and provide evidence in support of the spatial econometric model specification, I test U.S. containerized trade for cross-port spatial correlations. A test for cross-sectional dependence based on Pesaran (2015) decisively rejects the null hypothesis of weak cross-sectional dependence in favour of stronger cross-port correlations. Building on this initial evidence and following Anselin (2001), I calculate Moran's I-statistic[35] for each month of the data. The results provide overwhelming evidence in support of spatial correlations over the entire sample period for both U.S. exports and imports and warrants the use of the SEM estimator.[36] While I present the key export and import parameter estimates for ports within 500 nautical miles of Hurricane Katrina in Table 2, the remaining treatment effects for all other Gulf Coast sample ports are presented in Table 9 in the Appendix.

Overall, the estimated short-run treatment effects offer novel insights into the systematic spatial heterogeneity of the disaster-induced trade disruptions that are masked by aggregate estimations and evidence the static resilience of international trade. That is, with respect to the excluded East

[35] As shown by Anselin and Rey (1991) and Anselin and Florax (1995), Moran's test has power against any form of spatial dependence.

[36] Following suggestions by Greene (2003), the average I-statistics of 1.189 and 1.284 with average p-values of 0.00001 and $1.33\text{x}10^{-9}$ for exports and imports, respectively, strongly reject the null hypothesis of no spatial correlation present in U.S. containerized trade. For any specific month within the sample the maximum p-values are 0.0005 and $1.27\text{x}10^{-7}$ for exports and imports, respectively, indicating that the null hypothesis of no spatial correlation is indeed rejected for every sample period. Aggregating the data to yearly observations and reapplying Pesaran's and Moran's tests for cross-sectional dependence provides robust evidence consistent with the presence of spatial correlation across U.S. ports of entry and exit regardless of the time horizon under consideration.

Table 2: Port-Specific Trade Disruptions (< 500 miles from epicentre)

	OLS (1)	PPML (2)	SEM (3)	SAR (4)	SAC (5)
Panel A: ln(Exports)					
Galveston, TX	-0.071	0.448	-0.069	-0.111	-0.121
	(0.896)	(0.545)	(0.871)	(0.781)	(0.774)
Port Arthur, TX	-0.190	-0.354	-0.190	-0.175	-0.177
	(0.576)	(0.403)	(0.581)	(0.590)	(0.589)
Tampa, FL	-0.160	-0.128	-0.160*	-0.152*	-0.152*
	(0.247)	(0.244)	(0.065)	(0.081)	(0.087)
Panama City, FL	4.937***	5.598***	4.937***	4.948***	4.944***
	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)
Mobile, AL	0.183	0.269	0.183	0.183	0.181
	(0.290)	(0.104)	(0.240)	(0.204)	(0.217)
New Orleans, LA	-0.739***	-0.547***	-0.738**	-0.737**	-0.744**
	(0.006)	(0.008)	(0.036)	(0.041)	(0.037)
Gulfport, MS	-1.013***	-0.849***	-1.012***	-1.006***	-1.013***
	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)
Panel B: ln(Imports)					
Galveston, TX	-0.205	-0.397	-0.206	-0.207	-0.202
	(0.511)	(0.237)	(0.509)	(0.499)	(0.511)
Port Arthur, TX	0.417	1.993**	0.414	0.443	0.449
	(0.511)	(0.015)	(0.200)	(0.162)	(0.168)
Tampa, FL	0.014	0.046	0.014	0.012	0.012
	(0.949)	(0.826)	(0.927)	(0.937)	(0.936)
Panama City, FL	2.557***	2.290***	2.557***	2.554***	2.556***
	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)
Mobile, AL	0.384**	0.427**	0.382***	0.384***	0.383***
	(0.038)	(0.039)	(0.009)	(0.006)	(0.006)
New Orleans, LA	-1.203***	-0.926***	-1.204***	-1.211***	-1.207***
	(0.004)	(0.000)	(0.007)	(0.006)	(0.006)
Gulfport, MS	-1.161***	-0.889***	-1.161***	-1.172***	-1.168***
	(0.006)	(0.000)	(0.008)	(0.006)	(0.007)
Spatial-Weighting	-	-	Inv. Dist	Inv. Dist	Inv. Dist
Observations	480	480	480	480	480
Port FE	Yes	Yes	Yes	Yes	Yes
Time FE	Yes	Yes	Yes	Yes	Yes

Notes: P-values, reported parenthesis, are based on heteroskedasticity robust standard errors. The results presented in column (1) are based on a fixed effects model, results in column (2) are based on the PPML estimator and the results depicted in columns (3) through (5) are based on the SEM, SAR, and SAC models, for which the robust standard errors are based on Driscoll and Kraay (1998). While the direct effects are presented here, estimates of indirect trade effects for the SAR and SAC models are available upon request. Panel A depicts the aggregate disaster-induced disruptions for exports, presents the effects on imports. The coefficient estimates can be transformed to reflect percentage changes in port-level trade caused by Hurricane Katrina via the following equation: $\Delta x_{pt} = [exp(\gamma_p) - 1] * 100$, where γ_p represents the point estimates presented above. Statistical significance at the conventional levels is indicated by *** $p < 0.01$, ** $p < 0.05$, * $p < 0.1$.

Coast, West Coast, and Great Lakes' ports, the estimated short-run treatment effects tend to be statistically significant only in close proximity of the disaster's epicentre and lose significance as nautical distance increases. The ports of Gulfport and New Orleans, for example, those closest to Katrina's landfall, experience economically and statistically significant six-month average reductions in both exports and imports ranging from 42% to 70%, valued at around $160 million in exports and $323 million in imports based on pre-treatment averages. As previously discussed, these direct adverse effects on seaport trade represent a cumulative response to the direct devastation of local economic activity and destruction of critical transport infrastructure.

The spatial heterogeneity of trade effects and resulting static resilience of trade is evidenced when extending the scope just beyond the hurricane warning zone. In contrast to Gulfport and New Orleans, the port of Panama City experiences unparalleled and consistently estimated short-run increases in exports and imports in response to Hurricane Katrina. Across all estimators, statistically significant point estimates suggest a 1,200% and 13,800% average increase for imports and exports over six month post disaster that partially offsets the reductions in trade experienced at the ports of Gulfport and New Orleans. In addition, my findings point to the port of Mobile as another destination of rerouted imports, with average six month treatment effects ranging from 46.5% to 53.3% depending on the estimator. Interestingly, I find no consistent evidence of statistically significant treatment effects on ports located at greater distances from Hurricane Katrina's epicenter.

Cumulatively, these monthly export and import rerouting effects are valued at around $15 million of exports facilitated through the port of Panama City and $90 million of additional imports handled by the ports of Panama City and Mobile accounting for roughly 10% of the exports and 30% of the imports lost at the ports of New Orleans and Gulfport over the first six month after Hurricane Katrina's landfall. In the absence of shifting supply and demand patterns for internationally traded products, due to the aforementioned lack of displacement of evacuees towards these port locales, and the significant share of out-of-state trade flows handled by the ports of New Orleans and Gulport prior to Hurricane Katrina, these estimates are likely to reflect the true rerouting effect and static resilience of U.S. containerized trade against Hurricane Katrina.

B. The determinants of static resilience

In order to shed a brighter light on the role of distance in the determination of the spatial heterogeneity in the estimated short-run treatment effects, I conduct an additional analysis interacting the disaster-induced treatment effects with distance. The results offer insights for both positive and negative treatment effects alike and shed light on the potential differences in this distance-dependence of rerouteing exports and imports. To this end, I develop and estimate an alternative SEM model that incorporates an interaction term between an indicator variable for intraregional port groups affected by Hurricane Katrina and the inverse of nautical distance to Hurricane Katrina's epicenter, $f_{zt}/Dist_p$ where z=core or periphery.

For the purposes of this estimation, I utilize the same short-run sample of 40 seaports and 12 month of trade flows in order to differentiate the six month average treatment effects post Hurricane Katrina between *core* (co) and *peripheral* (pe) ports. The *core* is defined as those ports within Hurricane Katrina's warning zone, namely the ports of New Orleans, Gulfport, and Mobile (see Figure 1). Whereas the *periphery* is defined as those ports located outside of this warning zone, but within the Gulf Coast and Lower Atlantic regions. The resulting empirical specification can be expressed as follows

$$\ln(x_{pt}) = \beta_0 + \beta_{co} f_{co,t} + \beta_{co-d}\frac{f_{co,t}}{D_p} + \beta_{pe} f_{pe,t} + \beta_{pe-d}\frac{f_{pe,t}}{D_p} + a_p + a_t + \lambda W u_{pt} + \epsilon_{pt}, \quad (4)$$

where D_p indicates the respective nautical distance of core and peripheral ports with respect to Hurricane Katrina's epicenter, established in Table 1.

The resulting marginal effects are presented in Figures 5.1 through 5.4 and illustrate the transformed impact on exports and imports for core and peripheral ports over distance.[37] These can be interpreted similar to a standard DiD estimator that differentiates the average six-month change in exports and imports pre and post Hurricane Katrina relative to the average trade changes for the

[37]The conversion of the core and periphery point estimates into percentage changes in the value of trade is based on the following calculations: $\Delta\%X_{Core} = (exp(\beta_{co}) * exp(\beta_{co-d} * (1/(D_p)) - 1) * 100$ and $\Delta\%X_{Periphery} = (exp(\beta_{pe}) * exp(\beta_{pe-d} * (1/(D_p)) - 1) * 100$, respectively.

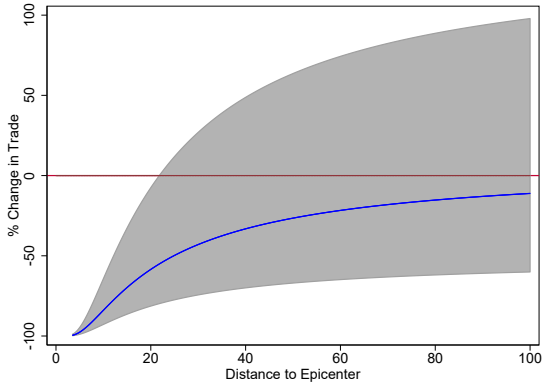
control group consisting of ports outside of the pre-defined core and peripheral areas. The interaction with distance allows us to evaluate each of these core and peripheral coefficient estimates at a given distance from Hurricane Katrina's second landfall. Standard errors are calculated via the delta method. The results reveal several key features of disaster-induced trade effects.

