The Indirect Effects of Hurricanes: Evidence from Firm Internal Networks*

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Abstract

Are the effects of hurricanes spatially *mitigated* or *propagated* by firms through their internal network of establishments? This paper quantifies the indirect spatial impacts of hurricanes by examining linkages that arise between disrupted and undisrupted regions via plant ties within firms. For a typical county hit by a hurricane in the United States, for every manufacturing job lost upon exposure, I estimate that an additional 0.19 to 0.25 manufacturing jobs are lost across undisrupted distant regions due to spatial propagation within multi-plant firms. The spatial propagation is consistent with mechanisms of resource-constraints and managerial distraction within the firm. Overall, the results indicate that we potentially underestimate the effects of hurricanes by ignoring inter-regional linkages emerging from firms' internal networks.

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1 Introduction

Hurricanes rank among the worst natural disasters in recent years that have inflicted significant costs on the economy. The recent hurricanes Harvey and Irma have jointly accounted for $50bn to $70bn in insured losses to affected areas alone, making 2017 one of the worst disaster years just midway through its hurricane season.[1] The continued warming of the earth's climate implies more severe and destructive cycles of droughts, floods, and hurricanes;[2] which poses additional risks to economic activity.

While prior studies have examined the adverse economic consequences of disasters within disrupted local areas,[3] their overall impacts need not be limited to disaster regions alone.[4] Economic linkages across regions may additionally either disrupt or benefit non-disaster areas in the macroeconomy. Such spatial ties, therefore, render the full impact of hurricanes to be potentially overlooked by assessments solely focused on directly affected regions alone.

In this paper, I assess the extent to which the impacts of hurricanes are spatially *mitigated* or *propagated* by firms through their internal network of plants. Spatial linkages between the disrupted and undisrupted establishments of exposed firms may originate via the resource allocation process (Stein, 1997; Gertner et al., 1994), supply chain linkages (Joskow, 1985; Atalay et al., 2014), or the managerial structure (Bandiera et al., 2011) in these firms. While economic networks also certainly arise directly *between-regions* and *between-firms*, the *within-firm* dimension explored in this paper is equally relevant as multi-plant businesses account for a significant portion of economic activity.[5] These big firms are also vulnerable to hurricanes,[6] with far-from-complete insur-

[1]Insurance estimates are from press releases of RMS, Lloyd's of London and Hiscox as of 09/13/2017.

[2]More intense (if not more frequent) droughts, floods, and hurricanes are potentially the combined result of increased temperatures over land, decreased equator-versus-pole temperature differences, and increased humidity (Field, 2012). Individual hurricanes will drop more precipitation in the future since warmer air can hold more water vapor (Emanuel, 2017).

[3]See Boustan et al., 2017; Strobl, 2011; Belasen and Polachek, 2009.

[4]A familiar narrative immediately after hurricanes Harvey and Irma was that most of the disaster impacts would be regional. Jim Baird, partner and chief investment officer at Plante Moran Financial Advisors, said on CNN Money, "The near-term economic impact of what increasingly appears to be two severe natural disasters in close proximity to one another will be a clear negative, and disruptive to the regional economies in the impacted areas. Having said that, the national economy appears to remain on track".

[5]In the United States, for example, firms that consist of 20 or more plants operate almost half of all the capital stock in U.S. manufacturing (Kehrig and Vincent, 2016).

[6]For example, Chevron Corporation on Friday, 2nd November 2012; blamed Hurricane Isaac (Cate-

ance coverage available to offset their disaster risks.[7]

One logical possibility is that if establishments within the firm are "independent," then plant ties within the firm are inconsequential to any spatial transmission of hurricane shocks. This possibility emerges if establishments operate their production, management, and financing decisions as disconnected units within the firm.

Alternatively, if establishments within the firm are "interdependent," then it is ambiguous if plant ties within the firm spatially mitigate or propagate hurricane impacts. The nature of geographical spillovers within the exposed firm, positive or negative, then depends on the extent to which its disrupted and undisrupted siblings respond as substitutes or complements to the hurricane shock.

On the one hand, the hurricane's impact may be spatially mitigated if undisrupted establishments respond as substitutes and make up for the firm's disaster area losses upon disruptions to their directly-hit siblings. This possibility arises either from resource-constrained firms opting to rebuild capacity in non-disaster areas because of depressed investment opportunities in hurricane regions (Stein, 1997; Giroud and Mueller, 2015), or from undisrupted units operating as substitutes along a horizontal supply chain (Vickery et al., 2003). Since undisrupted regions become "winners" from reallocated economic activity, the effects of hurricanes will be *overestimated* by ignoring such responses within multi-plant firms.

On the other hand, the hurricane's impact may be spatially propagated if undisrupted establishments also incur losses upon disruptions to their hurricane-affected siblings, because of certain complementarities across the firm's establishments. This possibility arises either from resource constrained firms decreasing capacity in both disrupted and undisrupted plants (Gertner et al., 1994; Lamont, 1997; Giroud and Mueller, 2016), complementarities along the supply chain (Joskow, 1985), or top executives in exposed firms being distracted (Schoar, 2002). Since undisrupted establishments are also adversely affected, the effects of hurricanes will be *underestimated* by ignoring such responses within multi-plant businesses.

I tackle this question by utilizing confidential establishment-level microdata provided by the United States Census Bureau and study the responses of multi-plant firms in

gory 1) for losses up to $2.58 billion in net income, $1.23 per share, and $5 billion in revenues.

