The Far Reach of Hurricane Maria:

Evidence from U.S. Pharmaceutical Sectors and Other Exposed Industries*

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Abstract

Environmental degradation raises the frequency of destructive natural disasters and the growing reliance on global value chains exposes domestic labor markets and consumers to the ripple effects of these interconnected international calamities. Shortages in medical supplies in the aftermath of Hurricane Maria, the Category 5 hurricane that devastated Puerto Rico in 2017, is a recent example of such repercussions. Despite the fact that anthropogenic climate change continues to produce devastating natural disasters around the world, we know relatively little about the exposure to and implications for the U.S. labor market resulting from such events. This study leverages the significant disruption of Puerto Rican production and exports due to Hurricane Maria to study employment ramifications spilling over into mainland U.S. labor markets. We find that adverse Puerto Rican supply shock and resulting reduction in import competition raises U.S. employment and the number of manufacturing establishments, particularly among chemical and pharmaceutical sectors with the highest level of industry exposure. Furthermore, our estimates suggest that within the local labor markets the rise of highly exposed manufacturing sectors creates positive spillovers on non-manufacturing industries and has adverse implications for less exposed manufacturing firms that compete for local resources.

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Key words: Hurricane Maria; Comparative Advantage; Local Exposure; Spatial spillovers; Trade Costs; Import Competition

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In recent decades, the landscapes of international production and trade have changed drastically. The emergence of global firms (Bernard et al. 2018) that create complex supply chains has led to the fragmentation of production processes concentrated in a few global hubs. Simultaneously, environmental degradation and anthropogenic climate change have caused a rise in the frequency and destructive force of natural disasters around the world (Emanuel 2005). Increasing trade in intermediates and final products that are part of these larger global value chains (GVC) exposes consumers and firms to the economic repercussions resulting from these international calamities.

A recent example of this unfortunate coincidence in economic and environmental trends is Hurricane Maria and its impact on the production of pharmaceuticals in Puerto Rico, which is one of the world's largest centers for pharmaceutical manufacturing. Vital drugs for treating cancer, heart-disease, and diabetes are produced in more than 50 plants on the island, which was devastated by Hurricane Maria in September of 2017. Prior to this calamity, Puerto Rican pharmaceutical manufacturing accounted for 8% of domestic medical drug consumption (FDA 2017b) and around 25% of U.S. pharmaceutical exports according to the U.S. Census Bureau trade database. Since then, plants have been faced with power failure, a lack of workers, and damaged machinery and equipment. As a result of significant damage to critical infrastructure, many of these plants were forced to shut down, leaving a significant void in the global pharmaceutical industry that has led to notable shortages of medical supplies in the United States (FDA 2017a).

How do firms and workers cope with these unexpected disruptions of global networks? How can these labor market responses inform policy designed to govern GVCs and safeguard U.S. consumers against these dangerous repercussions? To contribute to formulating answers to these difficult questions, we investigate the local labor market responses in the U.S. pharmaceutical industry and other sectors to Hurricane Maria. In particular, our focus is on the economic, disaster-induced spillover effects experienced by exposed industries located in otherwise unaffected U.S. labor markets. Treating the hurricane as a severe, yet geographically concentrated, adverse supply shock to Puerto Rico and negative trade shock to Puerto Rican exports to the United States, we estimate whether U.S. mainland employment in exposed industries and vulnerable labor markets responds to these shocks in the aftermath of Hurricane Maria. Our methodology follows that of recent advances of research investigating the impact of trade liberalization on local U.S. and Brazilian labor markets (Kovak 2013; Hakobyan and McLaren 2016; Autor et al. 2013; Dix-Carneiro and Kovak 2017, 2019), but distinguishes itself from this work along several dimensions.

First, we estimate the effects of an adverse, rather than positive, trade shock on local labor markets. Examples of the positive trade shocks explored in previous studies include Brazil's trade liberalization in the early 1990s (Kovak 2013; Dix-Carneiro and Kovak 2017, 2019) as well as increases in U.S. imports from Mexico (Hakobyan and McLaren 2016) and China (Autor et al. 2013; Acemoglu et al. 2016) in the aftermath of the North American Free Trade Agreement (NAFTA) and China joining the World Trade Organization (WTO). As such, our research provides first insights on whether the previously documented adverse labor market effects resulting from rising import competition can be reversed when this type of competition suddenly diminishes.

Secondly, our work differs from previous research in terms of the scope of the explored trade shock. While Hurricane Maria was devastating to Puerto Rico, its implication on mainland U.S. imports are several orders of magnitude smaller than the trade changes experienced in response to the well documented 'China shock' (Autor et al. 2016), for example. Indeed, our findings suggest that not only large increases in import competition, but also smaller, unexpected changes in U.S. imports can influence local labor market outcomes.

Lastly, our work distinguishes itself from previous research in terms of the mechanism we use to identify the changes in import competition and resulting labor market responses. In our study, we exploit the exogenous trade effects of a natural disaster, rather than deliberate alterations in trade policy. Our findings show that the previously highlighted long-run (decadal) policy-induced local labor market effects are robust to alternative types of trade shocks and can arise even in the short-run, one year after the disaster.

To estimate these U.S. mainland labor market spillover effects resulting from Hurricane Maria, we leverage the rich industry-specific information on county labor sheds provided by the Bureau of Labor Statistics (BLS) as well as the detailed trade statistics published by the U.S. Census Bureau. Similar to Autor et al. (2013), we define local labor markets as commuting zones (CZ) and exploit these data to derive the industry-specific and localized exposure in the spirit of Hakobyan and McLaren (2016). Intuitively, we model industry exposure as the Puerto Rican revealed comparative advantage (RCA) prior to the disaster and derive local exposure as the weighted average of these RCAs. Following the literature, local labor market vulnerability is a function of a CZ's employment concentration in the exposed manufacturing industries. Based on these calculations, we explore the disaster-induced spillover effects across U.S. commuting zone adjustments in employment, wages, and business formation.

Our empirical analysis provides evidence that Hurricane Maria and the resulting reduction in Puerto Rican exports had a positive direct impact on U.S. employment and the number of manufacturing establishments, particularly among chemical and pharmaceutical sectors with the highest level of industry exposure, and resulted in an increase in competition for workers among manufacturing industries located in the most exposed labor markets. Relative to pre-treatment averages, we find that the average manufacturing industry with an exposure at the 75th percentile experiences a rise in employment of 0.03 percentage points above that of a manufacturing sector with an exposure at the 25th percentile in the aftermath of Hurricane Maria and ensuing reduction in Puerto Rican import competition. Among chemicals and pharmaceutical sectors this response increases tenfold to around 0.3 percentage points. In comparison to the previous literature, these direct industry effects are sensible and economically significant accounting for about 4% of employment growth among manufacturing firms during our sample period.

In contrast, these positive employment effects among the most exposed industries create competition for local resources and lower average manufacturing industry employment by 0.6 percentage points post treatment for communities exposed at the 75th percentile relative to those at the 25th percentile. Moreover, we find that chemicals and pharmaceutical sectors appear immune to this local vulnerability. In comparison, this finding appears at odds with some of the previous literature, which has shown that both industry and local exposure work in concert when it comes to the effects on employment (Acemoglu et al. 2016) and wages (Hakobyan and McLaren 2016). Potential explanations may include differences in the complementarities between relatively exposed and unexposed industries specific to Puerto Rican RCAs as well as the varying local inter-industry dynamics at play in the short-run (i.e. more intense competition for scarce local resources) versus the long-run (i.e. greater interdependencies among local industries).

In line with the previous literature, we find that seemingly unrelated non-manufacturing sectors within geographically connected labor markets are also exposed to the adverse trade shock of Hurricane Maria and benefit from these direct industry exposure effect on manufacturing sectors (Acemoglu et al. 2016). Relative to a non-manufacturing sector located in an unexposed commuting zone, average local exposure raises non-manufacturing employment by 0.22 percentage points.

In terms of other potential margins of labor market adjustments, we find that the industry-specific effects on the number of manufacturing establishments and local spillover effects on non-manufacturing businesses mirror these employment effects, whereas wage impacts are less consistently estimated. Overall, our findings demonstrate the varied ways in which a natural disaster overseas can affect domestic labor market outcomes through cross-country trade linkages and suggest that employment is the primary short-run margin of adjustment.

Our findings contribute to several strands of the economic literature. First, our work advances the growing field of research focused on the economic consequences of natural disasters (Skidmore and Toya 2002; Noy 2009; Strobl 2012; Cavallo et al. 2013), particularly those related to international trade and labor markets. Studies by Belasen and Polachek (2008) McIntosh (2008), and Kirchberger (2017), for example, examine the effects of natural disasters on wages and employment in directly affected communities and neighboring locales facing the potential influx of evacuees. In general, the results point to a positive wage effect in directly affected markets that is driven by the flight of workers and a mild adverse effect on wages and the probability of employment in neighboring communities. Concerning the disaster effect on international trade, several studies have pointed to significant short-run reductions (Felbermayr et al. 2018; Friedt 2018a;

Sytsma 2018) that are typically more pronounced for poor, politically instable and developing countries (Gassebner et al. 2010; Oh and Reuveny 2010), and heterogeneous across industries and firms (Martincus and Blyde 2013; Friedt 2018a).

A closely related study by Friedt (2018b) combines these two literatures and investigates the disaster-induced diversion of international trade as a catalyst that influences otherwise unaffected Floridian labor markets in response to Hurricane Katrina. His findings indicate significant increases in urban employment, wages and land values in response to a rise in local seaport services that is triggered by the disaster-induced rerouting of international trade. Our work offers a new perspective on the effects of natural disasters and trade in geographically removed labor markets. In contrast to the rerouting of international cargo, however, we focus on the labor market outcomes across the U.S. in response to the disaster-induced overturning of a single state's comparative advantage, exemplified by the dynamics of the U.S. pharmaceutical sector in the aftermath of Hurricane Maria.

As a result, our research also contributes to the aforementioned series of recent studies on the issue of trade and labor. While the majority of this work concentrates on the employment and compensation consequences (Autor et al. 2013; Kovak 2013; Acemoglu et al. 2016; Dix-Carneiro and Kovak 2015) as well as distributional challenges (Autor et al. 2014; Dix-Carneiro and Kovak 2017, 2019) of trade liberalization, our study investigates the impact of the rise in an alternative barrier to trade. We show that natural disasters can overturn a local comparative advantage, effectively overcoming the lock-in effect of previous agglomeration (Fujita and Mori 1996), and have widespread geographic spillover effects among the most affected industries and local labor markets. As anthropogenic climate change continues to expose growing global production networks and international consumer markets to the ramifications of natural disasters, our analysis sheds light on the key issue of the ripple effects of these events on the greater economic system. While our findings are primarily based on the experience of the U.S. labor markets, we believe that the lessons learned can be extrapolated to alternative sectors and geographies.

Lastly, our work complements the growing field of research investigating the various effects of

Hurricane Maria and Puerto Rico's recovery. The majority of this research focuses on the local environmental devastation (Browning et al. 2019; Meléndez-Vazquez et al. 2019; Miller et al. 2019) future climate projections for the island Keellings and Hernández Ayala (2019); Ramos-Scharrón and Arima (2019), and efforts to rebuild the domestic economy (Perfecto et al. 2019; Román et al. 2019). Studies that highlight the more widespread effects of the hurricane are limited to the implications of out-migration to the U.S. (Alexander et al. 2019; Hinojosa and Meléndez 2018; Mora et al. 2018). Our research reveals how a reduction in Puerto Rico's domestic production and exports can have unexpected effects across local labor markets and industries in the United States.

The remainder of this study is organized as follows. In section I, we provide a concise summary of Puerto Rico's industrial composition of potentially exposed industries and discuss the dominant role of the chemicals and pharmaceutical sectors. Moreover, we provide some background on the historical developments that led to this composition and highlight the repercussions faced by this industry and the larger Puerto Rican community in the aftermath of Hurricane Maria. Grounded on this institutional knowledge and the previous review of the literature, we develop our empirical strategy in section II. We provide a detailed summary of our data in section III and present our empirical findings in section IV. In section V, we conclude our study and explore areas of future inquiry.

1 Institutional Background

Puerto Rico is one of the world's largest centers for pharmaceutical manufacturing. Vital drugs for treating cancer, heart-disease, and diabetes are produced in more than 50 plants on the island, which was devastated by Hurricane Maria in September of 2017. Since then, plants have been faced with power failure, a lack of workers, and damaged machinery and equipment. On top of that, the GOP tax reform bill issued a 12.5% tax on income from patents and licenses owned by foreign companies. Since, under federal tax codes, U.S. firms are treated as foreign companies in Puerto Rico, the tax has undermined Puerto Rico's status as a competitive site for investment and threatens post-storm recovery.