First, the negative trade disruptions experienced by those ports directly affected by the storm vanish exponentially as distance increases and become insignificant roughly 20 miles away from the epicenter six month after the disaster. To put this in perspective, exports handled by the port of Gulfport, 15.7 nautical miles to east, are estimated to experience a statistically significant 68% average reduction, whereas exports facilitated through the port of New Orleans, 40.4 nautical miles to the west, are estimated to experience a statistically insignificant decrease of 33%.[38] As illustrated by Figures 5.1 and 5.2, this finding is generally consistent across both exports and imports.

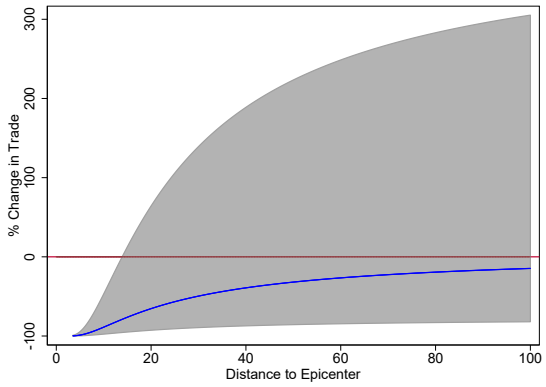
Second, the peripheral changes, depicted in Figures 5.3 and 5.4, are economically and statically significant for both exports and imports in close proximity of the disaster's epicentre. Similar to the previous estimations the relative export rerouting effect is much larger than the disaster-induced rerouting of imports, which can be traced back to small degree of pre-Hurricane exports facilitated by the port of Panama City and the considerable relative export gains post treatment. Rerouteing of traded products away from a fairly large port, like New Orleans, can result in dramatic throughput changes in smaller nearby ports, like Panama City, which is estimated to experience a statistically significant 3300% increase in exports, 237.7 miles east of Katrina's epicenter.

Third, marginal peripheral treatment effects decrease quickly with distance, but vanish faster for exports than for imports. In fact, both treatment effects, despite the initial size difference, approach zero roughly 450 miles away from the disaster epicentre. This finding provides further evidence in support of the hypothesis that rerouted exports tend to be more sensitive to additional shipping distance than imports.

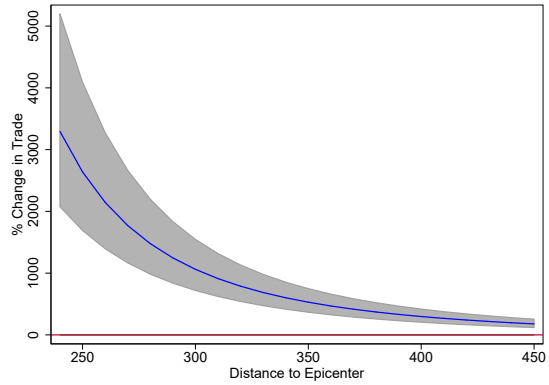
[38] Calculations are based on the point estimates obtained from the SEM model and are available upon request. The point estimates are robust against alternative spatial estimators or weight matrix specifications. Further, the general conclusions hold for the PPML estimator although there is some variation in the magnitude of the parameter estimates.



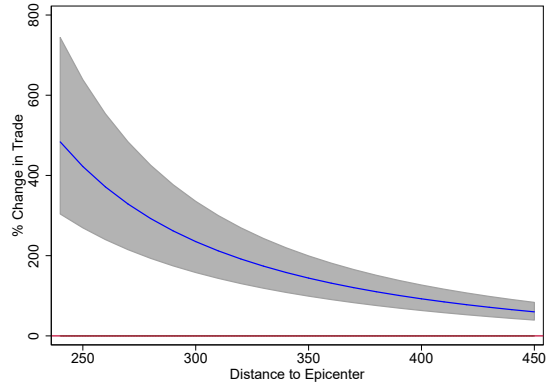
5.1: Exports - Core



5.2: Imports - Core



5.3: Exports - Periphery



5.4: Imports - Periphery

Figure 5: Direct Treatment Effects over Distance

C. Dynamic local analysis

The previous analyses address the central questions of how shippers and freight forwarders respond to the devastations in the immediate aftermath of a natural disaster, like Hurricane Katrina, and whether these short-run responses trigger the hypothesized rerouting effect and static resilience of international trade. The estimates show that the destruction of infrastructure and alterations in local patterns of supply and demand for internationally traded products cause significant reductions in seaport trade, while immediate rerouteing leads to the partial resilience against these adverse trade shocks. Further, I show that the specific port choice for rerouted cargo is not randomly determined, but instead critically hinges on distance to the disaster's epicenter. The remaining questions of interest concern the dynamic evolution of these geographically heterogeneous trade effects, the

long-run resilience of trade and whether these responses are driven by a particular set of products.

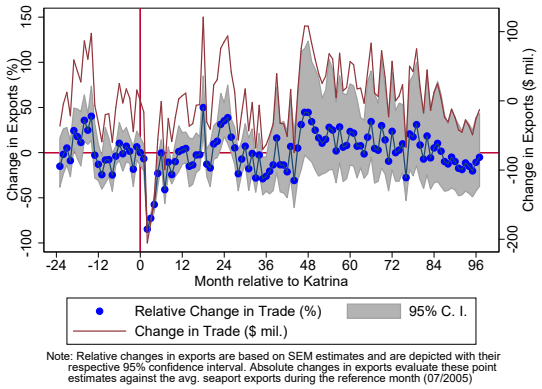
To address these questions, I estimate the empirical specification given by Equation (3) over the entire sample period of 120 month. Given the static port-specific treatment effects presented in Table 2, I focus this discussion around the ports closest to Hurricane Katrina, including Gulfport, New Orleans, Mobile and Panama City.[39] Since a tabular representation of these dynamic trade disruptions is quite convoluted, I use graphical representations of the estimated and transformed port-specific treatment effects and their respective 95% confidence intervals instead. On the left-hand y-axis of Figures 6.1 through 9.2, I display the port-specific monthly percentage change in trade relative to the baseline month, July 2005, given by the dotted line and shaded area. In addition, I evaluate these relative port-level trade changes in millions of U.S. dollars, depicted on the righ-hand y-axis and represented via the line plot depicted in Figures 6.1 through 9.2.

Since we expect U.S. port-level trade to adjust in the immediate aftermath of Hurricane Katrina in August 2005, the vertical line indicates the reference month, July 2005, prior to the disaster's landfall. Given the empirical specification, each point on the graph can be thought of as a DiD estimator. That is, each point estimate post treatment reflects a month-port-specific treatment effect evaluated against trade during the reference month and relative to the average change in trade across the excluded ports. The flexibility of this specification has several advantages. First, it allows us to scrutinize the parallel path assumption critical to the DiD estimator and investigate the deviation in pre-treatment trends that would confound the treatment effect analysis. Second, it allows us to conduct a pre-treatment analysis that serves as a type of placebo test against the actual treatment. Lastly, this flexible specification provides the opportunity to clearly evaluate the persistence of the disaster-induced trade effects and facilitates dynamic cross-port comparisons.[40]

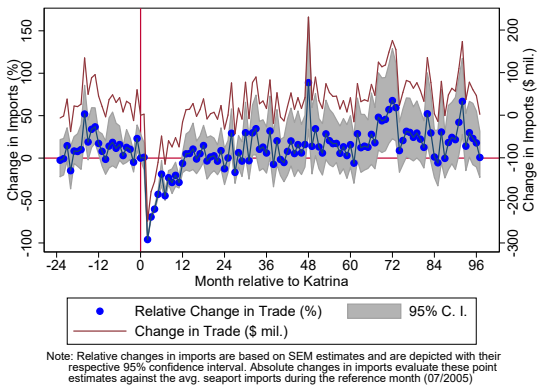
Figures 6.1 through 7.2, for example, display tremendous short-run trade disruptions experi-

[39] As part of the robustness analysis, I also provide the dynamic treatment effects for ports at greater distances, such as Port Arthur and Tampa in Figures 10.1 through 11.2 in the Appendix. The findings for these ports indicate no systematically significant treatment effects resulting from Hurricane Katrina. Moreover, my findings are robust to the expansion or reduction of the treatment group.

[40] The presented trade effects are based on the SEM model and are robust to the use of various weight matrix specifications as well as alternative spatial econometric specifications, such as the SAR or SAC models, or the more commonly used PPML estimator. I present the highly consistent dynamic treatment effect estimates obtained via these alternative estimators in relation to the estimated SEM parameter range in Figures 12.1 through 15.2 in the Appendix.

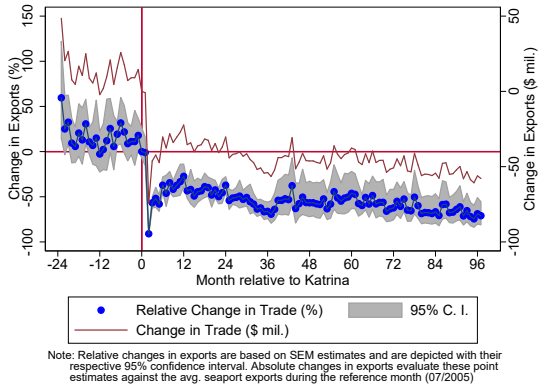


6.1: Exports

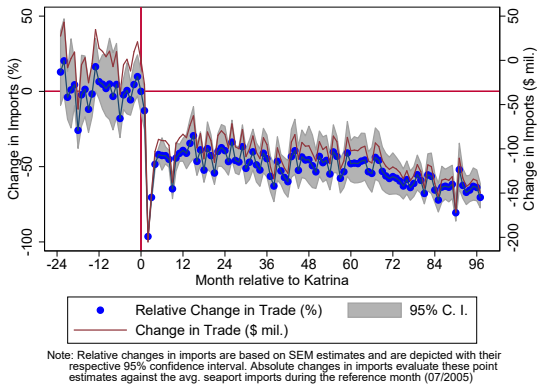


6.2: Import

Figure 6: Dynamic Treatment Effects - New Orleans, LA



7.1: Exports

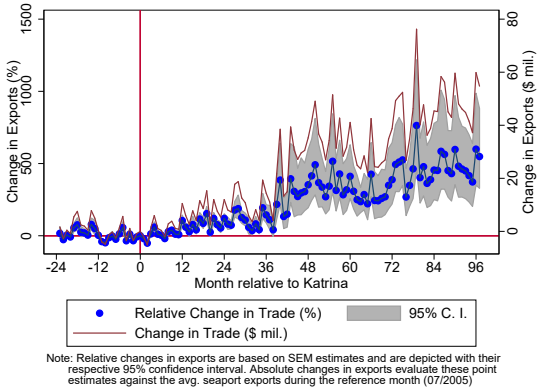


7.2: Imports

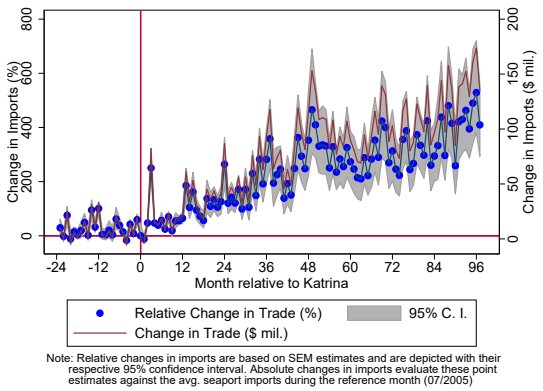
Figure 7: Dynamic Treatment Effects - Gulfport, MS

enced at the ports of New Orleans and Gulfport, but also reveal that the duration and magnitude of these disruptions vary across imports and exports as well as across the individual ports. For both ports, imports suffer a larger short-run reduction ($200-$300 million) than exports ($100-$200 million) one month after Katrina's landfall. This finding supports the previous conclusions and strengthens the claim that imports facilitated by container vessels are more easily rerouted than exports transported by train, truck or inland waterways. This is particularly true for the port of New Orleans, which is strategically located at the mouth of the Mississippi River and one of the main facilitator of bulk exports that have few transportation substitutes to the inland waterways.