[7] See Froot, 2001. Appendix A includes more details on the extent of insurance coverage and federal assistance available to exposed firms.

U.S. manufacturing to every hurricane episode in the U.S. between 1995 and 2014.[8] The U.S. Census Bureau provides the most detailed plant-level data for the manufacturing sector, which facilitates the study of a broad range of plant-level outcomes relevant to capital destruction from hurricanes, including investment, employment, productivity and input costs. The choice of a highly tradable sector like manufacturing also potentially helps to isolate demand-side channels that could affect businesses in hurricane areas, in addition to direct supply-side exposure.[9]

The research design to quantify the indirect spatial impacts of hurricanes via firm internal networks proceeds in two steps. In the first step, I estimate the hurricane's direct local impact on all manufacturing activity within disrupted counties. As the choice of a control group is not straightforward, I estimate the direct local effects by matching disaster exposed counties to similar undisrupted counties located in U.S. regions that are equally susceptible to hurricane strikes. The estimated results are consistent with hurricanes adversely impacting local labor supply (Boustan et al., 2017; Strobl, 2011; Belasen and Polachek, 2009) and with partial reconstruction of affected capacity (Hsiang and Jina, 2014; Skidmore and Toya, 2002). Total manufacturing employment in a hurricane hit county falls by 6.8% coupled with an increase in wages, consistent with hurricanes contracting local labor supply. While capital destruction in disaster areas spurs investments by 0.9 percentage points, material procurement and shipments decline in the hurricane post period. These results imply that the reconstruction only partially restores manufacturing capacity in disaster regions, but does not correspond to a complete rebound. Overall, the hurricanes negatively impact manufacturing activity in disaster local areas.

In the second step, I estimate spillover effects within hurricane exposed multi-plant firms by studying the responses of their undisrupted establishments upon disruptions to their directly-hit siblings (illustrated in Figure 1, Page 14). The undisrupted "spillover" establishments are compared to a control group located within the same non-disaster county, comparable in age, size, industry, and owned by similar parent firms. The estimations reveal that hurricanes spatially propagate within partially exposed companies. Employment falls in undisrupted plants by 3.26%, while investment

[8]See Appendix A for a detailed discussion on hurricanes and their relevance to climate change, the extent of insurance coverage and federal assistance available to exposed firms, and the degree of selection from strategic locational choice.

[9]Additionally, a variety of risks unique to manufacturing, such as equipment malfunction, chemical spills, and leaks, and employee injuries; make facilities in this sector highly susceptible to hurricanes.

also falls in undisrupted plants by 0.7 percentage points. These negative spillover estimates reflect complementarities in the responses of disrupted and undisrupted plants within the average hurricane-exposed firm in the economy.

The overall magnitude of the hurricane's within-firm indirect effects relative to the direct local effects indicates that for an average county hit by a hurricane, for every manufacturing job lost in that county, an additional 0.19 to 0.25 manufacturing jobs are lost across undisrupted counties in the United States due to spatial linkages within the firm. These findings indicate that we potentially underestimate the effects of hurricanes by focusing solely on disrupted areas, without considering the spatial implications of intra-firm networks in the economy.

The paper then investigates various mechanisms responsible for these negative spillover effects within the firm. The estimations indicate that resource constraints and managerial distraction are the main channels by which hurricane shocks spatially propagate within the firm, but not supply chain ties.

First, I test for evidence of propagation due to exposed firms facing resource constraints, by using firm size and age as a proxy for a firms' resource constraints.[10] The estimations present statistically significant negative spillovers on both employment and investments in the smallest terciles of firm-size. These losses in the smallest firms are consistent with resource-constrained firms co-insuring the hurricane shock across their disrupted and undisrupted plants (Gertner et al., 1994; Lamont, 1997; Giroud and Mueller, 2016).[11] In order to alleviate concerns that smaller firms may mechanically have a larger revenue share disrupted by a hurricane, all the regressions control for the firm's number of establishments.

Next, I explore the role supply chain linkages in propagating the hurricane shock by studying the heterogeneous responses of exposed firms with and without material procurements or transfers flowing across their establishments. The estimations present no statistically significant spillovers for exposed firms with supply chain ties. The lack of heterogeneity may arise because of very few large firms in the data reporting supply chain linkages, consistent with prior evidence from Atalay et al., 2014 and Ramondo

[10]Common measures of financial constraints generally tend to identify resource constrained firms as those that are smaller, younger and faster growing than unconstrained firms (Farre-Mensa and Ljungqvist, 2016).

[11]Firm size and age bins are defined in the pre-hurricane period to alleviate any concerns of hurricanes themselves imposing financial constraints to exposed firms. See Appendix A.4.1 for a detailed literature review on hurricanes as liquidity shocks.

et al., 2016 that the ownership of vertically linked affiliates is not primarily related to the transfer of tangible goods within the boundaries of the firm, but rather to promote efficient intra-firm transfers of intangible inputs. The lack of heterogeneity may also result because of either measurement error in the plant-reports of intra-firm procurements, or because of quick supply chains adjustments washed away in the annual time dimension of the data.