1.1 Importance of Pharmaceutical in Puerto Rico

Pharmaceutical manufacturing has played a significant role in the development of Puerto Rico's economy for the last half a century. At that time, Puerto Rico was in the midst of an economic crisis. The instatement of Operation Bootstrap in 1947 had created an economy held up by artificial advantages. Federal tax exemptions, low wages, and industrial subsidies (Cabán 2019), among other incentives, had drawn corporate investment to the island and brought with it rapid economic growth.

Around the mid-70s, Puerto Rico was no longer competitive for labor-intensive manufacturers, and firms began moving capital to less developed countries that promised lower wages. As a result, annual growth in Puerto Rico fell from 13.8% to just 1.7% (Cabán 2019). Once viewed as an economic model for smaller developing countries, the depressed island became a source of political tension. In 1976, in an effort to revitalize Puerto Rico's economy and encourage job creation, Congress enacted Section 936 as an investment incentive, granting federal tax benefits to capital-intensive manufacturers. Approximately half of all tax credits went to chemical manufacturing firms, which mainly comprised large pharmaceutical companies (Feliciano, 2018).

The results of this tax policy are highly visible today. In 2016, pharmaceutical exports from Puerto Rico accounted for 72.4% of total Puerto Rican exports and generated about $14.5 billion. According to the FDA, at least one third of Puerto Rico's GDP is generated by its pharmaceutical sector. Pharmaceutical manufacturing makes up 16% of all manufacturing jobs on the island and employs about 90,000 workers (FDA 2017b).

1.2 Hurricane Maria and the Impact on Pharmaceuticals

Hurricane Maria was the deadliest hurricane to hit the United States in over a century. The storm made landfall in Puerto Rico on September 20, 2017 and caused an estimated 5000 deaths according to a Harvard study. In addition, Maria devastated the island's critical infrastructure. With a

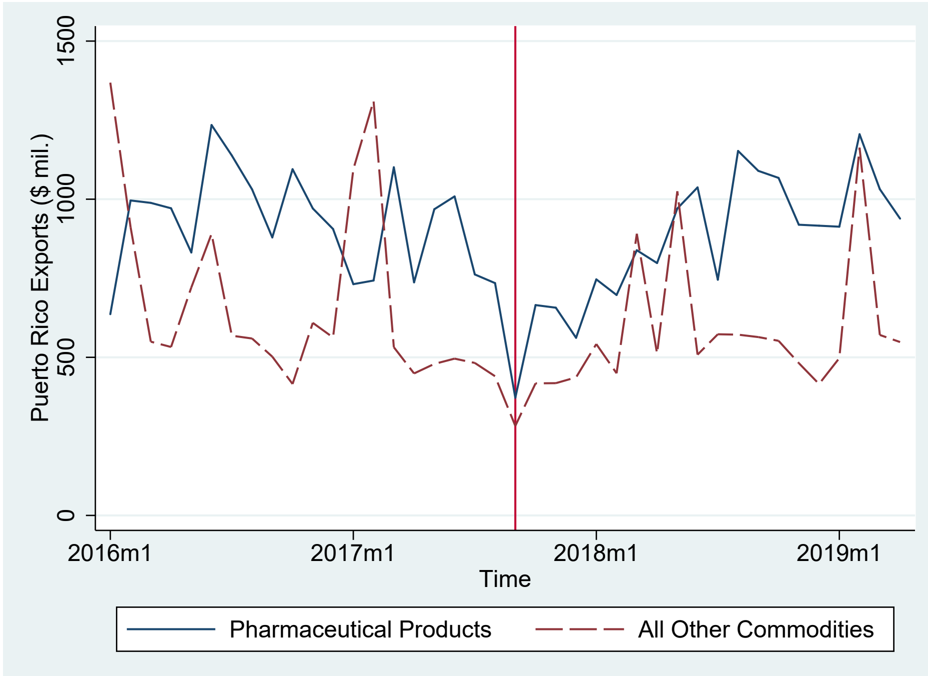


Figure 1: Monthly Puerto Rican Pharmaceutical and non-Pharmaceutical Exports

maximum sustained wind speed of up to 175 mph, the hurricane toppled 80 percent of utility poles and all transmission lines on the island. As a result, Puerto Rico was without power for 8 months, the longest blackout in U.S. history.

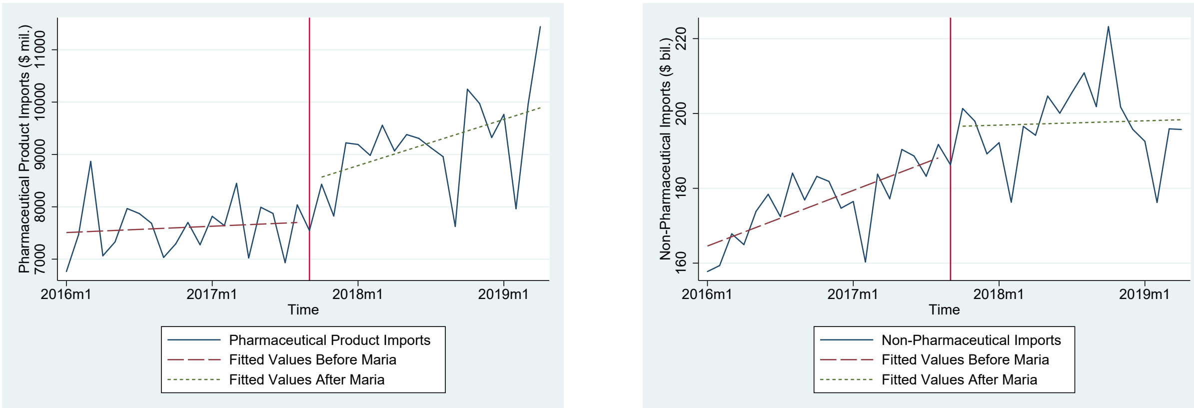
In 2017, the head of the FDA, Dr. Scott Gottlieb, testified that, “reports of manufacturing running below 50 percent are common, with many firms operating around 20 percent capacity, and some even less,” and that “[the FDA] found no firm operating above 70 percent of their normal operation” (FDA 2017c). Though the hurricane did not hit until September, the level of total annual exports decreased by 20% in 2017. Figure 1 depicts Puerto Rican monthly exports of pharmaceutical and non-pharmaceutical products and illustrates that this reduction in exports was primarily driven by the decline in the pharmaceutical sector, which lost as much as $1 billion in exports per month. Puerto Rican exports of non-pharmaceutical products show a much more moderate response, around $200 million per month, and more rapid recovery in the beginning of 2018.

1.3 Global Relevance of PR Pharmaceuticals

The U.S. is heavily dependent on the pharmaceutical production in Puerto Rico, both for domestic consumption, and international exports. Regarding domestic consumption, pharmaceuticals manufactured in Puerto Rico constitute approximately 8% of all drugs consumed by Americans (FDA 2017b). Among the main types of pharmaceuticals manufactured on the island are IV fluids, blood fraction products, cardiovascular drugs, and treatments for cancer and HIV. In October of 2017, the FDA was monitoring 30 pharmaceutical products, primarily or solely produced in Puerto Rico. At that time fourteen of the 30 were sourced solely in Puerto Rico (FDA 2017b). A month later, the FDA released a new statement that they were monitoring approximately 90 medical products manufactured on the island, including biologics, devices, and pharmaceuticals (FDA 2017d).

One particular disaster-induced shortage of pharmaceutical products that received significant press coverage in 2017 was that of IV solution product and metronidazole, which are manufactured by Baxter and supplied to the U.S. by facilities in Puerto Rico. As a result of the damage to manufacturing in Puerto Rico, the FDA had to import the products from Baxter's facilities in Ireland and Australia. Such sudden alterations in import sourcing are rare and reflect the severity of the blackouts experienced in Puerto Rico, the significance of the Puerto Rican pharmaceutical sector to the U.S. healthcare system, and the opportunities for mainland pharmaceutical sectors to fill this void. In the absence of actual production data, we present monthly U.S. pharmaceutical and non-pharmaceutical import statistics, excluding Puerto Rico, to convey the potential opportunities arising in the aftermath of Hurricane Maria, indicated by the vertical red line in Figures 2.1 and 2.2. The data show that pharmaceutical imports experienced a significant increase post Hurricane Maria, whereas other U.S. imports stagnated on average throughout 2018 and the beginning of 2019. The disaggregated country-specific import information reveal that among foreign producers, the primary winners of this rise in U.S. pharmaceutical imports are located in Belgium, Canada, Denmark, France, Germany, Italy, the UK or the Netherlands, as well as India, Japan and Singapore, for example.[1]

[1]The replacement of U.S. pharmaceutical imports from Puerto Rico with imports from other foreign countries



2.1: Pharmaceuticals

2.2: Non-Pharmaceuticals

Figure 2: Monthly U.S. Imports

As it relates to U.S. exports, Puerto Rico has consistently been the top exporter of pharmaceuticals for the United States. According to the statistics published by the U.S. Census Bureau, depicted in Figure 4, Puerto Rico accounted for around 25% of all pharmaceutical exports; a remarkable statistic given that all other commodities exported from Puerto Rico account for less than 1% of all U.S. export market share. Although the territory remained the top exporter in 2017 and thereafter, the share of U.S. pharmaceutical exports it accounted for declined by 5.3%, or around $2.9 billion, after Hurricane Maria illustrating the potential opportunities arising for mainland chemicals and pharmaceutical manufacturing sectors.

1.4 Response of U.S. Mainland Pharmaceuticals

In response to the hurricane-related shortages, the FDA assembled a task force, and developed a set of objectives in cooperation with drug manufacturers to address the supply shock. In a November press release, Gottlieb outlined three measures the FDA had formulated including the temporary importation of saline products from manufacturing facilities abroad, the encouragement of domestic manufacturing facilities to expand their production of the drugs in shortage, and the expedited review of new product alternatives (FDA 2017d). In the same press release, the FDA announced

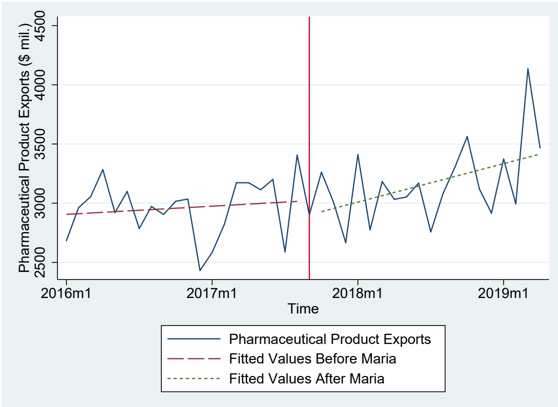
potentially mitigates the effects of the disaster-induced reduction in Puerto Rican import competition on U.S. employment. In other words, without U.S. adjustments in import sourcing one would expect the magnitude of our coefficient estimates to increase.

collaboration with B. Braun and ICU Medical to address the amino acid shortage (FDA 2017d).

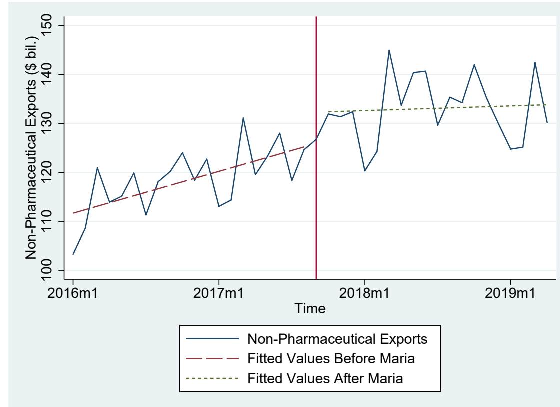
The implementation of these strategies led to significant efforts by major drug manufacturers to increase supplies of the affected products. Since 2016, Baxter has invested over $500 million to address the shortage of IV fluid (Lim 2019). In May of 2019, B. Braun Medical announced a $1 billion investment into new and existing IV solution manufacturing plants, as well as construction of a new factory in Daytona Beach, updates to an existing manufacturing facility in California, and an increase in production at a manufacturing plant in Pennsylvania. The company also announced the opening of a new distribution facility in Florida, and an initiative to enhance distribution hubs in Southern California and Pennsylvania to build out their supply network (Lim 2019). ICU Medical, which had previously experienced delays in the manufacture of amino acids, returned to the market in 2018 to restore production of IV amino acids (FDA 2018).