While these short-run export and import comparisons are similar for both ports, a long-run

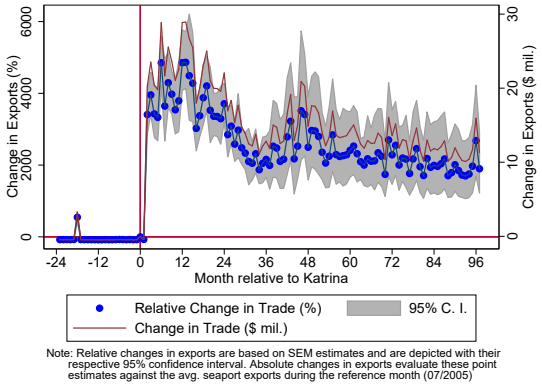


8.1: Exports

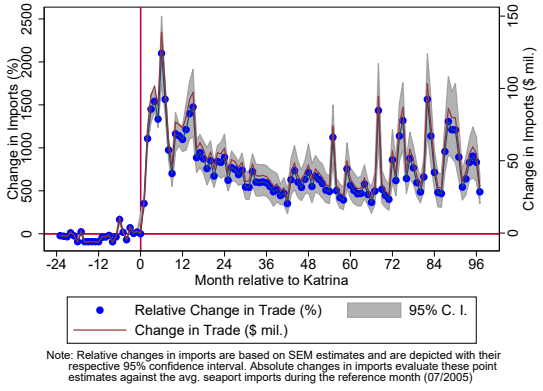


8.2: Imports

Figure 8: Dynamic Treatment Effects - Mobile, AL



9.1: Exports



9.2: Imports

Figure 9: Dynamic Treatment Effects - Panama City, FL

cross-port contrast reveals stark differences in terms of recovery. In fact, while exports and imports handled by the port of New Orleans experience a rapid recovery over the first six to twelve month post treatment, depicted in Figures 6.1 and 6.2, Gulfport's merely partial recovery of exports and imports is much more prolonged, as shown by Figures 7.1 and 7.2. These negative long-run effects are highly significant over the entire sample period and suggest that Gulfport continues to suffer trade reductions of around 50% to 70%, valued at around $50 million in monthly exports and $150 million in monthly imports, eight years after the disaster. This novel finding complements the case study by Grenzeback and Lukman (2008), who document the considerable damages experienced by this port and the 11 year reconstruction period noted by Bonney (2016).

While the evidenced recovery of New Orleans port-level trade flows represents the first channel of U.S. trade resilience, Gulfport's misfortune allows for the second mechanism of rerouting to contribute to the dynamic resilience of U.S. containerized trade. Permanent rerouteing away from the severely damaged infrastructure of the port of Gulfport is evidenced when expanding the spatial scope of the analysis to the ports of Mobile, AL and Panama City, FL. Both of these ports are just outside of the disaster-stricken region and, as the previous static port-specific analysis suggests, are the primary candidates for the evaluation of persistent alterations in carrier port choice. The results for both of these ports are presented in Figures 8.1 through 9.2 and illustrate significant short-run as well as long-run disruptions across both exports and imports. Treatment effects on exports, for example, suggest a slight one to two month reduction relative to July 2005, whereas the import trade effects at both ports are estimated to be positive and economically significant in the first two month following treatment. Despite this cross-port similarity in the immediate responses to Hurricane Katrina, the treatment effect estimates diverge across the two ports thereafter.

The trade effects at the port of Mobile, for example, start to revert towards pre-treatment levels three month after the disaster, before experiencing positive growth roughly three quarters post treatment; a finding that matches the time frame of restoration of some of the surrounding infrastructure vital to the port of Mobile (Grenzeback and Lukman 2008). Over the entire sample period, this disaster-induced growth in trade leads to economically and statistically significant trade effects suggesting a 550% increase exports and 400% increase in imports, respectively valued at $30 million and $100 million per month, eight years after Hurricane Katrina.

In contrast to the gradual changes in trade handled by the port of Mobile, exports and imports facilitated through the port of Panama City, depicted by Figures 9.1 and 9.2, experience immediate and unparalleled increases in response to Hurricane Katrina that are statistically significant at any conventional significance level and very persistent in the long-run. Panama City's exports, for example increase by 3,400% in September, 2005 relative to July, 2005 and reflect an economically and statistically significant export effect of around 2,000% at the end of the sample period. Imports rise by 1,100% in September of 2005 and continue to experience a persistent 490% increase relative

to July 2005 eight years post treatment. Given trade during July 2005, these relative changes translate into roughly $12 million of rerouted exports and $50 million of rerouted imports per month eight years after the disaster struck. Cumulatively, these long-run rerouting effects at the ports of Mobile and Panama City account for roughly $42 million in exports and $150 million in imports per month, which closely match the persistent losses experienced at the port of Gulfport and explain the negligible aggregate trade effects estimated by Parsons (2014).

Based on these estimated treatment effects across the ports of Gulfport, New Orleans, Mobile and Panama City, one can conclude that the static resilience of international trade is mainly driven by rerouted exports and imports through the port of Panama City, but only partial in nature. The dynamic, long-run resilience of international trade in response to Hurricane Katrina, however, is much more complete and primarily driven by the rapid recovery of the port of New Orleans and the persistent rerouting effects on exports and imports at the ports of Mobile and Panama City that offset the permanent trade reductions experienced by the port of Gulfport.

In contrast to these consistent and considerable short-run and long-run trade effects displayed by the ports of Gulfport, New Orleans, Mobile and Panama City, ports located at greater distances display largely insignificant responses to Hurricane Katrina. In fact, Figures 10.1 through 11.2 in the Appendix provide no evidence of any short-term or long-term responses in exports or imports that are distinguishable from pre-hurricane variation or can be directly linked to Hurricane Katrina. In summary, these findings suggest that albeit significant disaster-induced reductions in trade for those ports closest to the epicenter, a transport network similar to that of the U.S. can help offset the majority of trade reductions caused by a natural disaster, such as Hurricane Katrina, within a small geographic region.

D. Disaggregated analysis

Finally, I attempt to gain a better understanding of the underlying forces driving these dynamic disruptions in the value of containerized trade. I redirect the focus of the analysis towards the effects at an even more disaggregated port-product level and consider the effects of Hurricane

Katrina on the number of products facilitated by a given port. To this end, I re-estimate Equation (2) replacing the original dependent variable with the number of two-digit HS products handled by a given port. I estimate the resulting model over three distinct time horizons and obtain port-specific treatment effects over the short run (3 month), medium run (24 month) and long run (96 month) post Hurricane Katrina on the average number of traded products. Combined, these estimates provide insights into the specific industries driving the static and dynamic resilience of international trade. Similar to the dynamic analysis, the results reported here focus on the trade effects experienced by the primary ports of interest, including Gulfport, New Orleans, Mobile and Panama City, and are summarized in Tables 4 and 5 for exports and imports, respectively.[41]

The number of traded products for a given port-month pair is based on the 2 digit HS classification that consolidates individually traded products into 98 product groups. While column (1) of Tables 4 and 5 provides the treatment effects of Hurricane Katrina on the total number of traded products, columns (2) through (8) depict these trade effects for seven slightly more disaggregated product categories. The consolidation of the original 98 product groups into these seven product categories is based on sections and individual product group definitions obtained from Schedule B reported by the *U.S. Census Bureau*.[42] A legend providing the necessary details for each of these product categories is presented in Panel A of Table 3, while Panel B presents the port-specific average pre-treatment export and import shares of each product category. Across all four ports, exports are highly concentrated in one or two of the seven product categories. While New Orleans and Gulfport specialize in exports of categories three and five, respectively, the ports of Mobile and Panama City primarily facilitate exports of category four. In terms of imports, Gulfport and Panama City are similarly concentrated in shipments of product categories five and six respectively. In contrast, the ports of New Orleans and Mobile facilitate a more balanced portfolio of imported products prior to Hurricane Katrina.

[41]The remaining short-run to long-run port-specific treatment effects for Gulf Coast ports located at greater distances have been estimated and the results are available upon request. As expected, the majority of these treatment effects for more remote ports exhibit a significant degree of variation in the number of traded products, but depict no discernible patterns concerning the impact of Hurricane Katrina relative to the primary ports under consideration.

[42]Schedule B is the official U.S. schedule of commodity classifications used by shippers to report export shipments.

Table 3: Product Category Legend Key and Trade Shares

Panel A: Legend Key

Product Category	# of Products	Sections included	Type of Products
1	15	1-3	Animal and Vegetable Products
2	9	4	Prepared Food Stuffs, Beverages, Spirits, Tobacco, etc.
3	16	5-7	Mineral, Chemical, Rubber and Plastic Products
4	9	8-10	Wood and Paper and products thereof, Leather, etc.
5	18	11, 12	Textiles, Footwear, Umbrellas, etc.
6	15	13-15	Bulk products including Stone, Plaster and Base Metals
7	14	16-19, 21	Work of Art, Manufactured products (i.e. Vehicles, etc.)