Last, I investigate the role of CEO distraction in impacting the performance of undisrupted plants within exposed firms. Because top executives are required to divert their limited time towards their affected plants (Bandiera et al., 2011), this diversion of top-level supervision may adversely impact the performance of non-disaster establishments that have no structured plant-level management practices. Utilizing measures of managerial quality at the establishment-level from the Managerial and Organizational Practices Survey (MOPS),[12] I find that labor productivity falls by 23% only in undisrupted establishments that have no structured management practices, while there are no impacts for establishments that possess structured management practices. Therefore, the hurricane shocks causes a *Broken-Toy Effect* within firms with distracted top executives, analogous to the *New-Toy Effect* documented in Schoar, 2002. The evidence is robust to ensure that the lack of spillovers among better-managed establishments is not just explained by the size of their exposed parent firms.

This work contributes to various strands of literature in economics and finance. First, in the field of natural disasters and economic recovery, this paper makes an empirical contribution by quantifying the indirect effects of natural disasters accrued across the undisrupted economy via linkages within the firm. Such indirect disaster effects either remain unaccounted in prior microdata investigations focused only the direct local impact of natural disasters,[13] [14] or remain hidden in country-level studies of environmental shocks that capture both the direct and indirect effects of hurricanes as a

[12] A summary measure of structured management practices ranges from zero to one, with zero (one) indicating that an establishment has little (explicit) structure around all indicators of performance, monitoring, targets and incentives (Bloom et al., 2017).

[13] These prior studies include county-level panel studies on local labor markets (Belasen and Polachek, 2009), personal income growth (Strobl, 2011), out-migration, home prices and poverty (Boustan et al., 2017); establishment-level studies on plant survivorship and creative destruction among non-tradables in Katrina's affected areas (Basker et al., 2012); household- or individual-level studies on income and mortality (Anttila-Hughes and Hsiang, 2013), labor markets (Franklin and Labonne, 2017), fertility and education (Poertner, 2008).

[14] Case studies using specific major events include Basker et al., 2012; Deryugina et al., 2014; Vigdor, 2008 on Hurricane Katrina; Smith and McCarty, 1996 on Hurricane Andrew; Hornbeck and Naidu, 2014 on Mississippi Floods; Hornbeck and Naidu, 2014; Long and Siu, 2016 on the Dustbowl.

single aggregate effect.[15]

Second, this paper speaks to a burgeoning literature in macroeconomics that studies the propagation of local shocks throughout the economy via economic linkages.[16] In the sphere of natural disasters, prior work by Boehm et al., 2015 and Barrot and Sauvagnat, 2016 demonstrate the spatial propagation of disasters through *between-firm* supply chain linkages using firm-level data. The *within-firm* dimension explored in this paper using non-public establishment-level microdata provides a valuable setting where input-output synergies are just one among many other channels by which establishments within the firm interact.[17] This paper is also closely related to a small literature on the propagation of local shocks via firms' internal networks. Both Lamont, 1997 and Giroud and Mueller, 2016 study spillover effects within the firm from plant ties via the internal capital markets of resource-constrained firms. This paper is about natural disaster shocks, and explores many additional channels responsible for spillovers within the firm in addition to resource constraints, and is the first study to document the within-firm propagation of hurricane shocks that disrupt the *supply-side* of highly tradable manufacturing firms.

Last, this paper speaks to theories of the firms' internal organization by deciphering various channels of complementarities between the affected and unaffected establishments of exposed firms that spatially propagate hurricanes impacts. I find that complementary responses within hurricane-exposed firms are consistent with mechanisms of resource constraints,[18] limited CEO time and loose management practices,[19] [20] but

[15]See Hsiang and Jina, 2014; Burke et al., 2015.

[16]Local shocks transmit via input-output networks (Acemoglu et al., 2012; Caliendo et al., 2014; Boehm et al., 2015; Barrot and Sauvagnat, 2016; Acemoglu et al., 2016), financial networks (Acemoglu et al., 2015; Cabrales et al., 2015; Hosono et al., 2016), and social networks (Bailey et al., 2016).

[17]In fact, input-output relationships have been found to be a minor dimension by which plants are interconnected within the firm. Even vertical integrated firms are not found to primarily support the transfer of goods along the production chain within the firm. They are rather found to promote efficient intra-firm transfers of intangible inputs (Atalay et al., 2014; Ramondo et al., 2016).

[18]Gertner et al., 1994; Lamont, 1997; Inderst and Müller, 2003 and Giroud and Mueller, 2016 present theoretical and empirical evidence of resource constrained firms smoothing out liquidity shocks across their establishments.

[19]See Malmendier and Tate, 2009 and Bandiera et al., 2011 on the allocation of CEO time and their limited span of control; and Bennedsen et al., 2006; Bloom and Van Reenen, 2010, and Bloom et al., 2017 on the role of management practices in determining firm performance.

[20]Most notably, the evidence of managerial distraction from hurricane exposure spawning productivity losses within the firm (*Broken-Toy Effect*) is analogous to evidence of productivity losses during acquisitions due to managers distracted towards newly acquired establishments (*New-Toy Effect*) documented in Schoar, 2002. This paper's contribution lies in utilizing exogenous hurricane shocks as a setting to study the adverse productivity consequences of distracted management within the firm.

not supply chain ties.[21]

In the remainder of this paper, Section 2 describes the datasets. Section 3 presents hypotheses on the role of within-firm plant ties in either spatially mitigating or propagating hurricane shocks. Section 4 presents the empirical methodology to quantify the indirect effects of hurricanes through networks within the firm and to explore the mechanisms responsible for such spillovers. Section 5 presents the results and Section 6 concludes.