Coinciding with this expansion in pharmaceutical manufacturing, the Pharmaceutical Research and Manufacturers of America reports that the industry has been experiencing a shortage of workers (Higgins 2019). A 2019 report released by the National Association of Manufacturers (Moutray 2019), revealed that the total number of job openings in manufacturing had increased by on average more than 480,000 per month in the second half of 2018. Out of all manufacturing sectors, the pharmaceutical and medicine manufacturing industry had the highest amount of job openings in 2018, accounting for 12.6% of total manufacturing job openings.

In Figures 3.1 and 3.2, we provide the first evidence to support the spatial spillovers and creative destruction effect of Hurricane Maria on the U.S. pharmaceutical sector. The figures illustrate the U.S. pharmaceutical and non-pharmaceutical export statistics, excluding Puerto Rico, before and after the disaster. Similar to imports, the growth of exports of pharmaceutical products originating in U.S. states, aside from Puerto Rico, experience a visible rise post Hurricane Maria, whereas exports of other commodities become stagnant throughout 2018 and the beginning of 2019. This uncharacteristic rise in pharmaceutical exports suggests the positive spillover effects resulting from the disaster-induced devastation of this sector in Puerto Rico and the potential restructuring of the industry towards alternative production sites in the mainland United States.



3.1: Pharmaceuticals



3.2: Non-Pharmaceuticals

Figure 3: Monthly U.S. Exports

2 Model

As discussed by Acemoglu et al. (2016), the effects of an international trade shock can transmit onto local labor markets through any of four potential channels including the 1) direct impact on exposed industries; 2) the cross-industry spillover effect on linked sectors; 3) the reallocation effect within geographically connected labor markets; and 4) the impact of changes in demand. The theory to support this conceptual framework is provided by prior research, recent examples of which include ADH (2013) or Kovak (2013) who, among others, show that changes in the volume of trade or the prices at which goods are traded can influence labor market outcomes across industries and geographies. For the context of this study, these theoretical models suggest that the advent of Hurricane Maria, which destroyed vast parts of Puerto Rico's manufacturing sector and disrupted Puerto Rican exports, may have caused a systematic response in U.S. industries and labor markets exposed to adverse Puerto Rican supply shock.

One example of such an industry may be the chemicals and pharmaceutical manufacturing sectors where Puerto Rico had exhibited a significant revealed comparative advantage prior to Hurricane Maria. After the storm, these sectors experienced considerable disruptions in production and a subsequent reduction in exports. In response to this drop in Puerto Rican import competition, U.S. mainland labor markets may be experiencing the positive direct impact on these industries (channel 1). However, it is conceivable that the decline in Puerto Rican production may also cause a negative labor market response in these and other linked industries due to the potential supply chain linkages (channels 1 & 2). Further, in the presence of imperfect labor mobility (Blanchard et al. 1992; Glaeser and Gyourko 2005), these direct and indirect impacts of the labor demand shocks on chemicals and pharmaceutical sectors, as well as related manufacturing industries, may spill over across other sectors within the local labor markets. Immobility hinders the workers' ability to arbitrage wage and employment differences across geographic boundaries and exposes seemingly unrelated sectors, co-located in particularly vulnerable labor markets, to the adverse trade shock experienced by Puerto Rico (channel 3). Through these reallocation channels of labor across industries and within local labor markets, Hurricane Maria may have had a much farther reach than indicated by the tropical cyclone's geographic path. Whether U.S. mainland labor markets responded to Hurricane Maria, to which extent they responded, and which of these channels determined the response in labor are the central issues addressed by this study.[2]

Our empirical strategy is guided by this conceptual framework. Similar to Hakobyan and McLaren (2016), we determine industry-level exposure to disaster-induced reduction in Puerto Rican production and exports via the notion of revealed comparative advantage. Intuitively, the degree of U.S. mainland industry exposure to the direct impact of the adverse Puerto Rican supply shock should correlate to the degree of Puerto Rican specialization in that specific industry. Following Hakobyan and McLaren (2016), we determine Puerto Rico's industry-specific RCA as the share of Puerto Rican exports (x_j^{PR}) in global exports (x_j^{ROW}) of industry j relative to the share of total Puerto Rican exports across all N manufacturing industries in total global manufacturing exports (excluding trade between the U.S. and Puerto Rico):

$$RCA_j = \frac{\frac{x_{j,2016}^{PR}}{x_{j,2016}^{ROW}}}{\frac{\sum_{j=1}^{N} x_{j,2016}^{PR}}{\sum_{j=1}^{N} x_{j,2016}^{ROW}}}. \tag{1}$$

[2]Given the size of Puerto Rican population relative to that of the U.S. mainland ($\approx 1\%$), the aggregate changes in demand due to Hurricane Maria may be rather limited and are not the central focus of this study. To the extend that local demand changes, however, mimic those at the aggregate level, our analysis of the overall local labor market effects of Hurricane Maria will encompass these changes.

Akin to ADH (2013) and Hakobyan and McLaren (2016), we base our measure of industry exposure on pre-treatment 2016 exports to avoid the potential simultaneity of changes in Puerto Rican RCAs in response to Hurricane Maria.

Aside from the industry-level exposure that informs our analysis of the first two aforementioned transmission channels, we are also interested in measuring the overall vulnerability and response of local labor markets to the abrupt decline in Puerto Rican production and exports. In the spirit of Hakobyan and McLaren (2016), we calculate 'Local Industry Exposure' (LIE_{cj}) weighting the manufacturing industry's RCA by the local industry's share among all local manufacturing employment ($\sum_{j=1}^{N} L_{cj}$). Total labor market vulnerability is simply the sum across LIEs and yields the 'Cumulative Local Exposure' (CLE_c) by labor market c:

$$CLE_c = \sum_{j=1}^{N} LIE_{cj}^{2016} RCA_j = \sum_{j=1}^{N} \frac{L_{cj}^{2016}}{\sum_{j=1}^{N} L_{cj}^{2016}} RCA_j. \tag{2}$$

Intuitively, Equation 2 states that local exposure depends on the degree to which a labor market is concentrated in the industries in which Puerto Rico is specialized. Again, we fix these local labor market employment shares at their respective 2016 levels to 1) avoid the potential simultaneous changes in local labor market compositions in response to the spillovers resulting from Hurricane Maria; and 2) capture the most recent labor market composition prior to the disaster. When analyzing the effects of Chinese import competition, ADH (2013), for example, lag these labor market shares by ten years to avoid any anticipatory changes in labor market composition prior to China joining the WTO. While this strategy is reasonable for a major anticipated policy event, we expect no anticipatory employment adjustments prior to Hurricane Maria that would undermine our choice of 2016. Of course, one might argue that Puerto Rico is expected to be affected by a hurricane during hurricane season. But this expectation should not vary across years prior to Hurricane Maria and therefore should not trigger an extraordinary labor market adjustment in anticipation of Maria in 2016 relative to years prior. In other words, we believe that our choice of 2016 and identification of U.S. mainland spillover effects are justified by the fact that the severity and geographic location of Hurricane Maria were unpredictable for all but two weeks prior to the storm's landfall in Puerto Rico.

A related issue in calculating CLE, is the selection of industries. As indicated through the derivations by Kovak (2013), it is imperative to limit the calculations of local labor market compositions and exposure to tradable sectors, for which the RCA is observable. According to Kovak (2013), trade-shock-induced price changes in non-tradable sectors mimic those of the tradable industries. In the absence of observing these price changes, however, the inclusion of non-tradable sectors in the summation of overall local labor market employment and exposure would artificially underestimate CLE due to the fact that the observable RCA equals zero for non-tradable sectors. As Kovak (2013) shows and as our estimates confirm, the inclusion of non-tradable sectors in the calculation of CLE biases the geographic reallocation effect estimates because it understates the changes in local labor demand and consequently overstates the importance of the Puerto Rican trade shock to U.S. mainland labor markets. We follow the convention of the previous literature (i.e. ADH (2013) or Hakobyan and McLaren (2016)) and limit the CLE calculations to manufacturing industries.

With these industry- and labor-market-specific exposure measures in hand, we develop our primary empirical specification. Unlike Kovak (2013), Hakobyan and McLaren (2016), or Dix-Carneiro and Kovak (2017) and Dix-Carneiro and Kovak (2019), who study the labor market effects of trade liberalization, we investigate the effects of a disaster-induced trade shock. Accordingly, we are unable to calculate industry- or local labor-market-specific tariff changes over time and instead combine our exposure measures with the conventional difference-in-differences (DiD) setting used to evaluate the effects of a treatment, such as Hurricane Maria. Intuitively, the interaction of our exposure measures (RCA_j and CLE_c) with a dummy variable (δ_t) indicating the sample period after the landfall of Hurricane Maria (i.e. $\delta_t = 1 \forall t > 2017q3$) tests whether the intensity of the mainland spillover effects systematically varies with the vulnerability of industries and labor markets. Since all manufacturing industries and labor markets are potentially affected, however, this setup differs from the traditional DiD approach with clearly defined treatment and control groups. In the absence of this distinction, the critical assumption underlying our estimation is that the levels of industry and labor market exposure to Puerto Rican production and trade are uncorrelated to pre-treatment trends in industry and local labor market employment.

If, for example, the principle Puerto Rican export industries experience a positive global demand shock that leads to disproportionate industry growth both in Puerto Rico and the U.S. mainland relative to less exposed sectors prior to the landfall of Hurricane Maria, we would falsely attribute the positive effects of a rise in global demand on exposed industries for the impact of the adverse trade and supply shocks experienced by Puerto Rico due to Hurricane Maria. To address this specific concern and other potentially confounding factors, we follow the literature and include controls for pre-treatment industry-labor-market-specific employment trends (pt_{cj})[3] (Dix-Carneiro and Kovak 2017) and conduct several falsification tests with placebo treatments prior to Hurricane Maria (ADH, 2013) (see Table 5).

In addition to our key variables of interest and the employment pre-trend, we capture level differences in employment across industries with varying degrees of exposure to Puerto Rican import competition as well as other time-invariant unobservable differences across manufacturing sectors via industry-specific fixed effects (α_j).[4] Similarly, we recognize that labor market outcomes across industries and regions may be subject to differential trends before and after Hurricane Maria and capture these macroeconomic trends via time fixed effects (α_t). The use of these time-varying indicator variables has the added benefit of controlling for seasonal variation potentially present in the quarterly labor market statistics. In addition to these general macroeconomic conditions, local labor market outcomes may be shaped by regional differences in policies, climate, or resources. Similar to ADH (2013), who control for differences across census devisions, Kovak (2013), who controls for differences across Brazilian meso-regions, or Hakobyan and McLaren (2016), who control for differences across U.S. states, we capture otherwise unobservable time-invariant re-

[3]Employment, wage, and establishment count pre-trends are based on the respective 2012 to 2016 growth rates and calculated at the industry-CZ level.

[4]The inclusion of industry-fixed effects precludes the inclusion of industry-specific 2016 Puerto Rican RCA, which is time-invariant.

gional differences in labor market conditions via state fixed effects (α_s).[5]

Finally, at the labor market level, we rely on the county characteristics provided through the 2010 U.S. Census and aggregate the relevant statistics up to the commuting zone level as defined by Fowler et al. (2016). Our specific choice of labor market controls, given by the matrix X_c^{2010}, among many possible variables is guided by the previous literature and include the percent of employment in manufacturing, the percent of the population that is college-educated, the percent of the population that is foreign-born, the percent of employment held by women (see ADH, 2013), and relevant to our study specifically, the percent of the population of Puerto Rican decent.[6]

Combined, these variables give rise to the primary empirical specification described as follows:

$$ln(L_{cjt}) = \beta_0 + \beta_1 RCA_j * \delta_t + \beta_2 CLE_c * \delta_t + \beta_3 CLE_c + \beta_4 pt_{cj} + \gamma X_c^{2010} + \alpha_s + \alpha_j + \alpha_t + \epsilon_{cjt}, \quad (3)$$

where the random error component is given by ϵ_{cjt}. The coefficients of interest are given by β_1 and β_2. Restricting the sample to manufacturing industries only implies that β_1 captures the average direct impact of Puerto Rico's adverse disaster-induced supply and trade shocks on exposed U.S. mainland manufacturing industries relative to pre-treatment averages (channel 1), whereas β_2 signifies the average local labor market spillover effect among locally exposed manufacturing industries post Hurricane Maria (channels 2 and 3). Conceptually, the direct effects (β_1) may be positive due to the reduction in Puerto Rican import competition or negative due to adverse supply-chain effects resulting from the disruption of Puerto Rican intermediaries. Similarly, the indirect impacts (β_2) cannot be signed a priori due to the potential positive synergies among local manufacturing firms or negative effects of competition for scarce local resources.

When estimating this equation on the sample of non-manufacturing industries, β_1 now to cap-

[5]To the extent that state-level differences in policy and other unobservables may not be fixed during our sample period, we also test the sensitivity of our results against the inclusion of state-year fixed effects, akin to empirical strategy by Hakobyan and McLaren (2016). The results are largely robust and available upon request.