Panel B: Trade Shares

Product	New Orleans		Gulfport		Mobile		Panama City	
Category	Exports	Imports	Exports	Imports	Exports	Imports	Exports	Imports
1	0.023	0.142	0.024	0.086	0.060	0.009	0.000	0.002
2	0.020	0.053	0.011	0.001	0.003	0.172	0.002	0.000
3	0.681	0.248	0.091	0.013	0.283	0.245	0.000	0.032
4	0.054	0.033	0.086	0.012	0.426	0.224	0.986	0.000
5	0.066	0.209	0.666	0.824	0.059	0.002	0.000	0.000
6	0.028	0.111	0.008	0.005	0.013	0.107	0.000	0.966
7	0.125	0.200	0.111	0.051	0.133	0.240	0.012	0.000

Sources: Categorization is based Schedule B published by the *U.S. Census Bureau*. Trade data are sourced from the U.S. Census Bureau USA Trade database.

Notes: The pre-treatment product category shares are calculated based on port-specific containerized trade in 2003 and 2004. Excluded product groups include special classification provisions

Parameter estimates concerning the port-specific effects on the total number of traded products, presented in column (1) of Tables 4 and 5, reflect the expected patterns. In the short run, the ports of New Orleans and Gulfport experience economically and statistically significant reductions in the number of exported and imported products ranging from 12 to 28 lost product groups. In the case of New Orleans, however, these large initial reductions in the portfolio of traded products partially revert back towards pre-treatment levels. Averaged over eight years after Hurricane Katrina, the estimated treatment effects for New Orleans, for example, result in statistically significant reductions of only eight traded product groups, while Gulfport continues to suffer reductions around ten to 11 exported and imported product groups. In combination with the previously established

insignificant long-run impact on the value of containerized trade handled by the port of New Orleans, these new insights are important because they suggest a consolidation in the composition of trade in the aftermath of natural disasters. The value of trade recovers, but not for all products.

Considering the adjacent ports, the estimated treatment effects on the aggregate number of traded products provide further supporting evidence of the static and dynamic resilience of trade. In the short run, the port of Panama City experiences substantial increases in the number of imported and exported products ranging from 24 to 41, respectively, while the port of Mobile exhibits no statistically significant impact across exports or imports. Expanding the time horizon under consideration emphasizes the expected persistence of the positive gains in the portfolio of products handled by the port of Panama City. Over the first eight years after Hurricane Katrina, the number of imported products reflects a persistent increase of 24, while exports diversify to as many as 54 newly handled product groups. Similarly, the considerable trade growth experienced by the port of Mobile is also reflected in the number of exported and imported products, which respectively increase by 11 and 15 product groups over eight years after the disaster.

At the disaggregated level, the port of New Orleans experiences relatively consistent treatment effects, where all but one product category experience statistically significant short-run reductions. In terms of the coefficient magnitude, however, we observe a very heterogeneous response concerning the number of exported products that is driven by decreases in Categories 1 and 5, rather than category 3, which New Orleans main type of export. This heterogeneity in treatment effects continues to persist for the number of exported products in the medium to long run and also manifests itself for the number of imported products. While the number of traded products recovers over time for the majority of product categories handled by the port of New Orleans, the remaining negative aggregate treatment effect is almost exclusively driven by permanent reductions in the trade of *Animal and Vegetable products* and *Textiles, Footwear, and Umbrellas, etc.*, shown in columns (2) and (6) of Tables 4 and 5.

In contrast to New Orleans, the short-run effects for the port of Gulfport are fairly evenly spread across all imported and exported categories. While this relatively even distribution of treatment ef-

Table 4: Port-specific Treatment Effects on the Number of Exported Products

Ports	Total (1)	Category 1 (2)	Category 2 (3)	Category 3 (4)	Category 4 (5)	Category 5 (6)	Category 6 (7)	Category 7 (8)
Short Run								
Panama City, FL	41.772***	1.032***	3.385***	8.774***	4.514***	10.588***	5.308***	7.411***
	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)
Mobile, AL	0.106	0.033	-0.282***	0.773***	0.181**	0.252	-1.025***	0.411***
	(0.810)	(0.858)	(0.002)	(0.000)	(0.047)	(0.120)	(0.000)	(0.009)
New Orleans, LA	-16.561***	-3.634***	0.051	-1.560***	-1.153***	-6.081***	-2.692***	-1.589***
	(0.000)	(0.000)	(0.562)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)
Gulfport, MS	-19.228***	-0.967***	-2.949***	-2.893***	-2.486***	-1.081***	-4.692***	-4.256***
	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)
Medium Run								
Panama City, FL	50.720***	2.188***	4.896***	11.252***	4.567***	11.079***	7.042***	9.293***
	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)
Mobile, AL	7.644***	-0.617***	0.281**	2.243***	0.441***	1.418***	2.152***	2.464***
	(0.000)	(0.005)	(0.019)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)
New Orleans, LA	-11.480***	-2.332***	-0.592***	-1.120***	-1.131***	-4.275***	-0.946***	-1.019***
	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)
Gulfport, MS	-9.905***	-1.432***	-1.126***	-1.136***	-1.259***	-0.495*	-2.291***	-2.059***
	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.056)	(0.000)	(0.000)
Long Run								
Panama City, FL	54.091***	3.531***	5.020***	11.859***	5.288***	11.269***	8.116***	8.781***
	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)
Mobile, AL	11.325***	1.122***	2.082***	2.455***	0.223	1.671***	2.466***	1.817***
	(0.000)	(0.000)	(0.000)	(0.000)	(0.149)	(0.000)	(0.000)	(0.000)
New Orleans, LA	-8.021***	-1.968***	-0.062	-0.481*	-0.942***	-3.262***	-0.487*	-0.812***
	(0.000)	(0.000)	(0.745)	(0.088)	(0.000)	(0.000)	(0.065)	(0.000)
Gulfport, MS	-10.654***	-1.443***	0.123	-1.175***	-1.445***	-1.544***	-2.384***	-2.758***
	(0.000)	(0.000)	(0.518)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)
Port FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Time FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Spatial-Weighting	Inv. Dist	Inv. Dist	Inv. Dist	Inv. Dist	Inv. Dist	Inv. Dist	Inv. Dist	Inv. Dist

Notes: P-values, reported parenthesis, are based on heteroskedasticity robust standard errors. The presented results are based on the SEM estimator. Definitions of each product categories are provided in Table 3. In the short run, estimates are based on 240 observations, whereas medium-run and long-run estimates are based on 1960 and 4840 observations, respectively. Statistical significance at the conventional levels is indicated by *** $p < 0.01$, ** $p < 0.05$, * $p < 0.1$.

fects persists in the medium to long run for the number of exported products facilitated through Gulfport, the distribution of the trade disruptions becomes rather bimodal for the number of imported products. In particular, the estimates suggest that the sustained reduction in the number of imported products and incomplete overall long-term recovery appears to be mainly driven by the lack of imported *Animal and Vegetable product*, *Textiles, Footwear, Umbrellas, etc.* and *Bulk Products*, the first two of which make up over 90% of pre-treatment Gulfport imports.

Turning the attention towards the positively affected ports of Panama City and Mobile, the estimated product-specific treatment effects suggest rather heterogeneous responses across industries. For Panama City, for example, all exported product categories reveal statistically significant increases, but a large degree of volatility in the estimated coefficient magnitudes. Over the sample period, aggregate increases in the total number of exported products are predominantly driven by changes in categories 3 (*Mineral products, etc.*) and 5 (*Textiles*), neither of which were exported through the port of Panama City prior to the landfall of Hurricane Katrina. In contrast, *Animal and Vegetable Products* constitute a disproportionately small contributor to the increase in exported products. A similar pattern emerges on the import side. Increases in the number of imported *Textiles* dominate the average changes of the product portfolio across all time horizons under consideration. Since textile and footwear products were the main export and import commodities for the adversely affected port of Gulfport, but not part of the product mix handled by the port of Panama City prior to Hurricane Katrina, these particular compositional changes provide strong evidence in support of the hypothesized rerouting effects.

Similar observations can be made for the port of Mobile in the medium to long run. I find that *Textiles* are the main factor underlying Mobile's disaster-induced import growth and the most prominent contributor to the changes in the local trade composition. In contrast, exported and imported *Live Animal and Vegetable Products*, *Wood and Paper and products thereof*, as well as imported *Minerals, Chemicals, Rubber and Plastics* tend to defy this growth at the port of Mobile.

Overall, these results provide considerable insights into the previously described trade disruptions and rerouting effects caused by Hurricane Katrina. While the static and dynamic resilience of

Table 5: Port-specific Treatment Effects on the Number of Imported Products

Ports	Total (1)	Category 1 (2)	Category 2 (3)	Category 3 (4)	Category 4 (5)	Category 5 (6)	Category 6 (7)	Category 7 (8)
Short-Run								
Panama City, FL	24.318***	2.474***	-0.115	1.189***	3.000***	9.553***	3.488***	3.708***
	(0.000)	(0.000)	(0.467)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)
Mobile, AL	0.321	-0.192	-0.115	0.189	0.333***	0.886***	0.821***	-1.292***
	(0.389)	(0.123)	(0.467)	(0.202)	(0.002)	(0.000)	(0.000)	(0.000)
New Orleans, LA	-28.013***	-4.526***	-2.115***	-5.811***	-2.333***	-5.447***	-4.512***	-3.292***
	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)
Gulfport, MS	-12.013***	-1.526***	0.551***	-1.811***	-2.000***	-3.447***	-1.846***	-1.959***
	(0.000)	(0.000)	(0.001)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)
Medium-Run								
Panama City, FL	22.455***	3.105***	1.147***	1.027***	2.471***	7.273***	3.009***	3.425***
	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)
Mobile, AL	5.935***	-0.640***	1.117***	-0.087	0.056	2.388***	1.824***	1.454***
	(0.000)	(0.000)	(0.000)	(0.463)	(0.510)	(0.000)	(0.000)	(0.000)
New Orleans, LA	-12.849***	-3.550***	-1.728***	-1.076***	-1.502***	-3.084***	-0.989***	-0.916***
	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)
Gulfport, MS	-10.930***	-2.245***	-0.331***	-1.841***	-1.362***	-2.462***	-1.758***	-0.928***
	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)
Long-Run								
Panama City, FL	24.274***	3.994***	1.830***	1.008***	2.601***	7.275***	2.109***	4.466***
	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)
Mobile, AL	14.983***	0.135	1.821***	0.530**	0.956***	5.723***	2.966***	2.786***
	(0.000)	(0.307)	(0.000)	(0.037)	(0.000)	(0.000)	(0.000)	(0.000)
New Orleans, LA	-8.071***	-2.807***	-1.305***	-0.730***	-0.633***	-1.394***	-0.337*	-0.854***
	(0.000)	(0.000)	(0.000)	(0.004)	(0.000)	(0.000)	(0.083)	(0.000)
Gulfport, MS	-11.496***	-3.304***	0.956***	-1.287***	-1.389***	-2.314***	-3.387***	-0.762***
	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.001)
Port FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Time FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Spatial-Weighting	Inv. Dist	Inv. Dist	Inv. Dist	Inv. Dist	Inv. Dist	Inv. Dist	Inv. Dist	Inv. Dist

Notes: P-values, reported parenthesis, are based on heteroskedasticity robust standard errors. The presented results are based on the SEM estimator. Definitions of each product categories are provided in Table 3. In the short run, estimates are based on 240 observations, whereas medium-run and long-run estimates are based on 1960 and 4840 observations, respectively. Statistical significance at the conventional levels is indicated by *** $p < 0.01$, ** $p < 0.05$, * $p < 0.1$.

trade is evidenced for both the value of trade and number of traded products, the product-specific contributions to these offsetting trade disruptions and overall recovery are very heterogeneous across industries. High-value containers of *Textiles and Footwear*, the primary commodities facilitated through the port of Gulfport prior to Hurricane Katrina, tend to be very resilient types of trade that are consistently rerouted, whereas containerized trade of *Live Animals and Vegetable Products* or *Minerals and Plastics* appear to be less resilient and suffer disproportionately large disruptions from natural disasters.