2 Data

A. Plant-Level Data

Plant-level (or establishment-level) data is obtained using three primary data sets provided by the U.S. Census Bureau. The first data set is the Longitudinal Business Database (LBD), which is compiled from the business register. The LBD is available annually and covers all business establishments in the United States with at least one paid employee. The LBD contains data on employment, payroll, industry, location, and the corporate affiliation of each establishment. It also includes longitudinal identifiers for each establishment. The second data set is the Census of Manufactures (CMF). The CMF is conducted every five years, or "Census Years"[22] and contains information about all manufacturing plants in the United States with at least one paid employee. The third data set is the Annual Survey of Manufactures (ASM). The ASM is conducted in all "non-Census Years" and covers a subset of the plants covered by the CMF. Plants with at least 250 employees are included in every ASM year, while plants with fewer employees are randomly sampled every five years. The CMF and ASM cover approximately 350,000 and 50,000 plants per year, respectively, and contain information on key plant-level variables like capital expenditures, assets, shipments, material inputs, employment, industry, and location. Moreover, the ASM also includes the Management

[21] Recent evidence by Ramondo et al., 2016 and Atalay et al., 2014 suggest that vertical integration promotes efficient intra-firm transfers of intangible inputs rather than the transfer of goods along the supply chain. Early work on supply chain ties within the firm include Monteverde and Teece, 1982; Masten, 1984; Joskow, 1985.

[22] "Census Years" denote any years ending in "2" or "7". For example, 1992, 1997, 2002 and 2007 are Census years, but not 1991, 1993, and 2000. Years that do not end in 2 or 7 are denoted as "non-Census Years".

and Organizational Practices Survey (MOPS), which is a mandatory management survey supplementing the ASM. The MOPS was first conducted in 2010, and data has subsequently been recollected every five years. The survey covers over 30,000 plants across more than 10,000 firms.[23] Since such detailed information on inputs, capital expenditures, output, and management practices is not available for non-manufacturing establishments in the LBD, I focus only on the manufacturing sector for the purpose of this study. The LBD's longitudinal establishment identifiers are utilized to construct longitudinal linkages between the CMF and ASM, and to merge the two data sets into a single longitudinal panel of manufacturing plants. Crucially, the records of establishments' corporate affiliations in the LBD aid in constructing all plant linkages within each firm.

B. Hurricane Data

Information on hurricane strikes is collected from the Storm Events Database (SED), compiled by the U.S. Department of Commerce's National Oceanic and Atmospheric Administration (NOAA). The SED records weather phenomena that satisfy one of the following three criteria - (1) The event is comprised of sufficient intensity to cause injury, death, property damage, and disruptions to commerce; (2) The event is significant based on passing some minimum cutoff based on physical characteristics of the weather phenomena, even if it does not cause any major disruptions as mentioned in point (1);[24] (3) The event is a rare unusual weather phenomena that generates media attention, such as significant meteorological events (record minimum/maximum temperature & precipitation) that may also occur in connection to another event. All storms with windspeeds exceeding 74 miles per hour are recorded in the SED as "Hurricane (Typhoon)". The SED only records all hurricanes in the United States after 1995, and contains information at the county-level on the start and end date, estimates of property and crop damages, injuries and deaths per disaster. This information is provided by the National Weather Service, as well as external sources such as the media, law enforcement, govt. agencies, private companies, individuals, etc. Information on

[23]See the MOPS description in Bloom et al., 2017 and Buffington et al., 2016.

[24]Cutoffs may be classified into two broad categories - (a) a physical characteristic of the event, such as a minimum wind speed for a storm, or the diameter of a hail stone; and (b) exceeding locally/regionally defined advisory. Events below these cutoffs that satisfy criteria number (1) above also enter the dataset.

hurricanes from the SED is collapsed to the county-year aggregation, and merged into the longitudinally linked ASM-CMF panel of manufacturing establishments.

3 Theoretical Possibilities

Theories of the firm's internal organization provide hypotheses to evaluate the role of plant linkages within firms in spatially mitigating or propagating disaster impacts.

Under the *Null Hypothesis*, consider the case where plants within the firm are "independent". In this baseline case, establishments are disconnected in their production, managerial and financing decisions, with no interactions between them within the firm. Such independence provides no implications for any spatial transmission of disaster shocks within the firm.

Under the *Alternative Hypothesis*, consider the case where plants within the firm are "interdependent". In this case, plant within the firm may be interlinked via the firm's resource allocation process[25], supply chain linkages, and the managerial structure within the firm. Under this hypothesis, it is ambiguous if environmental shocks are spatially propagated or mitigated within the firm structure. The nature of spatial spillovers within the firm, positive or negative, are then determined by the extent to which the exposed firm's establishments respond as substitutes or complements to the hurricane disruption.

This section explores three mechanisms by which linkages arise between disrupted and undisrupted operations of exposed firms: (1) the resource allocation process within constrained firms (Stein, 1997; Gertner et al., 1994), (2) supply chain linkages (Joskow, 1985; Atalay et al., 2014) and (3) the limited managerial time of top executives (Bandiera et al., 2011; Malmendier and Tate, 2009).

Resource Constraints: First, resource constraints within the exposed firm's internal capital market may cause undisrupted plants to respond as either substitutes or com-

[25]As a budgetary authority, the firm is capable of both organizing external finance and pooling internal resources from its various establishments. As a strategic authority, the firm's CEO then allocates these combined funds in an internal capital market to its individual plants. This setup of the firm reflects the way large and complex firms like General Electric organize their production and financing operations. While they operate hundreds of plants, only the firm issues bonds, borrows from banks or raises equity (Kehrig and Vincent, 2016).

plements to the hurricane disrupted establishments.