[6]While these control variables capture a wide array of potential differences across local labor market conditions, we acknowledge the possibility that we could be missing important observable or unobservable determinants at the commuting-zone or commuting-zone-industry levels. To investigate this potential issue, we reestimate our model controlling for commuting-zone- or commuting-zone-industry-specific fixed effects. Reassuringly, the results are quantitatively and qualitatively robust to the inclusion of these indicator variables.

ture the average direct treatment effect on exposed non-manufacturing industries, such as agriculture, relative non-tradable industries, whereas β_2 signifies the reallocation effect within geographically bounded labor sheds (channel 3). In this case, one might expect insignificant results on non-manufacturing, agricultural industries with very limited exposure to Puerto Rican import competition or supply chain integration and significant local labor market effects that depend on the explicit synergies between the directly exposed manufacturing and indirectly exposed non-manufacturing sectors within a local labor market.

3 Data

The data we employ to estimate this model is a compilation from various sources. The main data on local labor market outcomes stems from the Quarterly Census of Employment and Wages (QCEW) published by the Bureau of Labor Statistics (BLS). This dataset provides quarterly statistics on employment, average weekly wages and establishment counts for U.S. counties from the first quarter of 2012 until the fourth quarter of 2018, disaggregating the information at the North American Industry Classification System (NAICS) 6-digit level. While establishment counts are publicly available for every time period, many of the employment and wage statistics are redacted due to concerns about anonymity. To address the obvious issues that can arise with an unbalanced sample when estimating and comparing pre- and post-treatment averages, we limit our analysis to those industry-county pairs for which we have data on all 12 quarters from 2016 through 2018.

Akin to ADH (2013), we define a local labor market as a commuting zone and aggregate this balanced industry-county dataset to the industry-commuting-zone level. Our mapping between counties and commuting zones is based on the Economic Research Service (ERS) delineations of commuting zones drawing on the work by Fowler et al. (2016). We choose this specific delineation of labor sheds due to its complete coverage of urban and rural areas, unlike other concordances such as the Census Core Based Statistical Areas, which only focus on urban centers. In our case, workers in urban areas may be in a better position to switch jobs than their counterparts in rural commuting zones. A sample that ignores the rural frictions may understate the impact of the Puerto Rican trade shock resulting from Hurricane Maria.

Based on this dataset, we establish our dependent variables, including quarterly employment, average weekly wages, and quarterly establishment counts, from the first quarter 2016 to the fourth quarter 2018. Furthermore, we calculate the 5-year industry-CZ-specific pre-treatment trends for each of these dependent variables to control for the possibility of unequal local industry growth from 2012 through 2016. Lastly, we use the QCEW dataset to determine each CZ's general labor market composition and calculate the 5-year lagged share of total manufacturing employment among all CZ employment in 2012. Each of these variables is summarized in Table 1.

We combine these labor market statistics with industry-specific information on Puerto Rican and global exports to the rest of the world (excluding trade between the U.S. and Puerto Rico). To this end, we merge global trade data, obtained from the United Nations Comtrade database, with Puerto Rican export statistics obtained through the U.S. Census 'Trade Online' database. We use these data to determine Puerto Rican RCAs, as defined by Equation (1), across all manufacturing and other traded industries. As Panel A of table 1 shows, Puerto Rico's RCA averages 0.49 across manufacturing industries, has an interquartile range of 0.17 between the 25th and 75th percentiles, and an industry-specific maximum value of 26.18. As Table 2 indicates, this remarkable degree of Puerto Rican specialization pertains to the 'In-Vitro Diagnostic Substance Manufacturing' (NAICS 325413) industry. In fact, panel A of Table 2 reveals that five of the top ten industries where Puerto Rico has a revealed comparative advantage, and thus the most exposed sectors to the trade shock resulting from Hurricane Maria, belong to chemicals manufacturing (NAICS 325). More specifically, the top three of the most exposed industries fall under pharmaceutical and medicine manufacturing (NAICS 3254). With respect to the least exposed manufacturing industries, where Puerto Rico has revealed a comparative disadvantage, we cannot discern any particular pattern. Among these sectors with lowest RCA scores are, for example, auto components, light fixtures, carpet and rug mills, as well as, aircraft engine manufacturing.

In addition to the ranking of RCAs among manufacturing industries, Table 2 also summarizes

Table 1: Summary Statistics (2016q1 - 2018q4)

	(1) Mean	(2) IQR	(3) Minimum	(4) Maximum	(5) Obs
Panel A: Manufacturing Sectors					
Qtrly Employment	599.94	441.83	3.67	51,529.00	73,104
Avg. Wkly Wage	1,056.74	451.00	134.00	25,045.00	73,104
Qtrly Establishments	5.43	3.00	0.00	1,700.00	701,328
RCA	0.49	0.17	0.00	26.18	73,104
RCA, Chemicals and Pharmaceuticals	4.46	1.07	0	26.18	6,814
CLE	0.39	0.60	0.00	1.98	73,104
PR Global Exports	20.87	0.95	0.00	3,200.33	73,104
IPW	181.00	253.44	0.00	2,365.52	73,104
Panel B: Non-Manufacturing Sectors					
Qtrly Employment	1,026.75	523.00	2.33	316,045.00	905,544
Avg. Wkly Wage	864.87	569.00	20.00	39,390.35	905,544
Qtrly Establishments	35.61	15.00	0.00	283,106.00	2,749,068
RCA	0.00	0.00	0.00	1.07	905,544
CLE	0.20	0.17	0.00	1.98	905,544
PR Global Exports	0.00	0.00	0.00	7.37	905,544
IPW	84.49	47.67	0.00	2,365.52	905,544
Panel C: Commuting Zone Characteristics					
% of employment in mfg (2012)	12.25	8.15	0.00	50.09	978,444
% of college-educated population (2010)	53.63	10.66	24.31	75.91	978,444
% of foreign-born population (2010)	8.06	7.61	0.10	40.82	978,444
% Puerto Rican population (2010)	1.02	0.61	0.00	12.67	978,444
% of employment held by women (2010)	47.06	2.07	40.23	52.06	978,444

Notes: The statistics are based on a balanced sample of 601 commuting zones and 329 distinct manufacturing as well as 636 non-manufacturing industries identified at the six digit NAICS level. Observations are averaged across a sample period from the first quarter 2016 to the fourth quarter 2018. Employment, wage, and establishment information are available through the QCEW published by the BLS. Puerto Rican trade data is available through the U.S. Census Bureau's 'Trade Online' database, while global trade data to calculate Puerto Rico's industry-specific RCA were sourced from the UN Comtrade dataset. We aggregate 2010 census county-level estimates available through the U.S. Census Bureau to approximate commuting zone characteristics.

industry-specific changes in average employment, weekly wages, and Puerto Rican exports pre and post Hurricane Maria. The latter of these changes, is the most obvious distinction between the most and least exposed industries. In the five quarters after Hurricane Maria, average Puerto Rican exports in industries where it held the highest RCAs prior to the disaster declined anywhere from 11 to 100%, most of which experienced declines in excess of 50%, relative to the pre-treatment average. In contrast, exports among least exposed industries, in fact, seem to rise in the aftermath of

Table 2: Top Ten Most And Least Exposed Manufacturing Industries in 2016

(1) Rank	(2) Industry	(3) NAICS	(4) RCA	(5) Δ Total Employ-ment (%)	(6) Δ Qrtly. Weekly Wages (%)	(7) Δ Avg. PR Exports
Panel A: Top 10						
1	In-Vitro Diagnostic Substance Manufacturing	325413	26.2	9.1	2.7	-95.2
2	Biological Product (except Diagnostic) Manufacturing	325414	24.9	12.2	3.5	-100.0
3	Pharmaceutical Preparation Manufacturing	325412	18.1	5.5	-1.8	-34.2
4	Household Furniture (except Wood and Metal) Manufacturing	337125	8.5	-7.5	0.6	-98.6
5	Surgical appliance and supplies manufacturing	339113	7.2	-2.3	5.0	-39.8
6	Secondary Smelting, Refining, and Alloying of Nonferrous Metal (except Copper and Aluminum)	331492	6.9	20.0	-5.4	-42.2
7	Ophthalmic Goods Manufacturing	339115	5.2	-4.8	6.0	-11.4
8	Plate work manufacturing	332313	5.0	4.2	6.6	-98.4
9	Medicinal and Botanical Manufacturing	325411	4.5	1.1	16.6	-87.1
10	All Other Basic Organic Chemical Manufacturing	325199	4.8	1.6	3.2	-66.5
Panel B: Bottom 10						
1	Motor Vehicle Steering and Suspension Components (except Spring) Manufacturing	336330	.00004	8.2	9.2	209.4
2	Blank magnetic and optical media mfg	334613	.00018	-49.2	50.4	2,595.4
3	Engineered wood member manufacturing	321213	.00033	4.8	0.9	1,475.0
4	Nonresidential electric lighting fixture mfg.	335122	.00036	2.0	6.5	259.3
5	Residential Electric Lighting Fixture Manufacturing	335121	.00036	-12.0	7.4	259.3
6	Aircraft Engine and Engine Parts Manufacturing	336412	.00039	-0.3	5.7	28,615.0
7	Fiber, yarn, and thread mills	313110	.00054	0.5	7.1	90.7
8	Carpet and rug mills	314110	.00057	7.9	-8.7	9.6
9	Footwear manufacturing	316210	.00088	-8.8	9.9	19.2
10	Optical instrument and lens manufacturing	333314	.001	6.0	2.1	88.9
Total	**All PR Traded Manufacturing Industries**		.59	.7	5.8	-39.3

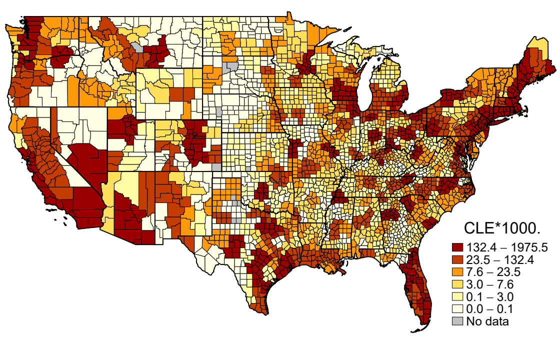
Notes: The listed industries are chosen from a set of 282 six-digit NAICS manufacturing sectors exported by Puerto Rico in 2016. While column (4) indicates the revealed comparative advantage of each of these industries, columns (5) through (7) give the percentage changes in total quarterly employment, average weekly wages, and Puerto Rican exports. The percentage changes are based on the difference in logged quarterly averages calculated over six quarters before Hurricane Maria (2016q1-2017q2) and five quarters after the disaster (2017q4-2018q4). The labor market statistics represent aggregates from the balanced panel of U.S. CZ-industry observations available through the QCEW provided by the BLS.

Hurricane Maria. Changes in employment and wages across industries are less distinct, although it appears that more exposed industries tend experience greater employment and weaker wage growth than their less exposed counterparts.

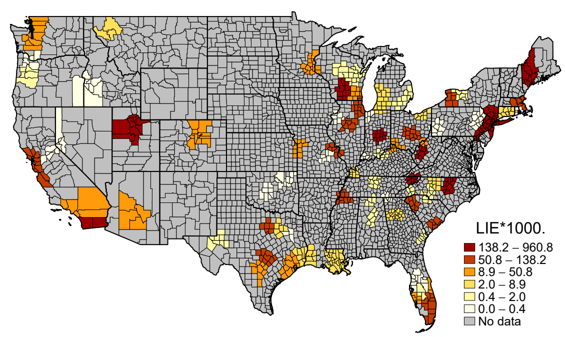
To understand the dynamics of local labor market exposure, we follow Equation (2) and combine the Puerto Rican RCA data with the CZ-level employment information. As Table 1 indicates, the resulting cumulative exposure of local labor markets tends to be higher among geographies where more manufacturing industries than non-manufacturing industries are present. Among manufactures, average CLE equals 0.39, with interquartile range of 0.6, a minimum exposure of approximately zero, and a maximum exposure of 1.98. Among non-manufacturing industries, CLE averages 0.2 and has an interquartile range of 0.17 across these sectors. Similar to industry exposure, we rank CZ vulnerability and present the top ten most and least exposed locales in Table 3. Unsurprisingly, the greatest exposure is concentrated among urban centers, such as New York - New Jersey, Philadelphia, San Diego, or Boston. Less exposed labor markets include rural areas in variety of states including Alabama, Minnesota, South and North Dakota, or Mississippi.