There are several contributing factors that may drive these insightful findings. First, origin and/or destination changes in containerized shipments of *Live Animals and Vegetable Products* are rather costly, as they require special handling and equipment. This added cost makes transportation adjustments more challenging. Second, *Minerals and Plastics* are typically bulky, low-value products that command relatively lower freight rates, particularly in comparison to shipments of *Textiles*.[43] The dependence of carrier revenue on the value of the containerized cargo could explain this preferential rerouteing behaviour. Lastly, the product mix handled by the port of Gulfport prior to Hurricane Katrina was heavily concentrated in *Textile and Footwear* products. Further analysis across more recent natural disasters may shed more light on the validity these explanations.

VI Conclusion

The increasing presence of and reliance on global value chains has led to the significant growth of international trade and its exposure to increasingly destructive natural disasters. Frequent, yet uncertain calamities continue to cause tremendous human and economic hardship, but have been largely ignored in the trade literature. In the present study, I evaluate the impacts of Hurricane Katrina on U.S. trade and find that this disaster represents a significant barrier to international trade at the local port level. In conjunction with negligible aggregate effects, the estimated dynamic and

[43]While each individual unit of textiles commands a relatively low price, the value-to-weight ratio is relatively high. As such, the value of containerized textiles can exceed $3 million per container and is, therefore, subject to higher freight rates than bulky products, such as assembled furniture, for which the container value can be as low as $20,000 (Rodrigue, Comtois, and Slack 2013).

spatially heterogeneous disruptions point to the static and dynamic resilience of international trade.

The primary mechanisms underlying this trade resiliency include the rapid recovery of the port of New Orleans and considerable rerouting of international cargo valued at nearly $200 million in exports and imports per month even eight years after the disaster. I find that this considerable rerouteing of both exports and imports offsets the significant reductions in trade handled by directly affected ports and leads to substantial gains in trade for those ports closest to the disaster-stricken region. While the port of New Orleans recovers within the first year of Katrina's landfall, trade is permanently rerouted away from the port of Gulfport and instead, handled by the ports of Panama City, FL and Mobile, AL. This novel result suggests that weather and climate extremes have lasting trade implications that are persistent over eight years after the occurrence of a disaster. While my findings provide convincing evidence that the aggregate port-level responses in exports and imports are strongly dependent on the distance between the affected and unaffected ports, port-product level analysis suggests that the resilience of containerized trade is driven by the primary and high-value containerized products, rather than bulky, low-value commodities. Overall, my findings indicate that natural disasters not only affect local economic activity and the demand for traded product, but also permanently alter the local shipping patterns and composition of international trade.

In conjunction, these empirical results illustrate the importance of a closely knit infrastructure network to mitigate aggregate repercussions resulting from natural disasters, even the ones as monumental as Hurricane Katrina. As developing countries continue to experience significant aggregate trade disruptions from natural disasters, the empirical evidence of the mitigating rerouting effects provided in this study are of considerable interest to global policy makers.

Interestingly, the empirical findings point to an east-west dichotomy concerning the significance and magnitude of the estimated trade effects resulting from Hurricane Katrina. Further inquiry may consider the role of hinterland transportation networks and other infrastructure characteristics that drive this spatially heterogeneous response and resulting resilience of containerized trade and investigate the resilience across other modes of transportation, such as air freight or dry- and break-bulk cargo.

References

Nezih Altay and Andres Ramirez. Impact of disasters on firms in different sectors: implications for supply chains. *Journal of Supply Chain Management*, 46(4):59–80, 2010.

James E Anderson and Eric van Wincoop. Gravity with gravitas: A solution to the border puzzle. *American Economic Review*, 93(1):170–192, 2003.

James E Anderson and Eric van Wincoop. Trade costs. *Journal of Economic Literature*, 42: 691–751, 2004.

Mitsuyo Ando and Fukunari Kimura. How did the japanese exports respond to two crises in the international production networks? the global financial crisis and the great east japan earthquake. *Asian Economic Journal*, 26(3):261–287, 2012.

Jorge Andrade da Silva and Lucian Cernat. Coping with loss: the impact of natural disasters on developing countries' trade flows. Technical report, Directorate General for Trade, European Commission, 2012.

Luc Anselin. Spatial econometrics. *A companion to theoretical econometrics*, 310330, 2001.

Luc Anselin and Raymond JGM Florax. Small sample properties of tests for spatial dependence in regression models: Some further results. In *New directions in spatial econometrics*, pages 21–74. Springer, 1995.

Luc Anselin and Serge Rey. Properties of tests for spatial dependence in linear regression models. *Geographical analysis*, 23(2):112–131, 1991.

BBC News. Mapping the destruction. 2005. URL `http://news.bbc.co.uk/2/shared/spl/hi/americas/05/katrina/html/evacuation.` Online; accessed 06/22/2018.

Ariel R Belasen and Solomon W Polachek. How hurricanes affect wages and employment in local labor markets. *The American Economic Review*, 98(2):49–53, 2008.

Bruce A Blonigen and Wesley W Wilson. The growth and patterns of international trade. *Maritime Policy & Management*, 40(7):618–635, 2013.

Joseph Bonney. 11 years after katrina, gulfports rebuilding is nearly complete, 2016. URL `https://www.joc.com/port-news/us-ports/gulfport/eleven-years-after-katrina`

Eduardo A Cavallo and Ilan Noy. The economics of natural disasters: a survey. 2009.

Centre for Research on Epidemiology of Disasters. The human cost of weather-related disasters 1995-2015. 2015.

Andrew D Cliff and J Keith Ord. *The problem of spatial autocorrelation*. University, 1968.

Michael L Dolfman, Solidelle Fortier Wasser, and Bruce Bergman. Effects of hurricane katrina on the new orleans economy, the. *Monthly Lab. Rev.*, 130:3, 2007.

John C Driscoll and Aart C Kraay. Consistent covariance matrix estimation with spatially dependent panel data. *Review of economics and statistics*, 80(4):549–560, 1998.

Kerry Emanuel. Increasing destructiveness of tropical cyclones over the past 30 years. *Nature*, 436 (7051):686–688, 2005.

Felix Friedt. Natural disasters, trade, and local factor prices: Labor market externalities arising from the disaster-induced diversion of trade. 2018.

John Frittelli. Hurricane katrina: Shipping disruptions. Washington, DC: Congressional Research Service, Library of Congress, RS22257, 2005.

Martin Gassebner, Alexander Keck, and Robert Teh. Shaken, not stirred: the impact of disasters on international trade. *Review of International Economics*, 18(2):351–368, 2010.

Arthur Getis. Spatial weights matrices. *Geographical Analysis*, 41(4):404–410, 2009.

William H Greene. *Econometric analysis*. Pearson Education India, 2003.

Lance R Grenzeback and Andrew T Lukman. *Case Study of the Transportation Sector's Response to and Recovery from Hurricane's Katrina and Rita*. Transportation Research Board, 2008.

Daniel A Griffith. Some guidelines for specifying the geographic weights matrix contained in spatial statistical models. *Practical handbook of spatial statistics*, pages 65–82, 1996.

Douglas Holtz-Eakin. *Macroeconomic and budgetary effects of Hurricanes Katrina and Rita*. Congressional Budget Office, 2005.

David Hummels. Toward a geography of trade costs. 2001.

James P LeSage and R Kelley Pace. *Introduction to Spatial Econometrics (Statistics, textbooks and monographs)*. CRC Press, 2009.

James P LeSage and R Kelley Pace. Interpreting spatial econometric models. In *Handbook of Regional Science*, pages 1535–1552. Springer, 2014.

Christian Volpe Martincus and Juan Blyde. Shaky roads and trembling exports: Assessing the trade effects of domestic infrastructure using a natural experiment. *Journal of International Economics*, 90(1):148–161, 2013.

Molly Fifer McIntosh. Measuring the labor market impacts of hurricane katrina migration: evidence from houston, texas. *American Economic Review*, 98(2):54–57, 2008.

Ilan Noy. The macroeconomic consequences of disasters. *Journal of Development economics*, 88 (2):221–231, 2009.

Chang Hoon Oh and Rafael Reuveny. Climatic natural disasters, political risk, and international trade. *Global Environmental Change*, 20(2):243–254, 2010.

Keith Ord. Estimation methods for models of spatial interaction. *Journal of the American Statistical Association*, 70(349):120–126, 1975.

Craig R Parsons. Disasters and trade: did hurricane katrina affect us imports? *International Economics and Economic Policy*, pages 1–18, 2014.

PEER. The impact of hurricane katrina on mississippis commercial public ports and opportunities for expansion of the ports, 2006.

M Hashem Pesaran. Testing weak cross-sectional dependence in large panels. *Econometric Reviews*, 34(6-10):1089–1117, 2015.

Jean-Paul Rodrigue, Claude Comtois, and Brian Slack. *The geography of transport systems*. Routledge, 2013.

Adam Rose. Economic resilience to natural and man-made disasters: Multidisciplinary origins and contextual dimensions. *Environmental Hazards*, 7(4):383–398, 2007.

Adam Rose and Dan Wei. Estimating the economic consequences of a port shutdown: the special role of resilience. *Economic Systems Research*, 25(2):212–232, 2013.

JMC Santos Silva and Silvana Tenreyro. The log of gravity. *The Review of Economics and statistics*, 88(4):641–658, 2006.

Eric Strobl. The economic growth impact of hurricanes: evidence from us coastal counties. *Review of Economics and Statistics*, 93(2):575–589, 2011.