Appendix Figures B1 and B2 illustrate both these possibilities. Consider a firm that has two establishments - one in Jefferson county, Louisiana, and another in Cook county, Illinois. The figures plot each establishment's capital allocation on the x-axis and turnover on the y-axis. Since the firm faces resource constraints, the capital allocations of both plants are equalized below the first best optimal level.

Now, say a hurricane hits only Jefferson county, Louisiana. This hurricane may either not destroy investment opportunities in Jefferson (Case 1), or may depress investment opportunities in Jefferson county (Case 2).

In Case 1, if the Jefferson hurricane only destroys capital but does not hurt investment opportunities locally (Panel A in Appendix Figure B1), the hurricane provides firms the incentive to rebuild capacity in Jefferson county as the marginal returns to invest are higher than in undisrupted Cook county. However, resource constrained firms can only partially tap external markets to reconstruct destroyed capacity in Jefferson. Therefore, these firms make up for their budget shortfalls by mobilizing internal resources from their undisrupted Cook county establishments, until the marginal returns to invest are equalized across exposed and unexposed establishments (Appendix Figure B1, Panel B). Such complementary responses within the firm gives rise to a *negative* spillover effect (Gertner et al., 1994; Giroud and Mueller, 2016), which spatially propagates the shock within the firm dimension.[26] [27]

In Case 2, if the hurricane destroys both capital and investment opportunities in Jefferson county (Appendix Figure B2, Panel A), the resource constrained parent firm will rather rebuild capacity in undisrupted Cook county whose marginal returns to invest are higher than in the exposed county. This rebuilding occurs until the marginal returns to invest across its exposed and unexposed establishments are equalized (Appendix Figure B2, Panel B). Such substitute responses between the firms exposed and unexposed plants gives rise to a *positive* spillover effect (Stein, 1997; Giroud and Mueller,

[26]Firms with no resource constraints will borrow from the external market to finance the rebuilding, with no implications of any spillover effects within the firm.

[27]The coinsurance function of internal capital markets from combining divisional cash flows benefit multi-plant organizations by increasing debt capacity, achieving resource allocative efficiency, and enjoying tax benefits. Thus, internal capital markets provide insurance for divisional cash flow risks in the presence of imperfect capital markets. Therefore, the same coinsurance benefit of a firm's internal capital market translates into contagion within the its network of plants from co-insuring the adverse liquidity shock (Gertner et al., 1994; Stein, 1997; Inderst and Müller, 2003).

2015), which spatially mitigates the shock within the firm dimension.

Supply Chain: Second, the supply chain structure within exposed firms may cause plants to respond as substitutes or complements to the hurricane disruption, which renders the hurricane shock to be spatially mitigated or propagated, respectively. This intuition is illustrated by a simple model of plant interdependencies within a multi-plant firm in Appendix B.2, where the elasticity of substitution governs the negative or positive spillover effect within the firm. On the one hand, substitutability between disrupted and undisrupted operations of exposed firms may manifest along a horizontally structured supply chain (Vickery et al., 2003) with plants producing similar products. In this case, the firm can reallocate economic activity to non-disaster establishments away from their disrupted establishments, thus spatially mitigating the shock. On the other hand, complementarities between the exposed firms plants may occur from supply chain ties via horizontal integration (Vickery et al., 2003) or vertical integration (Monteverde and Teece, 1982; Masten, 1984; Joskow, 1985).[28] Such complementarities negatively impact the firm's undisrupted plants, rendering disaster shocks to spatially propagate within the firm.[29]

Managerial Distraction: Lastly, CEO distraction upon disaster exposure can also hurt the performance of undisrupted plants within the exposed firm. This occurs because top executives may be required to over-invest their limited time and attention (Bandiera et al., 2011; Malmendier and Tate, 2009) on disrupted plants in disaster areas. For the undisrupted establishments within the firm, the withdrawal of CEO attention may negatively impact their performance only if these plants are not well-managed at the establishment-level, and cause hurricane shocks to propagate via the firm network. Such negative spillover effects may be termed a *"Broken-Toy Effect"*, along the lines of

[28]Examples of complementarities along a horizontal supply chain include the manufacturing of tables and chair, or bottles and caps in two separate plants. Complementarities could alternatively arise from interdependencies along a vertically integrated supply chain.

[29]These possibilities are highly likely, given the adoption of lean inventory and made-to-order manufacturing models adopted by firms. However, two recent studies suggest that vertical integration within firms does not appear to primarily facilitate transfers of goods along the production chain (Atalay et al., 2014; Ramondo et al., 2016). Evidence suggests that vertical ownership rather promotes the efficient intra-firm transfer of intangible inputs such as managerial oversight and planning, marketing know-how, intellectual property, and R&D capital.

the *"New-Toy Effect"* documented in (Schoar, 2002).[30]

4 Empirical Methodology

This section presents the empirical methodology to quantify the indirect spatial impacts of hurricanes via firm internal networks, and identify the mechanisms that spawn spillovers within the firm.