Figure 4.1 provides a more detailed summary of these labor market exposures across the entirety of the U.S. mainland. As darker shaded areas indicate greater levels of labor market exposure, Figure 4.1 confirms that the most vulnerable labor sheds tend to be located along the East, West, and Gulf Coasts and concentrated among urban centers, while parts of the American Grain Belt, including North and South Dakota, Nebraska and Kansas, appear to be the least exposed regions. Figure 4.1, however, also shows that exposure to Puerto Rican import competition and it's adverse supply shock from Hurricane Maria is not unique to larger metropolitan areas and, in fact, widely dispersed across urban and rural communities.

Given the predominant role of the chemicals and pharmaceutical sectors in shaping these CLEs, Figure 4.2 depicts the industry-specific local CZ exposure levels unique to these manufacturing sectors. As expected, the most exposed pharmaceutical industry labor markets coincide with the aggregate CLEs, but are heavily concentrated geographically. In fact, for most of the CZs we do not observe 2016 employment statistics in the chemicals and pharmaceutical sectors.



4.1: Cumulative CZ Exposure, 2016



4.2: Chemical & Pharmaceutical CZ Exposure, 2016

Figure 4: Geography of Exposure

Table 3: Top Ten Most And Least Exposed Labor Markets in 2016

(1) Rank	(2) Commuting Zone	(3) Cumulative Local Exposure	(4) Δ Qrtly. Employ-ment (%)	(5) Δ Avg. Wkly. Wage (%)	(6) Δ Avg. IPW (%)
Panel A: Top 10					
1	Warsaw-Plymouth, IN	1.96	.7	7.5	-28.1
2	New York-Newark-Jersey City, NY-NJ-PA	1.81	.6	5.4	-36.1
	Allentown-Bethlehem-Easton, PA-NJ				
3	Philadelphia-Camden-Wilmington, PA-NJ-DE-MD	1.79	1.6	4.6	-30.1
4	El Centro-San Diego-Carlsbad, CA	1.78	3.7	5.9	-75.9
5	Gainesville, FL	1.47	2	7.2	-30.9
6	New York-Newark-Jersey City, NY-NJ-PA	1.33	1.6	7.3	-19.7
7	Memphis, TN-MS-AR	1.12	2.1	6.2	-25.5
8	Dunn-Durham-Chapel Hill-Henderson-Oxford-Raleigh-Sanford, NC	1.07	4.4	7.1	-21
9	Salt Lake City-Ogden-Clearfield-Provo-Heber-Orem-Summit Park, UT	1.07	7.2	7.7	-19.8
10	Boston-Cambridge-Newton-Worcester, MA-NH-CT	1.02	3.2	6.5	-32.7
Panel B: Bottom 10					
0	Unexposed Commuting Zones	0	-0.3	7.0	.
1	Conecuh-Escambia-Monroe County, AL	.00002	4.2	3.3	-79.7
2	Grand Forks, ND-MN	.00004	-1.5	6.4	-85.7
3	Scottsbluff, NE	.00004	-5	3.2	-100
4	Accomack-Northampton County, VA	.00006	-1.8	2.5	31.8
5	Owensboro, KY	.00007	-2.3	5.7	192.8
6	Columbus-Starkville, MS	.00007	2.4	5.4	2.3
7	Crossville-Dayton, TN	.00008	5.3	5.4	-12.6
8	Aberdeen, SD	.00009	-2.5	3.9	-100
9	Middlesborough, KY	.0001	-.7	5.8	-100
10	Dickinson, ND	.00012	.9	4.3	-79.7
Total	**All Commuting Zones**	.07	1.2	6.5	-6.2

Notes: The listed labor markets are chosen from the set of 601 commuting zones, as defined by Fowler et al. (2016). While column (3) indicates the cumulative local exposure for these labor markets, columns (4) through (6) give the percentage changes in average quarterly employment, average weekly wages, and average imports per worker. The percentage changes are based on the difference in logged quarterly averages calculated over six quarters before Hurricane Maria (2016q1-2017q2) and five quarters after the disaster (2017q4-2018q4). The labor market statistics represent aggregates from the balanced panel of U.S. mainland county-industry observations available through the QCEW provided by the BLS.

In terms of the correlations between changes in outcome variables and exposure, we observe that the changes in average weekly wages appear relatively similar across more and less exposed labor markets (Table 3, column (5)), while labor market exposure seems to be positively correlated with changes in employment (Table 3, column (4)). In the absence of a more rigorous regression analysis, however, this observation is merely tentative as there are many confounding factors that may lead to greater changes in employment among these exposed urban centers relative to the less exposed rural labor markets. To control for these differences in labor market conditions, we combine our labor and trade dataset with county-level characteristics from the 2010 U.S. Census. Among these characteristics describing the local labor market conditions are familiar statistics, such as the percentage of the population that is college educated, foreign born, or of Puerto Rican descent. Additionally, we follow ADH (2013) and control for the percentage of employment held among women. Similar to the labor market information, we aggregate this county-level data to the CZ level using the ERS county-CZ concordances (Fowler et al. 2016) and provide the relevant summary statistics in panel C of Table 1.

To preview the potential effects of Hurricane Maria on U.S. mainland labor markets, we split our sample and calculate the pre and post Hurricane Maria averages for employment and wages for each of the resulting five subsamples. The specific categories include all manufacturing industries (Table 4, columns (1)-(3)), all non-manufacturing industries (Table 4, columns (4)-(6)), chemicals and pharmaceutical sectors (Table 4, columns (7)-(9)), industries with local exposure above the 95th percentile (Table 4, columns (10)-(12)), and labor markets with CLE above the 95th percentile (Table 4, columns (13)-(15)). The differences in these averages reveal that more exposed manufacturing employment experienced slightly more growth than that of non-manufacturing industries, while the heavily exposed work force in chemicals and pharmaceutical sectors experienced above average growth among the manufacturing industries. Differences in wages illustrate the opposite pattern with changes in non-manufacturing wages out pacing those for the average manufacturing industry and particularly those of the chemicals and pharmaceutical sectors. In contrast, the most locally-exposed industries and labor markets exhibit smaller than average wage and employment

Table 4: Pre and Post Hurricane Maria Averages by Industry and Labor Market

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)	(13)	(14)	(15)
	Manufacturing			Non-Manufacturing			Chemicals/Pharmaceuticals			LIE$>95^{th}$ Perc.			CLE$>95^{th}$ Perc.		
	Pre	Post	Dif. (%)	Pre	Post	Dif. (%)	Pre	Post	Dif. (%)	Pre	Post	Dif. (%)	Pre	Post	Dif. (%)
ln(L)	5.25	5.28	2.6**	5.25	5.28	2.52***	5.64	5.66	2.73	6.32	6.32	-.24	5.51	5.53	1.27
ln(w)	6.8	6.86	6.09***	6.57	6.63	6.42***	7.28	7.32	3.66***	7.09	7.13	4.01***	6.97	7.03	5.88***
CLE	.15			0.0003			4.42			3.8			.38		
LIE	.25			.20			.54			.29			1.45		
Obs.	29,970	24,975		452,772	377,310		1,248	1,040		3,684	3,070		1,650	1,375	

Notes: In this table, we compare pre and post Hurricane Maria log averages and resulting percentage changes in the total quarterly wage bill, total quarterly employment, and average weekly wages. The 'pre' averages are calculated over six quarters before Hurricane Maria (2016q1-2017q2) and 'post' averages are based on five quarters after the disaster (2017q4-2018q4). We consider these averages from an industry perspective differentiating across three groups including manufacturing and non-manufacturing sectors and the chemicals/pharmaceutical industries. Moreover, we consider these averages from a labor market perspective differentiating across most locally-exposed industries (LIE$>75^{th}$ percentile) and labor markets (CLE$>75^{th}$ percentile). For manufacturing, pre and post averages are based on labor market statistics of a balanced panel of 6,092 commuting zone-industry pairings including 408 unique commuting zones, as defined by Fowler et al. (2016), and 329 unique industries, while non-manufacturing averages boast 75,462 unique industry-CZ pairings based on 608 CZs and 636 unique sectors. The labor market statistics represent aggregates from the balanced panel of U.S. mainland county-industry observations available through the QCEW provided by the BLS.

growth.

4 Results

In our first attempt to quantify the industry and labor market effects of the adverse Puerto Rican supply and trade shocks on U.S. mainland manufacturing employment, we establish our baseline, parsimonious model results and put these estimates to the test against alternative placebo treatments. Controlling for time and industry fixed effects, we begin by separately estimating the average direct industry and average indirect local effects of Hurricane Maria on industry-CZ quarterly employment between 2016 and 2018. As columns (1) and (2) of Table 5 indicate, the hurricane-induced impacts on manufacturing employment carry the opposite sign and both are statistically significant at the 5% and 1% levels, respectively. The joint estimation, presented in column (3), yields nearly identical results suggesting that an increase in industry exposure going from the 25th percentile to the 75th percentile post Hurricane Maria raises manufacturing employment by 0.034(=0.002*0.017*100%) percentage points. In contrast, the coefficient estimate on the cumulative exposure of the local labor market suggests that an increase in local vulnerability from the 25th percentile to the 75th percentile reduces industry-CZ employment by 0.84 percentage points in the aftermath of Hurricane Maria. Combined, we argue that these estimates indicate the positive effects of the reduction in Puerto Rican import competition on U.S. manufacturing employment and the resulting increase in localized competition for immobile workers among those benefiting industries and less exposed sectors in the most heavily exposed labor markets.

As with any DiD estimation, one must be concerned about the possibility that these estimates are, in fact, driven by pre-existing differences in employment growth across more or less exposed industries and/or labor markets. A violation of this pre-treatment parallel paths assumption would bias the treatment effect estimates presented in columns (1) through (3). An example of such a confounding factor may be a global rise in demand for U.S. mainland and Puerto Rican manufacturing exports that spurs growth in these industries and naturally correlates with the RCA exposure

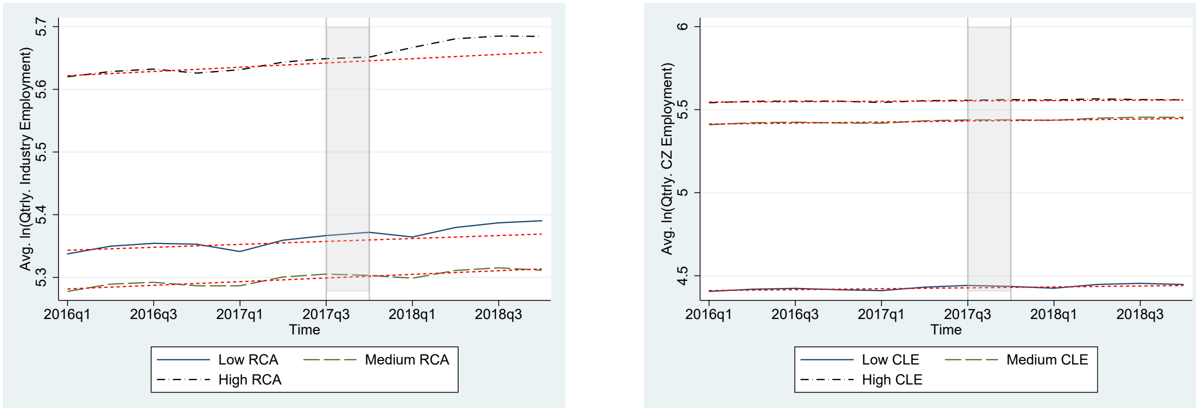
Table 5: Baseline and Placebo Employment Effect Estimates

	(1)	(2)	(3)	(4)	(5)	(6)
		Baseline			**Placebo (pre-Exposure)**	
				2013	2014	2015
RCAxPost	0.002**		0.002**	-0.002	0.004	0.003
	(0.001)		(0.001)	(0.003)	(0.003)	(0.003)
CLExPost		-0.014***	-0.014***	0.012	0.020	-0.012
		(0.004)	(0.004)	(0.015)	(0.017)	(0.010)
CLE		0.576***	0.576***	0.565***	0.577***	0.594***
		(0.123)	(0.123)	(0.122)	(0.123)	(0.125)
Observations	73,104	73,104	73,104	61,384	64,572	68,523
R^2	0.186	0.217	0.217	0.240	0.231	0.223
Time FE	Y	Y	Y	Y	Y	Y
Industry FE	Y	Y	Y	Y	Y	Y

Notes: This table presents the quarterly employment effects of Hurricane Maria on U.S. industries and mainland labor markets industry and time fixed effects. Labor markets are defined as commuting zones following Fowler et al. (2016). All estimates are based on the balanced sample of six-digit NAICS manufacturing industry-CZ pairs. Columns (4) through (6) report the estimates of our falsification tests assuming Hurricane Maria occurred in during the third quarter 2013 (column (4)), 2014 (column (5)), and 2015 (column (6)). Heteroskedasticity robust standard errors are clustered at the U.S. CZ level and reported in parenthesis. Statistical significance at the conventional levels is indicated by *** p<0.01, ** p<0.05, * p<0.1.

measure. As a result, we would falsely attribute the demand-driven growth in manufacturing employment to the disaster-induced decline in Puerto Rican import competition.