Eric Strobl. The economic growth impact of natural disasters in developing countries: Evidence from hurricane strikes in the central american and caribbean regions. *Journal of Development economics*, 97(1):130–141, 2012.

Tobias Sytsma. Boon or bane? temporal and spatial dynamics in the response of port-level trade to hurricanes. *Temporal and Spatial Dynamics in the Response of Port-Level Trade to Hurricanes (November 7, 2017)*, 2017.

Tobias Sytsma. Do domestic trade frictions have global consequences? the welfare impact of hurricanes activity around us ports. *The Welfare Impact of Hurricanes Activity Around US Ports (November 27, 2018)*, 2018.

Hideki Toya and Mark Skidmore. Economic development and the impacts of natural disasters. *Economics Letters*, 94(1):20–25, 2007.

Jacob Vigdor. The economic aftermath of hurricane katrina. *The Journal of Economic Perspectives*, 22(4):135–154, 2008.

A Appendix - For On-line Publication

A.1 Port-to-Port Distances

Table 6 depicts the port-to-port nautical distances based on the charts produced by the *U.S. Department of Commerce* in collaboration with the *National Oceanic and Atmospheric Administration*

(NOAA) and the *National Ocean Service*. Because the distance between any two ports is symmetric regardless of the point of origin and destination, I only report the lower triangle of this symmetric matrix as a matter of convenience.

	Corpus Christi, TX	Freeport, TX	Galveston, TX	Houston, TX	Port Arthur, TX	New Orleans, LA	Gulfport, MS	Mobile, AL	Panama City, FL	Tampa, FL	Miami, FL
Corpus Christi	0										
Freeport	160	0									
Galveston	244	84	0								
Houston	291	131	47	0							
Port Arthur	423	263	179	132	0						
New Orleans	864	704	620	573	441	0					
Gulfport	1135	975	891	844	712	271	0				
Mobile	1233	1073	989	942	810	369	98	0			
Panama City	1426	1266	1182	1135	1003	562	291	193	0		
Tampa	1691	1531	1447	1400	1268	827	556	458	265	0	
Miami	2134	1974	1890	1843	1711	1270	999	901	708	443	0
Port Everglades	2161	2001	1917	1870	1738	1297	1026	928	735	470	27
Palm Beach	2207	2047	1963	1916	1784	1343	1072	974	781	516	73
Jacksonville	2463	2303	2219	2172	2040	1599	1328	1230	1037	772	329
Brunswick	2545	2385	2301	2254	2122	1681	1410	1312	1119	854	411
Savannah	2649	2489	2405	2358	2226	1785	1514	1416	1223	958	515
Charleston	2751	2591	2507	2460	2328	1887	1616	1518	1325	1060	617
Wilmington	2902	2742	2658	2611	2479	2038	1767	1669	1476	1211	768
Newport News	3262	3102	3018	2971	2839	2398	2127	2029	1836	1571	1128
Baltimore	3432	3272	3188	3141	3009	2568	2297	2199	2006	1741	1298
Chester	3509	3349	3265	3218	3086	2645	2374	2276	2083	1818	1375
Philadelphia	3524	3364	3280	3233	3101	2660	2389	2291	2098	1833	1390
Perth Amboy	3744	3584	3500	3453	3321	2880	2609	2511	2318	2053	1610
Newark	3759	3599	3515	3468	3336	2895	2624	2526	2333	2068	1625
New York City	3771	3611	3527	3480	3348	2907	2636	2538	2345	2080	1637
Boston	4157	3997	3913	3866	3734	3293	3022	2924	2731	2466	2023
Portland, ME	4257	4097	4013	3966	3834	3393	3122	3024	2831	2566	2123
Detroit	6146	5986	5902	5855	5723	5282	5011	4913	4720	4455	4012
Port Huron	6208	6048	5964	5917	5785	5344	5073	4975	4782	4517	4074
Chicago	6779	6619	6535	6488	6356	5915	5644	5546	5353	5088	4645

Continued on next page

Table 6: Distances between U.S. Ports of Entry

	Tacoma, WA	Seattle, WA	Portland, OR	San Francisco, CA	Richmond, CA	Oakland, CA	Port Hueneme, CA	Los Angeles, CA	Long Beach, CA	San Diego, CA
Tacoma	0									
Seattle	25	0								
Portland, OR	387	362	0							
San Francisco	1039	1014	652	0						
Richmond	1050	1025	663	11	0					
Oakland	1064	1039	677	25	14	0				
Port Hueneme	1379	1354	992	340	329	315	0			
Los Angeles	1441	1416	1054	402	391	377	62	0		
Long Beach	1444	1419	1057	405	394	380	65	3	0	
San Diego	1538	1513	1151	499	488	474	159	97	94	0
Corpus Christi	6000	5975	5613	4961	4950	4936	4621	4559	4556	4462
Freeport	6160	6135	5773	5121	5110	5096	4781	4719	4716	4622
Galveston	6244	6219	5857	5205	5194	5180	4865	4803	4800	4706
Houston	6291	6266	5904	5252	5241	5227	4912	4850	4847	4753
Port Arthur	6423	6398	6036	5384	5373	5359	5044	4982	4979	4885
New Orleans	6864	6839	6477	5825	5814	5800	5485	5423	5420	5326
Gulfport	7135	7110	6748	6096	6085	6071	5756	5694	5691	5597
Mobile	7233	7208	6846	6194	6183	6169	5854	5792	5789	5695
Panama City	7426	7401	7039	6387	6376	6362	6047	5985	5982	5888
Tampa	7691	7666	7304	6652	6641	6627	6312	6250	6247	6153
Miami	8134	8109	7747	7095	7084	7070	6755	6693	6690	6596
Port Everglades	8161	8136	7774	7122	7111	7097	6782	6720	6717	6623
Palm Beach	8207	8182	7820	7168	7157	7143	6828	6766	6763	6669
Jacksonville	8463	8438	8076	7424	7413	7399	7084	7022	7019	6925
Brunswick	8545	8520	8158	7506	7495	7481	7166	7104	7101	7007
Savannah	8649	8624	8262	7610	7599	7585	7270	7208	7205	7111
Charleston	8751	8726	8364	7712	7701	7687	7372	7310	7307	7213
Wilmington	8902	8877	8515	7863	7852	7838	7523	7461	7458	7364
Newport News	9262	9237	8875	8223	8212	8198	7883	7821	7818	7724
Baltimore	9432	9407	9045	8393	8382	8368	8053	7991	7988	7894
Chester	9509	9484	9122	8470	8459	8445	8130	8068	8065	7971
Philadelphia	9524	9499	9137	8485	8474	8460	8145	8083	8080	7986
Perth Amboy	9744	9719	9357	8705	8694	8680	8365	8303	8300	8206
Newark	9759	9734	9372	8720	8709	8695	8380	8318	8315	8221
New York City	9771	9746	9384	8732	8721	8707	8392	8330	8327	8233
Boston	10157	10132	9770	9118	9107	9093	8778	8716	8713	8619
Portland, ME	10257	10232	9870	9218	9207	9193	8878	8816	8813	8719
Detroit	12146	12121	11759	11107	11096	11082	10767	10705	10702	10608
Port Huron	12208	12183	11821	11169	11158	11144	10829	10767	10764	10670
Chicago	12779	12754	12392	11740	11729	11715	11400	11338	11335	11241

Continued on next page

	Port Everglades, FL	Palm Beach, FL	Jacksonville, FL	Brunswick, GA	Savannah, GA	Charleston, SC	Wilmington, NC	Newport News, VA	Baltimore, MD	Chester, PA	Philadelphia, PA
Port Everglades	0										
Palm Beach	46	0									
Jacksonville	302	256	0								
Brunswick	384	338	82	0							
Savannah	488	442	186	104	0						
Charleston	590	544	288	206	102	0					
Wilmington	741	695	439	357	253	151	0				
Newport News	1101	1055	799	717	613	511	360	0			
Baltimore	1271	1225	969	887	783	681	530	170	0		
Chester	1348	1302	1046	964	860	758	607	247	77	0	
Philadelphia	1363	1317	1061	979	875	773	622	262	92	15	0
Perth Amboy	1583	1537	1281	1199	1095	993	842	482	312	235	220
Newark	1598	1552	1296	1214	1110	1008	857	497	327	250	235
New York City	1610	1564	1308	1226	1122	1020	869	509	339	262	247
Boston	1996	1950	1694	1612	1508	1406	1255	895	725	648	633
Portland, ME	2096	2050	1794	1712	1608	1506	1355	995	825	748	733
Detroit	3985	3939	3683	3601	3497	3395	3244	2884	2714	2637	2622
Port Huron	4047	4001	3745	3663	3559	3457	3306	2946	2776	2699	2684
Chicago	4618	4572	4316	4234	4130	4028	3877	3517	3347	3270	3255

	Perth Amboy, NJ	Newark, NJ	New York City, NY	Boston, MA	Portland, ME	Detroit, MI	Port Huron, MI	Chicago, IL
Perth Amboy	0							
Newark	15	0						
New York City	27	12	0					
Boston	413	398	386	0				
Portland, ME	513	498	486	100	0			
Detroit	2402	2387	2375	1989	1889	0		
Port Huron	2464	2449	2437	2051	1951	62	0	
Chicago	3035	3020	3008	2622	2522	633	571	0

Source: *Department of Commerce, NOAA & National Ocean Service*

A.2 Aggregate Results

The preliminary analysis involves estimations of Hurricane Katrina's average treatment effects on aggregate and regional U.S. trade over two years after the disaster's landfall. To this end, the estimations are based on two modified versions of Equation (2). To investigate the aggregate effect of Hurricane Katrina, port-specific disaster indicators, f_{pt}, are replaced with a national disaster shock, f_t, that represents a dummy variable turning equal to one for the months of August, 2005 and six months thereafter. The resulting empirical equation is given by

$$\ln(x_{pt}) = \beta_0 + \beta_1 tr + \beta_2 f_t + a_p + \lambda W u_{pt} + \epsilon_{pt}, \tag{5}$$

and prohibits the use of time fixed effects in order to identify the aggregate impact of Hurricane Katrina. However, to crudely control for the growth of U.S. trade over the one year sample period, I incorporate a time trend, tr, instead.

The results, presented in Table 7, generally indicate the expected insignificant impact of Hurricane Katrina on U.S. trade. While the findings on exports tend to render positive but statistically insignificant point estimates, the treatment effects on imports suggest a negative adjustment in response to the disaster that is statistically significant at the 5% level for the SEM, SAR and SAC models. OLS and PPML results for imports are statistically insignificant at any conventional level. The significant import estimates suggest a 8% reduction in average seaport imports six month after Hurricane Katrina relative to the six month pre-treatment average. The estimated indirect effects of Hurricane Katrina suggest inversely related port-to-port spillovers originating from the directly affected ports that trigger negligible and insignificant feedback effects in aggregate trade across the connected infrastructure network.