These indirect impacts are quantified in two steps. First, Section 4.1 estimates the total direct impact of disasters at the to all manufacturing activity within disrupted county (both single-plant and multi-plant firms). This step sets up the baseline to quantify the magnitude of indirect effects via plant linkages within the firm. Second, Section 4.2 presents methodology to identify *plant-level* spillover effects within partially exposed firms. Subsection 4.2 then expresses the magnitude of these within-firm indirect spatial effects of hurricanes across undisrupted counties, relative to the direct effects within a typical disaster county. Last, Section 4.3 demonstrates methods to test the mechanisms that spawn spillovers within the firm.

4.1 County-Level Direct Impact of Hurricanes

This section presents methodology to estimate the county-level local treatment effect of hurricane exposure to "all" manufacturing activity (both single-plant and multi-plant) inside a typical disaster county. The following difference-in-differences specification is estimated. The unit of analysis is a county (c) and year (t).

$$y_{c,t} = \alpha_c + \alpha_t + \beta^D Exposure_{c,t} + \gamma^{'} \mathbf{X}_{c,t-1} + \epsilon_{c,t} \tag{1}$$

In Equation 1, y is the dependent variable of interest. Fixed effects α_c and α_t absorb any time-invariant characteristics particular to each county and year respectively. *Exposure* is a 0-1 indicator variable that equals one if county c witnesses a hurricane in year t

[30] Schoar, 2002 documents the effects of CEO distraction during conglomerate diversifications as a *"New-Toy Effect"*, wherein diversification by corporates leads to a net reduction in their total productivity. This is because management invest more time focusing on their newly acquired segments, which comes at the expense of inattention in existing establishments.

and five years after. **X** is a vector of time varying county characteristics in the pre-period. The coefficient of interest is β^D, measures the "Direct" impact of hurricanes on exposed counties relative to a counterfactual group of unexposed counties from the northeastern and southern states of the United States that are equally susceptible to hurricane strikes. Standard errors are clustered at the county-level.

The dependent variables at the county-level are employment, investment, material costs, wages and shipments; obtained from the county's establishments owned by both single-plant and multi-plant manufacturing firms. Employment is the logarithm of the number of employees in the county. Investment is the ratio of county-level real capital expenditures to county-level capital stock in the previous year. Real capital expenditures are obtained from plant-level data by deflating capital expenditures by the four-digit SIC deflator from the NBER-CES Manufacturing Industry Database. Capital stock is computed from plant-level data using the perpetual inventory method. Material Costs are the logarithm of the total cost of materials and inputs procured by plants in that county. Shipments are the logarithm of all manufacturing shipments in the county. Wages are the logarithm of county-level payroll divided by employment. To mitigate the effect of outliers, all dependent variables are winsorized at the 1^{st} and 99^{th} percentiles of their empirical distributions.

The vector **X** of time varying controls include county characteristics lagged by one year, to facilitate the comparison of exposed and unexposed counties that are identical. Table 1 presents a t-test of difference in means between the exposed and unexposed counties in the pre-hurricane period. As we can see, the two samples are well-balanced on pre-period characteristics.

Predicting the sign of the direct impact β^D, whether positive or negative, is non-trivial. Investment may be positively or negatively impacted if the hurricane improves or depresses investment opportunities in the disrupted county (See details in Appendix A.4.1). Similarly, employment responses in disaster areas depends on the degree to which hurricanes hurt local labor supply relative to improving or depressing local labor demand (See details in Appendix A.4.2). The final estimated direct impact of hurricanes, β^D, on county-level outcomes in Equation (1) will be a "net" investment or employment impact.

4.2 Spillover Effects Within Firm Networks

This section presents the empirical methodology to estimate the transmission of hurricane shocks via plant-ties within the firm. The purpose of this exercise is to assess a hurricane's indirect costs by additionally accounting spillovers effects within the firm network. The identification strategy is demonstrated by the following thought experiment illustrated in Figure 1.

Consider two firms A and B in Figure 1, each of whom owns establishments located across Jefferson county, Louisiana and Cook county, Illinois. Firm A owns two plants (p_1^A and p_2^A) in Jefferson county and the rest (p_3^A and p_4^A) in Cook county, while Firm B owns two plants (p_1^B and p_2^B) in Cook county. When Jefferson, Louisiana is unexpectedly struck by a hurricane, Firm A becomes "Exposed" as it owns a fraction of plants located in directly-hit Jefferson county, while Firm B continues to be "Un-Exposed" on that account. The disrupted plants of exposed Firm A are then called "Direct Hit" plants and the undisrupted plants are called "Spillover" plants.

I estimate the hurricane's spillover effects within exposed Firm A by focusing within undisrupted Cook county, and comparing Firm A's "Spillover" plants (p_3^A and p_4^A) to a "Control" group of unexposed plants (p_1^B and p_2^B) that are similar in age, size, industry of operation, located in the same non-disaster Cook county, and owned by a similarly sized unexposed parent Firm B which has no establishments located directly in hurricane-hit Jefferson county.

The difference-in-differences specification below estimates the hurricane's "Spillover" impact within the exposed multi-plant firm. The unit of analysis is a plant (p) owned by firm (f), located in county (c) and year (t).

$$y_{p,f,c,t} = \alpha_p + \alpha_{ct} + \beta^S Spillover_{p,f,c,t-j} + \gamma^{'} \mathbf{X}_{p,f,c,t-1} + \epsilon_{p,f,c,t} \qquad (2)$$

In Equation 2, y is the dependent variable of interest. Fixed effect α_p absorbs any time-invariant characteristics particular to each plant. Fixed effect α_{ct} absorbs local shocks at the county-level that independently affect non-disaster plants in addition to spillovers via firm internal networks by matching "Spillover" plants to undisrupted "Control" plants within the same county and year. *Spillover* is a 0-1 indicator variable for plants of exposed firms, which equals one after the first hurricane disruption affects its "*Direct Hit*" sibling and five years after. **X** is a vector of time varying control variables of plant and firm characteristics in the disaster's pre-period, so that spillover and control groups with similar traits are being compared. The coefficient of interest is β^S, which measures the indirect spillover effects of hurricanes within exposed firm. Standard errors are clustered at the county-level, to account for serial and cross-sectional dependence across plants within the same county.