While we are unable to test the validity of our parallel pre-trends assumption directly, we can plot average industry and CZ employment across varying levels of exposure. Figures 5.1 and 5.2 respectively show the average of logged quarterly industry and CZ manufacturing employment differentiating across three types of industries and locales: 1) Those below the 10th percentile of exposure; 2) Those between the 10th and 90th percentile of exposure and; 3) Those above the 90th percentile of exposure. Reassuringly, Figures 5.1 and 5.2 illustrate that pre-treatment trends of average industry and CZ manufacturing employment (2016q1-2017q2), indicated by the short-dashed lines, are on similar trajectories regardless of the level of industry or local exposure. Moreover, Figure 5.1 indicates the rise in post treatment employment growth in highly exposed industries relative to those with low to medium RCAs. In contrast, Figure 5.2 displays no clear



5.1: Industry Employment

5.2: CZ Employment

Figure 5: Average Employment Trends by Level of Exposure

effect on CZ employment across varying levels of local exposure post Hurricane Maria, indicated via the shaded area.

In addition to these graphs, we also conduct falsification tests by creating placebo treatments prior to Hurricane Maria. If, indeed, a global demand shock or other factor was driving our findings, it stands to reason that this unobserved determinant also systematically influences industry employment prior to Hurricane Maria and should yield quantitatively and qualitatively similar results in years prior to the disaster. To this end, we create three placebo treatments occurring during the third quarter of 2013, 2014, and 2015 and separately estimate the average placebo treatment effects on industry-CZ employment over a sliding three-year sample period (i.e. the sample for a placebo treatment in 2013 runs from the first quarter 2012 to the fourth quarter 2014).

As expected, we find that level differences across CZs continue to persist. That is, irrespective of the time period under consideration, more exposed urban centers have higher manufacturing employment than less exposed rural labor sheds. Reassuringly, the placebo effect estimates, however, are insignificant and switch signs for each of the 2013 through 2015 placebo treatments (see Table 5, columns (4) through (6)). Consequently, these results support our hypothesis that Hurricane Maria and the associated adverse Puerto Rican supply and trade shocks cause the estimated employment effects and are unlikely to be driven by a contemporaneous demand-side factor.

Encouraged by these baseline findings, we expand the set of control variables and estimate the full model, given by Equation (3), under multiple sample restrictions. Column (1) of Table 6 presents our primary estimates and shows that our baseline findings are robust to the inclusion of state fixed effects, industry-CZ-specific employment pre-trends, and CZ characteristics in addition to the previously included time and industry fixed effects.[7] With regards to these control variables we observe the expected results. Previously fast growing industries in labor markets with greater lagged shares of manufacturing employment, for example, are associated with greater manufacturing employment today. Similarly, an increase in the percent of college-educated and foreign-born residents raises average commuting zone manufacturing employment. Similar to ADH (2013), we also find that the percentage of employment held among women is negatively correlated with average manufacturing-CZ employment.

As one might expect, controlling for these labor market characteristics renders the CLE coefficient insignificant. That is, conditional on local labor market conditions, cumulative local exposure has no inherent effect on manufacturing employment prior to Hurricane Maria. The treatment effects of interest, however, remain consistent in terms of coefficient magnitude and statistical significance with the initial baseline findings. Column (1) of Table 6 shows that relative to pre-treatment averages, a manufacturing industry with an exposure at the 75th percentile experiences a rise in employment by 0.03(=β_1*IQR(RCA)*100%=0.002*0.17*100) percentage points above that of a manufacturing sector with an exposure at the 25th percentile in the aftermath of the adverse Puerto Rican supply shock and reduction in import competition. Moreover, we find that this positive direct impact on manufacturing industries causes a rise in competition for local resources and lowers average manufacturing employment in the most exposed labor markets. Comparing commuting zones at the 75th percentile to those at the 25th percentile of local exposure yields a 0.6% reduction in manufacturing employment post treatment.

To further explore the reallocation effect within labor sheds, we reestimate the model on our balanced sample of non-manufacturing industries. Again, the coefficient estimates on our control

[7] This qualitative and quantitative consistency also holds true if we replace CZ characteristics with the corresponding labor market fixed effects or employ an even more flexible specification that controls for CZ-industry fixed effects in lieu of CZ characteristics and CZ-industry employment pre-trends.

Table 6: Full Model Employment Effects

	(1) Mfg.	(2) Non-Mfg.	(3) Chemicals & Pharma	(4) LIE$>95^{th}$ Percentile	(5) CLE$>95^{th}$ Percentile
RCAxPost	0.002***	-0.117	0.003**	0.004***	0.002
	(0.001)	(0.090)	(0.001)	(0.001)	(0.001)
CLExPost	-0.010**	0.011**	-0.028	0.031*	-0.030*
	(0.004)	(0.004)	(0.019)	(0.018)	(0.014)
CLE	0.213	0.603***	0.131	1.133***	0.314***
	(0.153)	(0.181)	(0.217)	(0.305)	(0.092)
% of employment in mfg (2012)	0.021**	-0.008	-0.050	0.047***	0.253***
	(0.010)	(0.007)	(0.043)	(0.018)	(0.006)
% of college-educated population (2010)	0.033***	0.081***	-0.044	-0.003	0.330***
	(0.012)	(0.007)	(0.031)	(0.019)	(0.008)
% of foreign-born population (2010)	0.040***	0.083***	0.045*	0.055***	-0.152***
	(0.012)	(0.015)	(0.025)	(0.017)	(0.029)
% Puerto Rican population (2010)	0.040	0.125***	0.128	0.006	1.482***
	(0.030)	(0.031)	(0.122)	(0.048)	(0.101)
% of employment held by women (2010)	-0.094**	-0.023	0.020	0.023	-0.185***
	(0.044)	(0.036)	(0.148)	(0.083)	(0.022)
Pre-trend Employment (2012-2016)	0.080***	0.116***	0.039	-0.004	0.033
	(0.023)	(0.009)	(0.034)	(0.027)	(0.029)
Observations	61,308	833,472	2,544	3,120	6,876
R^2	0.343	0.593	0.615	0.640	0.656
Time FE	Y	Y	Y	Y	Y
Industry FE	Y	Y	Y	Y	Y
State FE	Y	Y	Y	Y	Y

Notes: This table presents the quarterly employment effects of Hurricane Maria on U.S. industries and mainland labor markets based on the full model specification including CZ characteristics, industry-CZ-specific employment pre-trend, as well as time, industry, and state fixed effects. We separately estimate the full model effects for all manufacturing (column (1)) and non-manufacturing sectors (column (2)), as well as the chemicals and pharmaceutical sectors in particular (NAICS 325100-325999) (column (3)). The results presented in columns (4) and (5) are respectively based on a sample restricted to the most locally-exposed manufacturing industries and labor markets with the greatest cumulative local exposure. Heteroskedasticity robust standard errors are clustered at the U.S. CZ level and reported in parenthesis. Statistical significance at the conventional levels is indicated by *** p<0.01, ** p<0.05, * p<0.1.

variables, presented in column (2) of Table 6 reflect the expected patterns. Greater past shares in manufacturing employment lower today's non-manufacturing employment, while pre-treatment industry-CZ employment growth is associated with a rise in today's non-manufacturing employment. A greater share of college-educated and foreign-born workers continues to stimulate employment among non-manufacturing sectors and a rise in the share of Puerto Rican descendants exerts a statistically significant positive influence on non-manufacturing employment (column 2, Table 6).

Conditional on these factors, we find that greater CZ exposure to Puerto Rican import competition among manufacturing sectors is associated with greater local employment in non-manufacturing industries prior to Hurricane Maria. In the aftermath of the disaster, we find the expected coefficient estimates. That is, the direct impact of a reduction in Puerto Rican import competition on U.S. mainland non-manufacturing industries (which primarily includes agricultural sectors with only limited exposure) is indistinguishable from zero, while the estimate of the indirect impact of CZ exposure reveals positive synergies between directly affected manufacturing sectors and non-manufacturing sectors located within heavily exposed labor markets. More specifically the estimate in column (2) of Table 6 suggests that a non-manufacturing industry located in a CZ with an exposure at the 75th percentile experiences an average increase in employment of around 0.2($\approx$0.011*0.17*100) percentage points above that of a non-manufacturing sector placed in a CZ with an exposure at the 25th percentile in the aftermath of the adverse Puerto Rican supply shock, reduction in import competition, and resulting growth in the exposed manufacturing sectors. This estimate confirms that all three of the previously highlighted channels are at play when determining the overall response in U.S. mainland labor to the disaster-induced changes in Puerto Rican export capability.

Given the extraordinary position of the chemicals and pharmaceutical industries among the Puerto Rican manufacturing sectors, we also reestimate the primary model restricting the sample to these industries. As one would expect, the average direct industry treatment effect, given in column (3) of Table 6, continues to be statistically significant at the 5%, while the local labor market spillover effects among these selected sectors becomes indistinguishable from zero. Although the magnitude of the direct treatment effect estimate increases only marginally relative to the average manufacturing industry estimate presented in column (1), the economic significance of this finding greatly exceeds that for the average manufacturing sector. Among chemical and pharmaceutical sectors, Puerto Rico's RCA averages 4.46 and has an interquartile range of 1.07 suggesting that a pharmaceutical industry at the 75th percentile of sectoral exposure experiences a rise in employment of 0.3 percentage points above that of a chemical industry at the 25th percentile due to the reduction in Puerto Rican import competition. This estimate represents a 10-fold increase above the treatment effects for the average manufacturing sector. Moreover, it suggests that a U.S. chemical and pharmaceutical sector experiencing average industry exposure grew by 1.2 percentage points more than the average U.S. non-pharmaceutical manufacturing sector in the aftermath of Hurricane Maria.

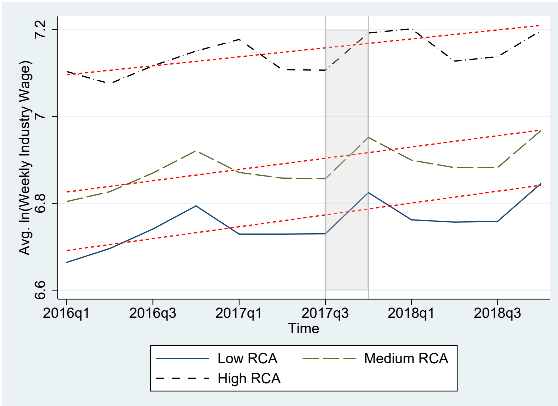
A similar conclusion holds when we limit the sample to the most locally-exposed manufacturing industries (Table 6, column (4)). The direct treatment effect estimate increases to 0.004 and is statistically significant at the 1% level. Based on the interquartile RCA exposure range specific to these industries, the point estimate suggests that in the aftermath of Hurricane Maria a manufacturing industry at the 75th percentile of sector-specific exposure experiences an increase in employment of 1.8 percentage points above that of a manufacturing industry at the 25th percentile. Interestingly, we find that the local spillover effect among these heavily exposed manufacturing industries within a given labor market is, in fact, positive and marginally significant at the 10% level. This reversal in sign may indicate that among those manufacturing sectors that face the greatest Puerto Rican import competition prior to Hurricane Maria the adverse foreign supply shock and resulting industry-specific growth may create external economies of scale within the boundaries of the local labor market.

In contrast to these treatment effect estimates on industries with the highest levels of exposure, a restriction of the sample to all manufacturing industries located within only the most exposed labor markets suppresses the statistical significance of the average industry exposure treatment effect and increases the estimated adverse spillovers within these highly exposed commuting zones (Column (5), Table 6). Among these labor sheds, we find that the average manufacturing industry located in a labor market with exposure at the 75th percentile experiences a reduction in employment 2.2 percentage points greater than that relative to the average manufacturer in a commuting zone with exposure at the 25th percentile post Hurricane Maria. In combination with the previous results, this finding suggests that competition for local workers among manufacturing firms, indeed, increases after the reduction in Puerto Rican import competition and that only the most heavily exposed industries can insulate against this indirect reallocation effect within labor markets.