For the purposes of the regional analysis, I slightly augment the empirical specification given by Equation (5) and integrate regionally varying disaster indicators, instead of a national trade shock. Specifically, I differentiate the average treatment effects across the U.S. Gulf Coast (GC) and Lower Atlantic (LA) regions as defined by the Energy Information Administration and estimate the regional trade shocks in reference to all other U.S. coastal and great lakes' regions. The resulting empirical model is given by

$$\ln(x_{pt}) = \beta_0 + \beta_1 f_{GC,t} + \beta_2 f_{LA,t} + a_p + a_t + \lambda W u_{pt} + \epsilon_{pt}, \tag{6}$$

and replaces the previously incorporated time trend with the more flexible and preferred time fixed effects. Differentiating across two or more regions avoids the issue of perfect multicollinearity between the disaster indicator and national time fixed effects and allows for their joint estimation.

The results, given in columns (1) through (5) of Table 8, paint a very different picture concerning the disaster-induced trade effects. Controlling for port and time fixed effects, the average response in Gulf Coast exports is found to be negative, yet statistically indistinguishable from zero, while exports facilitated through ports located in the Lower Atlantic appear to experience a significant average increase of around 50% over six month post Hurricane Katrina relative to pre-treatment levels and relative to the average change in exports experienced by ports located in all other U.S. regions. The indirect treatment effect estimates for regional exports are largely insignificant.

On the import side, however, Hurricane Katrina appears to have caused considerable disruptions at the regional level resulting in a statistically significant reduction in average Gulf Coast im-

Table 7: Aggregate U.S. Trade Effects in Response to Hurricane Katrina

VARIABLES	(1) OLS	(2) PPML	(3) SEM	(4) SAR	(5) SAC
Panel A: ln(Exports)					
Direct ATE	0.032	-0.034	0.031	0.028	0.028
	(0.780)	(0.187)	(0.660)	(0.702)	(0.705)
Indirect ATE				-0.001	-0.0001
				(0.598)	(0.573)
Panel B: ln(Imports)					
Direct ATE	-0.084	-0.004	-0.083**	-0.086**	-0.086**
	(0.356)	(0.923)	(0.041)	(0.037)	(0.039)
Indirect ATE				0.001	0.001
				(0.436)	(0.345)
Trend	Yes	Yes	Yes	Yes	Yes
Port FE	Yes	Yes	Yes	Yes	Yes
Spatial Weight	-	-	Inv. Dist.	Inv. Dist.	Inv. Dist.

Notes: P-values, reported parenthesis, are based on heteroskedasticity robust standard errors. The results presented in column (1) are based on an OLS regression, whereas the findings reported in column (2) are based on the PPML estimator. The results depicted in columns (3) through (5) are based on the SEM, SAR, and SAC models, for which the robust standard errors are based on Driscoll and Kraay (1998). For the latter two, I present the direct and indirect trade effect estimates of Hurricane Katrina. Panel A depicts the aggregate disaster-induced disruptions for exports, whereas Panel B presents these findings for U.S. imports. The coefficient estimates can be transformed to reflect the average six month percentage changes in port-level trade post Hurricane Katrina. The transformation is based on the following equation: $\Delta x_{pt} = [exp(\gamma_p) - 1] * 100$, where γ_p represents the point estimates presented above. Statistical significance at the conventional levels is indicated by *** $p < 0.01$, ** $p < 0.05$, * $p < 0.1$.

ports six month after the hurricane ranging from 13% to 37% depending on the estimator. Similar to exports, all coefficient estimates, but those based on the PPML estimator, suggest a statistically significant positive treatment effect on imports facilitated through ports located in the Lower Atlantic region of around 20%. Lastly, Table 8 suggests that the indirect treatment effects on imports, based on the SAR and SAC estimators, are all statistically significant and indicate inversely-related spillover effects across port regions.

A.3 Disaggregated Static Results

Table 9 presents the static short-run trade deviations for Gulf Coast ports at a distance greater than 500 miles from Hurricane Katrina's epicenter. The results indicate that the estimated export and import treatment effects averaged over six month after Hurricane Katrina's landfall are largely insignificant across these ports. Exceptions are given by the port of Everglades, Freeport, Palm

Table 8: Regional U.S. Trade Effects in Response to Hurricane Katrina

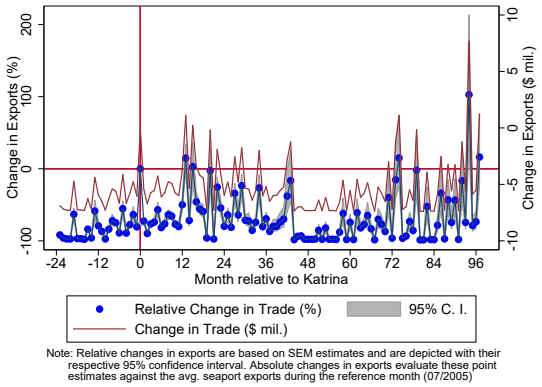
VARIABLES	(1) OLS	(2) PPML	(3) SEM	(4) SAR	(5) SAC
Panel A: ln(Exports)					
Gulf Coast (Direct)	-0.042	-0.064	-0.040	-0.035	-0.033
	(0.793)	(0.185)	(0.858)	(0.887)	(0.885)
Gulf Coast (Indirect)				-0.001	-0.001
				(0.793)	(0.758)
Lower Atlantic (Direct)	0.450***	0.026	0.455***	0.449***	0.453***
	(0.003)	(0.185)	(0.000)	(0.000)	(0.000)
Lower Atlantic (Indirect)				-0.007*	-0.006
				(0.088)	(0.142)
Panel B: ln(Imports)					
Gulf Coast (Direct)	-0.309**	-0.133**	-0.315**	-0.308**	-0.311**
	(0.039)	(0.028)	(0.021)	(0.027)	(0.027)
Gulf Coast (Indirect)				0.006**	0.003*
				(0.0.019)	(0.052)
Lower Atlantic (Direct)	0.205**	0.016	0.209***	0.204***	0.207***
	(0.021)	(0.475)	(0.000)	(0.000)	(0.000)
Lower Atlantic (Indirect)				-0.004***	-0.002***
				(0.000)	(0.002)
Port FE	Yes	Yes	Yes	Yes	Yes
Time FE	Yes	Yes	Yes	Yes	Yes
Spatial Weight	No	No	Inv. Dist.	Inv. Dist.	Inv. Dist.

Notes: P-values, reported parenthesis, are based on heteroskedasticity robust standard errors. The results presented in column (1) are based on an OLS regression, whereas the findings reported in column (2) are based on the PPML estimator. The results depicted in columns (3) through (5) are based on the SEM, SAR, and SAC models, for which the robust standard errors are based on Driscoll and Kraay (1998). For the latter two, I present the direct and indirect trade effect estimates of Hurricane Katrina. Panel A depicts the aggregate disaster-induced disruptions for exports, whereas Panel B presents these findings for U.S. imports. The coefficient estimates can be transformed to reflect the average six month percentage changes in port-level trade post Hurricane Katrina. The transformation is based on the following equation: $\Delta x_{pt} = [exp(\gamma_p) - 1]*100$, where γ_p represents the point estimates presented above. Statistical significance at the conventional levels is indicated by *** $p < 0.01$, ** $p < 0.05$, * $p < 0.1$.

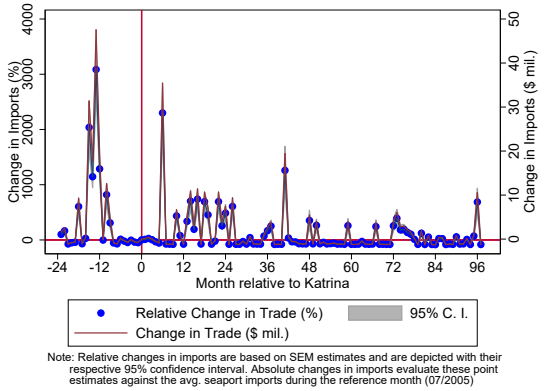
Beach. Based on the estimates I find that the port of Everglades experiences a statistically significant increase of around 10% or $20 million when evaluated at the pre-treatment average. In contrast, I find that the ports of Palm Beach and Freeport exhibit significant reductions in imports relative to pre-Katrina levels. While these estimates are relatively consistent across estimators, there is little anecdotal evidence to directly link these trade change to the implications of Hurricane Katrina. In fact, the dynamic analysis of these ports suggest rather erratic export and import volatilities that cannot be attributed to the disaster, but are subject to alternative unobserved factors.

A.4 Disaggregated Dynamic Results

Figures 10.1 and 10.2 illustrate the month-to-month deviations in trade for Port Arthur. While these deviations are highly significant due to the large degree of trade volatility the graphs clearly indicate not particular influence of Hurricane Katrina. Similarly, Figures 11.1 and 11.2 suggest that trade through the port of Tampa, FL was not affected by the landfall of Hurricane Katrina. Only imports handled by this port indicate a systematic level change around 15 month after the disaster and is therefore not directly attributable to the storm.