The dependent variables at the plant-level are employment, investment, and labor productivity. Employment is the logarithm of the number of employees. Investment is the ratio of real capital expenditures to capital stock in the previous year. Real capital expenditures are obtained from deflating capital expenditures by the four-digit SIC deflator from the NBER-CES Manufacturing Industry Database. Capital stock is computed using the perpetual inventory method. Labor productivity is the logarithm of value-added per employee. To mitigate the effect of outliers, all dependent variables are winsorized at the 1^{st} and 99^{th} percentiles of their empirical distributions.

The vector **X** of time varying controls include plant and firm characteristics lagged by one year, to facilitate the comparison of treated and control plants that are identical and belong to identical exposed and unexposed parent firms. Table 2 presents a t-test of difference in means between the spillover plants and the control plants in the pre-hurricane period. The last column in Table 2 suggests that spillover plants and exposed firms are on an average bigger than control plants. This imbalance in the sample is not surprising, given that the sample selection only includes firms that have less than a 100% of its establishments in a disaster county, which mechanically obtains bigger exposed firms with a large geographical reach. The regressions will include plant/firm age and size into the vector **X**. Plant age is the logarithm of one plus the age of the plant, plant size is the logarithm of shipments, and firm size is the logarithm of the firm's establishment count. All control variables in the vector **X** are lagged by one year.

Several threats to identification are addressed by the empirical methdology here. Firstly, hurricane spillovers must only originate only through the firm's internal network, and not from local shocks to Cook county that coincides with the hurricane strike in Jefferson. This can occur if Jefferson and Cook counties are neighbors or connected directly by infrastructure, communication, and financial channels suffering hurricane exposures. To alleviate this concern, the full set of county-year fixed effects in the regressions absorb any such local shocks that are common to all non-disaster counties. Secondly, product market rivalry between the "Spillover" and "Control" establishments inside Cook county after the hurricane can overestimate the spillover impact; i.e., "Control" establishments may perform better if the "Spillover" plants perform worse if they are competitors, which further widens the estimated impact. I address this concern by both including and excluding industry-year fixed effects at the 4 digit aggregation, under the assumption that plants are reasonably rivals within the same narrowly defined industry. Therefore, if market rivalry is an issue, the spillover estimates must be overestimated only within the same industry and year.

Quantifying the Indirect Impacts of Hurricanes

Having estimated both the hurricane's direct effects at the county-level and its within-firm indirect effects at the plant-level, the overall magnitude of indirect effects across the undirsupted areas is given below. For a typical county hit by a hurricane, for every unit of direct impact, the total additional indirect impacts across non-disaster counties via spillovers within the firm is given by the ratio:

$$\frac{\text{Spillover Impact (Plant)} \times \overline{\text{\#Siblings}} \text{ (Hurricane County)}}{\text{Direct Impact (Hurricane County)}} \tag{3}$$

The denominator in Equation 3 is the direct county-level change in total manufacturing investment or employment from direct hurricane exposure. This is obtained by multiplying the county-level estimate of hurricane's "Direct" impact (β^D) with the pre-hurricane county-level mean of the respective outcome variable.

The numerator is the estimated spillover effect for a typical unexposed "Spillover" plant within the partially exposed firm, obtained by multiplying the plant-level within-firm *Spillover* estimate (β^S) with the pre-hurricane plant-level mean of the respective outcome variable for the spillover establishment. These plant-level spillovers are then scaled up by the average number of "Spillover" siblings that a typical disaster county is connected with, given by the term $\overline{\text{\#Siblings}}$ (Hurricane County).

On the whole, the ratio quantifies a hurricane's total indirect spatial effects incurred across the undisrupted economy due to within-firm networks upon disruptions to a typical hurricane-county.

4.3 Mechanisms driving Within-Firm Spillovers

This section provides the methodology to empirically investigate the mechanisms that spawn hurricane spillovers within the firm network.

4.3.1 Resource Constraints:

Plants are financially linked within a firm via an internal capital market, which is an internal pool of resources of all the firm's establishments. Upon hurricane exposure, exposed firms that face damages may desire to rebuild if investment opportunities still remain in the disaster area. While financially unconstrained firms can make up for their budget shortfalls by borrowing from the external market, financially constrained firms may only partially shore up their budgets via the external market. In order to make up for their budget shortfalls, resource constrained firms will then mobilize resource internally until the marginal returns to invest across their plants are equalized. This leads to a negative spillover effect, as the exposed firm essentially smooths-out the adverse impact of hurricanes across their disrupted and undisrupted plants (Gertner et al., 1994; Giroud and Mueller, 2016). Alternatively, if investment opportunities are completely destroyed in the hurricane areas, resource constrained firms would rather rebuild capacity outside the disaster area, leading to a positive spillover effect.