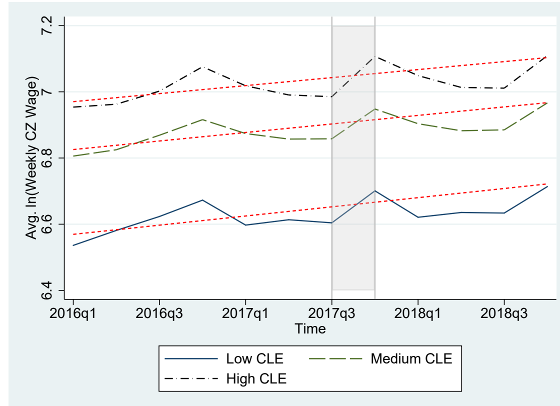
4.1 Additional Margins of Adjustment

As is evidenced by the research of ADH (2013), Acemoglu et al. (2016), Hakobyan and McLaren (2016), and Dix-Carneiro and Kovak (2017), among others, changes in import competition tend to affect labor markets not just at the employment margin, but also in terms of wages, labor force participation, the number of establishments, and transfer payments. In line with the previous literature, we investigate whether the disaster-induced reduction in Puerto Rican import competition also leads to wage and establishment adjustments.

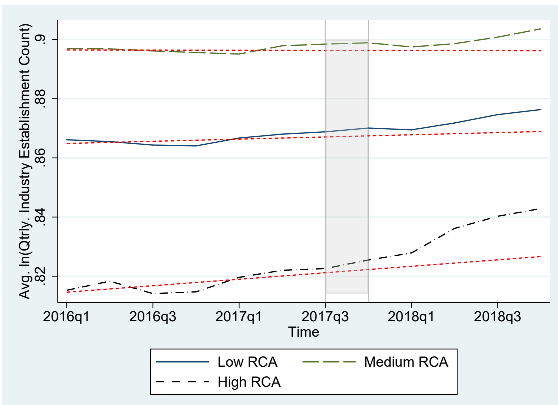
To begin this analysis, we investigate the validity of the parallel pre-trends assumptions and produce wage and establishment Figures analogous to Figures 5.1 and 5.2. Splitting the sample across low (<10th Percentile), medium (10th-90th percentile), and high (>90th percentile) levels of industry and CZ exposure, we plot the average of logged weekly wages and establishment counts at the industry (Figures 6.1 and 6.3) and CZ (Figures 6.2 and 6.4) levels. Consistent with the employment graphs, average wages and establishment counts at the industry and CZ levels are similar across different levels of industry and CZ exposure. Figures 6.1 and 6.2, however, also suggest that there is no clearly discernible wage effect at the industry or CZ levels due to Hurricane Maria and the disruption of Puerto Rican production and exports. In contrast, Figure 6.3 clearly indicates a rise in the number establishment counts across all levels of industry exposure post Hurricane Maria, the largest of which is experienced by sectors with the highest degree of



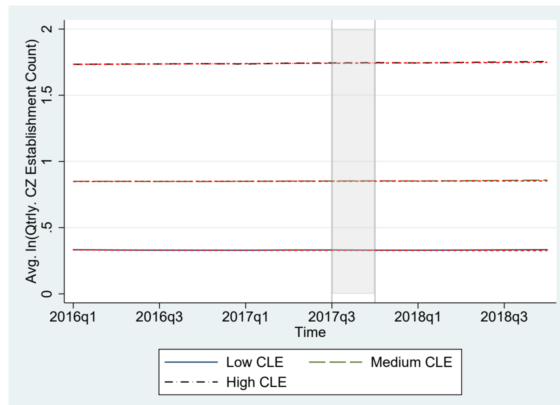
6.1: Industry Wages



6.2: CZ Wages



6.3: Industry Establishment Count



6.4: CZ Establishment Count

Figure 6: Average Wage and Establishment Trends by Level of Exposure

industry exposure.

Encouraged by the consistent pre-treatment trends depicted in Figures 6.1 through 6.4, we estimate the hurricane-induced wage and establishment treatment effects across various sample restrictions, analogous to the primary estimates given in Table 6. We present our wage and establishment count findings in Table 7. Panel A of Table 7 depicts the full model industry- and location-specific treatment effects on average weekly wages, while panel B offers these insights with respect to the number of establishments. Among manufacturing industries (column (1)), we find that average weekly wages experience a statistically significant reduction of around 0.03 percentage points, while the number of establishments tend to increase by 0.03 percentage points when comparing an industry at the 75th percentile of industry exposure to one at the 25th percentile after

Table 7: Full Model Avg. Weekly Wage & Establishment Effect Estimates

	(1) Mfg.	(2) Non-Mfg.	(3) Chemicals & Pharma	(4) LIE$> 95^{th}$ Percentile	(5) CLE$> 95^{th}$ Percentile
Panel A: Avg. Weekly Wage					
RCAxPost	-0.002**	0.057*	-0.001	-0.002	-0.001
	(0.001)	(0.032)	(0.001)	(0.001)	(0.001)
CLExPost	0.007	0.002	-0.006	0.004	-0.028*
	(0.005)	(0.002)	(0.016)	(0.010)	(0.015)
Observations	61,308	833,472	2,544	3,120	6,876
R^2	0.650	0.798	0.564	0.724	0.717
Panel B: Quarterly Establishments					
RCAxPost	0.002***	-0.029	0.002***	0.002**	0.003**
	(0.000)	(0.021)	(0.000)	(0.001)	(0.001)
CLExPost	0.006	0.024***	0.003	0.038**	0.011
	(0.005)	(0.006)	(0.007)	(0.018)	(0.018)
Observations	626,824	2,588,682	42,409	5,472	49,321
R^2	0.447	0.613	0.397	0.696	0.708
Pre-Trend	Y	Y	Y	Y	Y
CZ Controls	Y	Y	Y	Y	Y
Time FE	Y	Y	Y	Y	Y
Industry FE	Y	Y	Y	Y	Y
State FE	Y	Y	Y	Y	Y

Notes: This table presents the average weekly wage (Panel A) and quarterly establishment (Panel B) effects of Hurricane Maria on U.S. industries and mainland labor markets based on the full model specification including CZ characteristics, industry-CZ-specific dependent variable pre-trends, as well as time, industry, and state fixed effects. We separately estimate the full model effects for all manufacturing (column (1)) and non-manufacturing sectors (column (2)) as well as the chemicals and pharmaceutical sectors in particular (NAICS 325100-325999) (column (3)). The results presented in columns (4) and (5) are respectively based on a sample restricted to the most exposed local industries and most exposed local labor markets, defined as commuting zones following Fowler et al. (2016). In both panels, we employ a balanced sample of 12 observations per industry-CZ pairing over the 2016q1 to 2018q4 sample period. While wage and employment statistics are heavily redacted in the QCEW, quarterly establishment counts are available for nearly every industry-CZ combination leading to the notable difference in observations across panels. Heteroskedasticity robust standard errors are clustered at the U.S. CZ level and reported in parenthesis. Statistical significance at the conventional levels is indicated by *** p<0.01, ** p<0.05, * p<0.1.

the adverse Puerto Rican trade shock. These findings are in line with the employment estimates and likely reflect the post disaster reduction in the marginal product of labor as more workers are hired by new businesses in the exposed industries. In contrast, the local exposure treatment effect on average weekly wages reflects the disaster-induced increase in competition for immobile local workers and exhibits a positive influence on wages, although not statistically significant at any of the conventional levels. Similarly, the estimated spillover effect from local exposure on the number of establishments in the aftermath of Hurricane Maria is insignificant.

Turning to the non-manufacturing sectors (see Column (2) of Table 7), we find a marginally significant positive treatment effect on wages at the sectoral level (primarily agricultural industries with low levels of industry exposure) and insignificant industry exposure effects on the number establishments. While wages in the non-manufacturing sector seem to be unaffected by the level of cumulative labor market exposure in response to the reduction in Puerto Rican import competition among manufacturing sectors, the number of establishments in non-manufacturing industries rises with the level of CLE post Hurricane Maria. Comparing the average non-manufacturing industry located in a labor market at the 75th percentile of exposure to one located at the 25th percentile, we find that the adverse Puerto Rican supply shock raises the number of U.S. mainland establishment in this industry by 0.4 percentage points, which supports the previously highlighted increase in locally exposed non-manufacturing employment (see Column (2) of Table 6).

Aside from these wage effects on the average manufacturing and non-manufacturing industries, panel A of Table 7 exhibits largely insignificant manufacturing wage effects across chemical and pharmaceutical sectors (column (3)), those industries with highest degree of local sectoral-specific exposure (column (4)), and those located in labor markets with the highest degree of cumulative local exposure (column (5)). In terms of the treatment effects on the number of establishments across these more selective subsamples, we find consistent positive industry exposure effects that range from 0.2 percentage points for pharmaceutical sectors to 1.2 percentage points for the most locally exposed industries when comparing industries across the restricted sample interquartile range of Puerto Rican RCAs. Similarly, local spillover effects on the number of establishments post Hurricane Maria are positive, but only statistically significant in the case of sectors with the largest degree of local industry-specific exposure (column (4)). For these industries, locating in a labor market at the 75th percentile of CLE, rather than the 25th percentile, raises the number of establishments by nearly 2.1 percentage points - a finding that echoes the aforementioned potential for external economies of scale for these highly exposed local manufacturing industries that also experience an increase in employment.

4.2 Robustness

To explore the robustness of our findings, we test the sensitivity of our primary employment estimates against the use of alternative measures of exposure, varying levels of industry aggregation and labor market definitions, and the inclusion of changes in U.S. exposure to Chinese import competition due to the U.S.-China trade war (Table 8). Additionally, we also investigate the impact of employing an alternative estimation strategy, akin to ADH (2013), where we regress the change, rather than the level, in industry-CZ employment between 2016 and 2018 on industry and local exposure controlling for a varying set of labor market and industry characteristics (see Table 9).

For the ease of comparison, we report the primary employment effect estimates resulting from the reduction in Puerto Rican import competition across all manufacturing sectors in column (1) of Table 8. Underlying these coefficient estimates are the industry-specific measures of RCA, which are derived from Puerto Rican and global exports aggregated at the 6-digit NAICS level. The original trade statistics, however, are only available at the 6-digit Harmonized Schedule (HS), which must be mapped into the NAICS to match the labor market data. To test whether the discrepancies between HS-NAICS concordances influence our results, we calculate Puerto Rican RCAs based on the HS trade data and then aggregate these statistics to the NAICS level. The results presented in column (2) of Table 8 indicate that this alternative strategy of calculating industry and local levels of exposure have no qualitative impact on the primary estimates and slightly increase coefficient estimates in absolute magnitude.

Following the derivations by Kovak (2013), we also test whether the inclusion of non-manufacturing

Table 8: Robustness - Alternative Measures of Exposure & Sample Restrictions

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
		Exposure Measures				**Sample Restrictions**		**U.S.-**
	Primary	HS code	All Sectors	Exports & IPW	NAICS 4-digit	NAICS 3-digit	County	**China Trade War**
RCAxPost	0.002***	0.004***	0.002***		0.003***	0.003***	0.002*	0.002***
	(0.001)	(0.001)	(0.001)		(0.001)	(0.001)	(0.001)	(0.001)
CLExPost	-0.010**	-0.011**	-0.049		-0.008**	-0.013***	-0.006**	-0.008*
	(0.004)	(0.006)	(0.038)		(0.004)	(0.004)	(0.002)	(0.004)
PR Exports				-0.065**				
				(0.027)				
IPW				0.149				
				(0.153)				
Chinese RCA x								-0.013***
Post Trade War								(0.003)
Chinese CLE x								-0.005
Post Trade War								(0.007)
Observations	61,308	61,308	61,308	61,308	71,280	59,304	88,476	61,308
R^2	0.343	0.343	0.343	0.342	0.297	0.427	0.316	0.360
Pre-Trend	Y	Y	Y	Y	Y	Y	Y	Y
CZ Controls	Y	Y	Y	Y	Y	Y	Y	Y
Time FE	Y	Y	Y	Y	Y	Y	Y	Y
Industry FE	Y	Y	Y	Y	Y	Y	Y	Y
State FE	Y	Y	Y	Y	Y	Y	Y	Y

Notes: This table explores the robustness of the quarterly employment effect estimates against alternative measures of exposure and varying sample restrictions. For all specifications, we estimate the full model including CZ characteristics, industry-CZ-specific dependent variable pre-trends, as well as time, industry, and state fixed effects. In column (1), we repeat the primary estimates with an exposure measure based on the sample of manufacturing industries. The results in column (2) employ an exposure measure that is based on a Harmonized Schedule (HS) RCA and aggregated to the NAICS level. Column (3) presents the findings based on an NAICS exposure measure calculated across all industries. Further, we estimate the effect of PR exports and CZ imports per worker (IPW) directly (column (4)). Alternative sample restrictions include aggregations to the NAICS 4-digit (column (5)) and 3-digit (column (6)) levels and disaggregation of labor markets to the county level (column (7)). Lastly, we estimate the disaster-induced employment effects while controlling for changes in Chinese import competition due to the onset of the U.S. China Trade War in July 2018. Heteroskedasticity robust standard errors are clustered at the U.S. CZ level and reported in parenthesis. Statistical significance at the conventional levels is indicated by *** p<0.01, ** p<0.05, * p<0.1.

industries in the determination of CLE truly biases our estimate of the local exposure effect as suggested by Kovak. Indeed, we find corroborating evidence that the inclusion of non-manufacturing employment, for which the RCA is zero, in the calculation of cumulative local exposure understates the changes in local labor demand and consequently overstates the importance of the Puerto Rican trade shock to U.S. mainland labor markets. The biased coefficient estimate on CLE increases nearly five-fold and is rather imprecisely estimated (see Table 8, column (3)).