10.1: Exports



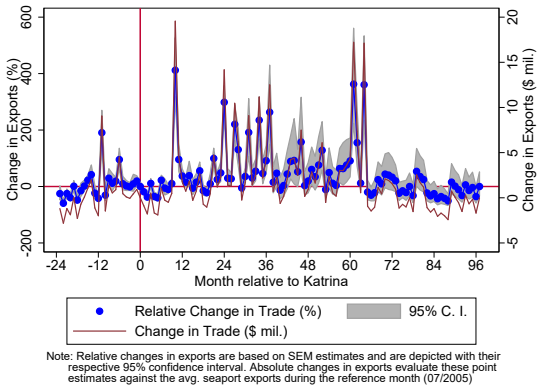
10.2: Imports

Figure 10: Dynamic Treatment Effects - Port Arthur, TX

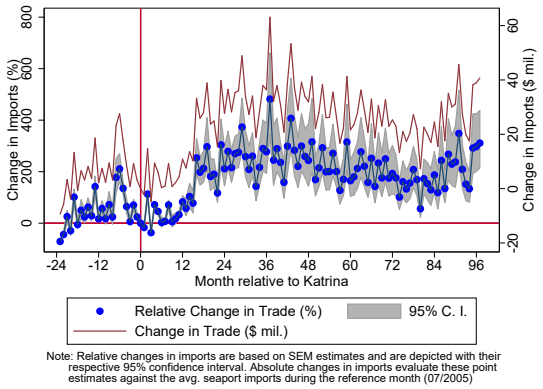
Table 9: Port-Specific Trade Disruptions (> 500 miles from epicentre)

	OLS (1)	PPML (2)	SEM (3)	SAR (4)	SAC (5)
Panel A: ln(Exports)					
Jacksonville, FL	0.044	0.066	0.045	0.045	0.046
	(0.666)	(0.323)	(0.386)	(0.410)	(0.405)
Palm Beach, FL	-0.028	-0.008	-0.028	-0.029	-0.029
	(0.738)	(0.872)	(0.494)	(0.513)	(0.491)
Port Everglades, FL	0.090	0.110***	0.091***	0.093***	0.093***
	(0.251)	(0.005)	(0.002)	(0.002)	(0.001)
Miami, FL	-0.072	-0.055	-0.075**	-0.060**	-0.066**
	(0.347)	(0.113)	(0.012)	(0.031)	(0.031)
Corpus Christi, TX	1.288	12.983***	1.289*	1.310*	1.303*
	(0.101)	(0.000)	(0.068)	(0.069)	(0.071)
Houston, TX	0.009	0.033	0.010	0.011	0.010
	(0.897)	(0.350)	(0.892)	(0.885)	(0.896)
Freeport, TX	0.161	0.189*	0.161*	0.161	0.159
	(0.103)	(0.058)	(0.094)	(0.102)	(0.109)
Panel B: ln(Imports)					
Jacksonville, FL	0.137	0.128	0.136	0.137	0.137
	(0.226)	(0.276)	(0.126)	(0.136)	(0.136)
Palm Beach, FL	-0.250**	-0.240***	-0.252***	-0.253***	-0.254***
	(0.035)	(0.009)	(0.008)	(0.007)	(0.005)
Port Everglades, FL	0.083	0.082	0.083	0.082	0.082
	(0.307)	(0.131)	(0.153)	(0.158)	(0.160)
Miami, FL	-0.052	-0.060	-0.048	-0.042	-0.043
	(0.334)	(0.239)	(0.284)	(0.316)	(0.324)
Corpus Christi, TX	-0.013	-0.454	-0.014	-0.022	-0.023
	(0.973)	(0.370)	(0.970)	(0.949)	(0.947)
Houston, TX	0.060	0.051*	0.059*	0.057*	0.057
	(0.201)	(0.067)	(0.055)	(0.060)	(0.127)
Freeport, TX	-0.694**	-0.880***	-0.694**	-0.690**	-0.693**
	(0.012)	(0.000)	(0.039)	(0.032)	(0.031)
Spatial-Weighting	-	-	Inv. Dist	Inv. Dist	Inv. Dist
Observations	480	480	480	480	480
Port FE	Yes	Yes	Yes	Yes	Yes
Time FE	Yes	Yes	Yes	Yes	Yes

Notes: P-values, reported parenthesis, are based on heteroskedasticity robust standard errors. The results presented in column (1) are based on a fixed effects model, results in column (2) are based on the PPML estimator and the results depicted in columns (3) through (5) are based on the SEM, SAR, and SAC models, for which the robust standard errors are based on Driscoll and Kraay (1998). While the direct effects are presented here, estimates of indirect trade effects for the SAR and SAC models are available upon request. Panel A depicts the aggregate disaster-induced disruptions for exports, presents the effects on imports. The coefficient estimates can be transformed to reflect percentage changes in port-level trade caused by Hurricane Katrina via the following equation: $\Delta x_{pt} = [exp(\gamma_p) - 1] * 100$, where γ_p represents the point estimates presented above. Statistical significance at the conventional levels is indicated by *** $p < 0.01$, ** $p < 0.05$, * $p < 0.1$.



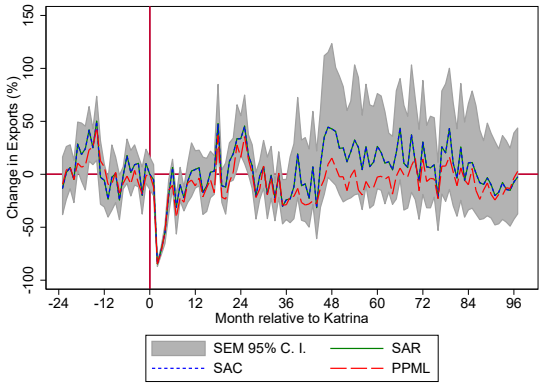
11.1: Exports



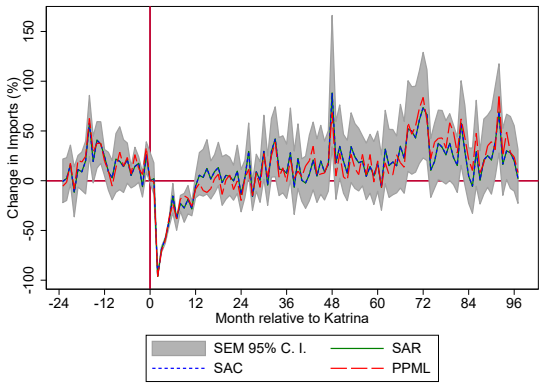
11.2: Imports

Figure 11: Dynamic Treatment Effects - Tampa, FL

Figures 12.1 through 15.2 present the results from the robustness analysis employing various spatial and traditional trade estimators to the dynamic specification given by Equation (3). Specifically, each figure presents the month-to-month dynamic treatment effect estimates for the PPML, SAR, SAC models plotted in relation to the 95% confidence interval obtained via the SEM model. Given the focus of the primary analysis, I present these findings for the four ports of interest, including the ports of New Orleans, Gulfport, Mobile, and Panama City. The figures provide strong evidence in support of the primary results indicating that the large majority of coefficient estimates fall within the tightly estimated SEM parameter range. The only deviations are given by the PPML estimates for the Port of Panama City prior to Hurricane Katrina's landfall indicative of the zero-valued pre-treatment trade flows. Post treatment estimates, however, paint a consistent picture for the economically and statistically significant impact of natural disasters on U.S. port-level trade and its considerable resilience in response to such calamities.

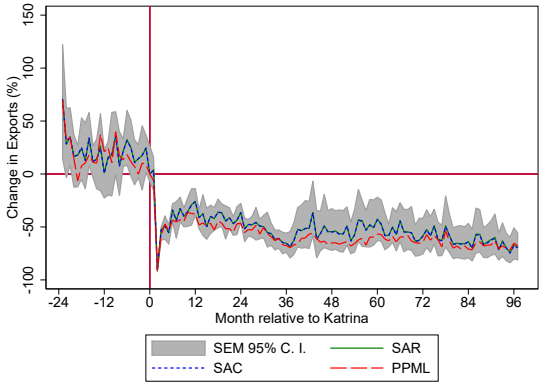


12.1: Exports

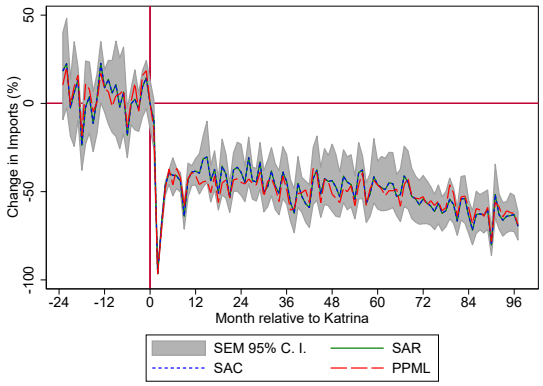


12.2: Imports

Figure 12: Dynamic Treatment Effects - New Orleans

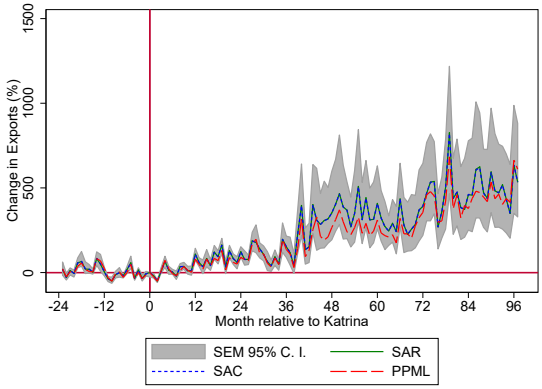


13.1: Exports

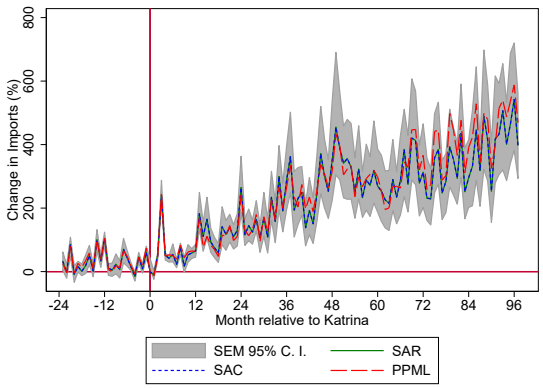


13.2: Imports

Figure 13: Dynamic Treatment Effects - Gulfport

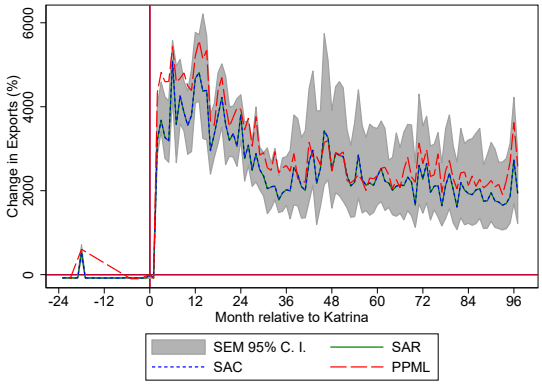


14.1: Exports

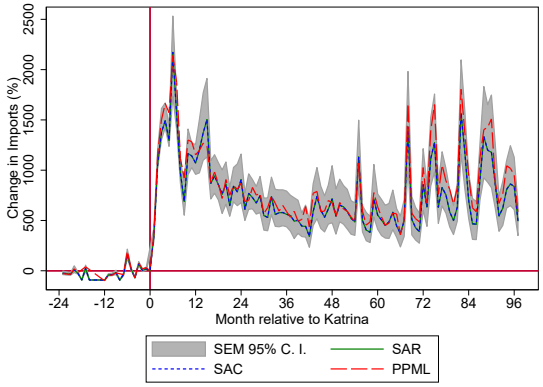


14.2: Imports

Figure 14: Dynamic Treatment Effects - Mobile



15.1: Exports



15.2: Imports

Figure 15: Dynamic Treatment Effects - Panama City