Table 9: Robustness - Change in Employment (2016 to 2018)

	(1)	(2)	(3)	(4)	(5)
RCA	0.275**	0.330**	0.329**	0.316**	0.299**
	(0.126)	(0.128)	(0.128)	(0.128)	(0.128)
CLE	-1.973***	-1.347*	-1.511**	-0.726	-1.384*
	(0.637)	(0.687)	(0.761)	(0.677)	(0.774)
Pre-trend (2012-2016)		2.163***	2.155***	2.176***	2.138***
		(0.738)	(0.743)	(0.750)	(0.751)
% of employment in mfg (2012)			-0.036	-0.009	0.020
			(0.072)	(0.075)	(0.096)
% of college-educated population (2010)					0.153**
					(0.070)
% of foreign-born population (2010)					-0.041
					(0.056)
% Puerto Rican population (2010)					0.256
					(0.264)
% of employment held by women (2010)					-0.636**
					(0.323)
Observations	6,092	5,109	5,109	5,109	5,109
R^2	0.001	0.005	0.005	0.008	0.009
Census Division FE	N	N	N	Y	Y

Notes: This table presents the estimated impact of Hurricane Maria on the change in U.S. employment between 2016 and 2018. We estimate industry and labor market responses of all manufacturing sectors from the parsimonious baseline model (column (1)) to the full model (column (5)) including CZ characteristics, a industry-CZ-specific employment pre-trend, and Census division fixed effects following ADH (2013). Heteroskedasticity robust standard errors are clustered at the U.S. CZ level and reported in parenthesis. Statistical significance at the conventional levels is indicated by *** $p<0.01$, ** $p<0.05$, * $p<0.1$.

Rather than using the revealed comparative advantage, an alternative approach to measuring labor market exposure was proposed by ADH (2013) and determines the local degree of import competition via changes in weighted imports per worker (IPW) (see Appendix for further discussion). Rather than estimating exposure-varying treatment effects resulting from Hurricane Maria via a DiD framework that interacts industry-specific pre-treatment RCAs with a binary indicator variable distinguishing pre and post disaster periods, this measure of import competition is rather continuous and directly accounts for decline in Puerto Rican exports. Analogous to the primary estimates, the industry-specific exposure is simply approximated via total Puerto Rican exports to the rest of the world (excluding the U.S.), while IPW represents the cumulative local exposure for a given labor market. Our findings are similar to the primary estimates and suggest that a \$1 billion increase in global Puerto Rican exports reduces U.S. mainland manufacturing employment by 6.5%. The largest reduction in global Puerto Rican exports due to Hurricane Maria was experienced in 'Biological Product Manufacturing' (NAICS 325414) and amounted to around \$700 million dollars between 2016 and 2018. Accordingly, our estimate suggests that this sector experienced an increase in employment by 4.6% due to the reduction in Puerto Rican import competition - a reasonable estimate given the anecdotal evidence discussed in section I and the fact that this sector is in the 99th percentile of industry exposure with an RCA of 24.9. In terms of local exposure, the insignificant coefficient estimate on IPW suggests that when controlling for the industry-specific exposure an increase in cumulative local import competition per worker does not add to the decline in U.S. mainland manufacturing.

Aside from these alterations in exposure measures, we also explore the sensitivity of our findings against alternative industry and labor market classifications. In columns (5) and (6) of Table 8, we present the full model treatment effect estimates on manufacturing industries defined at the 4-digit and 3-digit NAICS levels, respectively. In general, the coefficient estimates are consistent in magnitude and gain in statistical significance. In terms of labor market delineations, we reestimate our model using a balanced sample of industry-county, rather than commuting zone, observations. Again, the estimates presented in column (7) of Table 8 are quantitatively and qualitatively similar.

Lastly, we test whether our primary estimates are robust to the inclusion of industry and CZ exposure to Chinese import competition and their respective changes due to the onset of the U.S.-China trade war in July 2018. The results presented in column (8) of Table 8 indicate that the disaster-induced disruption of Puerto Rican import competition has distinctly different manufacturing employment effects from the U.S.-China trade war and that our primary estimates continue to be consistently estimated. Interestingly, the direct industry exposure effect of the U.S.-China trade war has negative implications for U.S. manufacturing employment, while the associated local labor market exposure effect is statistically insignificant (see Column (8) of Table 8). Unsurprisingly, the industry-specific Chinese exposure effects due to the trade war exceed those resulting from changes in Puerto Rican import competition in absolute magnitude suggesting that changes in Chinese import competition exert greater influence on U.S. manufacturing employment than Puerto Rican production.

As a final empirical exercise, we explore the impact of Hurricane Maria and the resulting reduction in Puerto Rican import competition on the growth of industry-CZ employment among manufacturing industries between 2016 and 2018, akin to ADH (2013). Estimating the treatment effects from a parsimonious to full model specification that includes Census Division dummy variables, an industry-CZ-specific pre-trend, and the aforementioned CZ characteristics we find rather robust evidence in support of our primary findings. Focusing on the full model coefficient estimates presented in column (5) of Table 9, we find that a rise in industry-specific exposure from the 25th to the 75th percentile leads to increased employment growth by 0.05 percentage points in response to Hurricane Maria. In contrast, a similar rise in cumulative local exposure from the 25th to the 75th percentile leads to a reduction in employment growth by 0.8 percentage points post disaster.

4.3 Discussion

How do these estimates agree with existing body of research? Most of the previous literature on the local labor market effects of increasing import competition has either focused on the rise in U.S. import shares from China (Autor et al. 2013, 2014; Acemoglu et al. 2016), the tariff reductions against Mexican imports through NAFTA (Hakobyan and McLaren 2016), or the Brazilian trade liberalization (Kovak 2013; Dix-Carneiro and Kovak 2017, 2019). In general, this literature finds that a rise in the exposure to foreign imports reduces local U.S. employment and depresses wages in the directly and indirectly affected industries. As noted by Acemoglu et al. (2016), more specific comparisons are difficult to draw as the exact methodologies and interpretations of coefficient estimates vary across these studies. Hakobyan and McLaren (2016), for example, find that a one standard deviation increase in industry exposure to the tariff reductions from NAFTA between 1990 and 2000 reduces wage growth for high school dropouts by 8.36 percentage points. Similarly, Kovak (2013) finds that a region facing a 10 percentage point larger reduction in prices due to Brazilian trade liberalization also experienced a 4 percentage point larger wage decline.

The preferred estimate of ADH (2013) suggests that a $1,000 increase in Chinese import competition per worker reduces manufacturing employment by 0.596 percentage points, which implies an average decline in employment growth of 0.68 percentage points between 1990 and 2000 and 1.1 percentage points between 2000 and 2007. Acemoglu et al. (2016) find significant responses in the change in U.S. employment both in response to direct import shocks at the industry level (including downstream industries) and to the commuting zone import shock. With respect to the industry effect the authors argue that the one percentage point rise in industry exposure to Chinese import penetration lowered employment by 1.3 percentage points, while local import penetration amplified this decline. In fact, a one percentage point increase in local import penetration is found to reduce the share of CZ's working-age population employed in exposed industries by 1.21 percentage points, which accounts for about 36% of the change in employment when evaluated at the average changes in employment and import penetration between 1999 and 2011.

For the ease of comparison, we evaluate our preferred estimate of the industry exposure employment effect at the average level of RCA among manufacturing sectors and compare our result to overall change in U.S. manufacturing during our sample period. Based on an average RCA of 0.49, our estimate suggests that manufacturing employment in a sector with average industry exposure rose by 0.1(=0.002*0.49*100) percentage points above that of an industry with no exposure and thus, accounts for around 4%(=0.1/2.6*100%) of the average employment growth before and after Hurricane Maria. When we look to the chemicals and pharmaceutical sectors, however, this effect rises sharply. Based on an average chemicals and pharmaceuticals RCA of 4.46, our estimate suggests that manufacturing employment in one of these sectors with average industry exposure rises by 0.89 percentage points, which accounts for more than 50% of average industry employment growth before and after Hurricane Maria. Under the circumstances provided in our study, these estimates are sensible given the facts: 1) that we only consider the change in employment over a five quarter period post Hurricane Maria, rather than the decadal changes considered in previous work; 2) that we consider the effects of a temporary supply shock to Puerto Rico compared to the consequences of long-term shocks, such as China joining the WTO, the U.S. signing NAFTA with Mexico and Canada, and the Brazilian trade liberalization of the early 1990s; and 3) that Puerto Rican chemicals and pharmaceutical production was a major supplier of U.S. medical supplies, which experienced significant shortages after Hurricane Maria.

In terms of the local exposure effect, we find evidence that partly conflicts and partly supports previous findings. That is, among manufacturing sectors our estimates suggest a significant positive relationship between Puerto Rican import competition and U.S. mainland employment growth that counteracts the direct industry impacts. This is at odds with some of the previous literature, which has shown that both industry and local exposure work in concert when it comes to the effects on employment (Acemoglu et al. 2016) and wages (Hakobyan and McLaren 2016). Among non-manufacturing industries located in exposed labor markets, however, we find the expected inverse relationship between import competition and employment growth spilling over among non-manufacturing, yet exposed downstream industries as shown by Acemoglu et al. (2016). Evaluated at the means, our point estimate of 0.011 suggests that the demise of Puerto Rican import competition causes non-manufacturing employment located in a U.S. mainland CZ of average exposure to increase by 0.22(=0.011*0.2*100) percentage points more than that of a similar industry located in a labor market with no exposure. Overall, this accounts for around 9%(=0.22/2.52*100%) of the employment growth experienced among U.S. non-manufacturing sample industries between 2016 and 2018. Taking the specific disruption of import competition and short time horizon into consideration, this is a smaller, but sensible finding in comparison to the previous literature.

As such, our results are unique in this strand of literature and show that even smaller changes in industry and local import competition can affect U.S. manufacturing and non-manufacturing employment over a much shorter time horizon than previously studied. Furthermore, our estimates shine light on the fact that not only trade liberalization, but also global natural disasters can shape domestic labor market outcomes through the channel of import competition. As such our work complements the findings by Boehm et al. (2019), who show that the cross-country industry linkages established through global value chains act as another transmission mechanism through which international natural disasters affect domestic output.

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A Appendix

Following the theoretical derivations by ADH (2013), which go beyond the scope of this paper, one can approximate the cumulative local labor market exposure as a function of the weighted sum of industry-specific Puerto Rican exports to the U.S. (M_{pujt}) relative to the size of the local labor market in manufacturing industries (L_{it}) and weighted by the share of local industry-specific employment (L_{ijt}) relative to total U.S. employment in that particular industry (L_{ujt}):

$$IPW_{uit} = \sum_{j=1} \frac{L_{ijt}}{L_{ujt}} \frac{M_{pujt}}{L_{it}} \tag{4}$$

As the authors discuss, this measure of local exposure may be subject to several concerns regarding the anticipatory adjustments in labor market composition and potential endogeneity between foreign exports and U.S. industry employment due to common demand shocks. In response, the authors propose an instrumental variable approach, whereby labor market composition is lagged and foreign-country exports to the U.S. are instrumented for via foreign-country exports to other developed countries:

$$IPW_{oit} = \sum_{j=1} \frac{L_{ijt-1}}{L_{ujt-1}} \frac{M_{pojt}}{L_{it-1}} \tag{5}$$

Applying this local exposure measure in the context of our study raises a few issues that require modifications from the original ADH (2013) specification. As previously discussed, our analysis focuses on the effects of the unexpected event of Hurricane Maria, rather than the anticipated joining of China in the WTO. Consequently, we lag labor market composition one year rather than a full decade. Moreover, in the absence of data for Puerto Rican exports to the United States, we simply approximate U.S. imports from Puerto Rico with Puerto Rican exports to the rest of the world, rather than employing the 2-stage IV estimator.