I test this hypothesis by estimating the heterogeneous impact of hurricanes by terciles of firm-size (measured by firm employment) and firm-age (age of the firm's oldest establishment). Both these measures proxy common measures of financial constraints, which generally tend to identify resource constrained firms as those that are smaller, younger and faster growing than unconstrained firms (Farre-Mensa and Ljungqvist, 2016). The heterogeneous spillover effects are estimated in Equation (4) by interacting $Spillover$ in Equation (2) with the measure of firm size tercile bins $FirmSize_f$, which categorizes firms by terciles of firm employment (similarly for firm-age):

$$\begin{aligned} y_{pfct} = \alpha_p + \alpha_{ct} + \beta_1^S Spillover_{pfct} + \beta_2^S (Spillover_{pfct} \times FirmSize_f) \\ + \beta_3 FirmSize_f + \gamma^{'} \mathbf{X}_{pfct-1} + \epsilon_{pfct} \end{aligned} \tag{4}$$

If the within-firm spillovers are consistent with mechanisms of resource constraints, the spillover effects must obtain in the smaller terciles of firm-size and firm-age. To alleviate concerns that smaller firms may mechanically have a larger revenue share disrupted by a hurricane, all the regressions control for the firm's number of establishments. Firm size and age bins are defined in the pre-hurricane period to alleviate any concerns of hurricanes themselves imposing financial constraints to exposed firms.[31]

4.3.2 Supply Chain:

Plants can be linked within the firm via supply chain relationships. Therefore, the nature of spillover effects within the firm, positive or negative, are governed by the extent to which the firm's establishments respond as substitutes or complements in the production process.[32]

I test for the supply-chain mechanism by transforming the same hurricane into different treatments, depending on whether the firm possesses internal supply chain linkages. A firm (f) is defined to be supply chain linked using an indicator variable $SupChain_f$, which equals one if the firm's establishments report a positive value of materials and transfers sourced from its sibling plants within the same firm. The heterogeneous spillover effects are then estimated in Equation (5) below:

$$y_{p,f,c,t} = \alpha_p + \alpha_{ct} + \beta_1 Spillover_{p,f,c,t} + \beta_2 (Spillover_{p,f,c,t} \times SupChain_f) + \beta_3 SupChain_f + \gamma' \mathbf{X}_{p,f,c,t-1} + \epsilon_{p,f,c,t} \tag{5}$$

where β_1 estimates the spillover effect for non-supply chain integrated firms, while $\beta_1 + \beta_2$ estimates the spillover effects for supply chain integrated firms. If supply chain linkages matter for the spatial mitigation or propagation of disasters within the firm, then the estimate $\beta_1 + \beta_2$ must be positive if the plants interact as substitutes or negative if complements.

[31]See Appendix A.4.1 for a detailed literature review on natural disasters imposing liquidity shocks on firms.

[32]See Appendix B.2 for a model within-firm supply chain ties and its predictions for cases of either positive or negative spillover effects upon hurricane disruptions.

4.3.3 Managerial Distraction:

In the event of hurricane disruptions, the CEO may have to divert a disproportionate amount of attention towards directly-hit operations, because of the nature of disruption or the politics of their job. Due to limited managerial time and span of control, the resulting top-level CEO inattention towards other unaffected operations may cause negative spillovers if these establishments are poorly managed at the plant-level.

To investigate this hypothesis of managerial time, I utilize each establishment's measure of managerial quality obtained from the Management and Organizational Practices Survey (MOPS) in the U.S. Census data.[33] The management score is the unweighted average of individual scores pertaining to questions in the survey, where each question's score is normalized to be on a 0-1 scale. There are totally 16 questions that measures each quality of establishment-level management across three dimensions - performance, monitoring, targeting and incentive structures. Thus the summary management score is scaled from 0 to 1, with 0 representing a plant that selected the bottom category on all management dimensions, and a 1 representing an establishment that selected the top category on all dimensions.[34]

For the sample of surveyed establishments, I estimate the differential spillover impact for better managed establishments by interacting *Spillover* in Equation (6) with the average management score of each establishment $Mgmt_{p,f}$.

$$y_{p,f,c,t} = \alpha_p + \alpha_{ct} + \beta_1 Spillover_{p,f,c,t} + \beta_2 (Spillover_{p,f,c,t} \times Mgmt_{p,f}) + \beta_3 Mgmt_{p,f} + \gamma^{'} \mathbf{X}_{p,f,c,t-1} + \epsilon_{p,f,c,t} \tag{6}$$

If distraction of the firm's top CEOs upon hurricane exposure incites spatial propagation within firms only for poorly managed undisrupted establishments, then the negative spillover effects must only occur among establishments without explicit management practices to be consistent with the hypothesis.

[33]See the MOPS description in Bloom et al., 2017 and Buffington et al., 2016.

[34]Since the MOPS survey is only conducted in the years 2005 and 2010, I compute every surveyed establishment's management score across 1995-2014 as the average score of its 2005 and 2010 values. While there is an assumption of persistence in plant-level management practices, Bloom et al., 2017 show that the score is persistent between the two surveys.

4.4 Sample Selection and Summary Statistics

County-Level: Direct Impact of Hurricanes

The county-level sample to estimate the hurricane's direct effects in disaster counties includes 24,964 county-year observations in the northeast and southern United States, spanning the years 1995 to 2014.

The sample includes all manufacturing establishments of single-plant and multi-plant firms, excluding those plants whose information is imputed from administrative records rather than directly collected. The sample keeps counties from states located in the northeast and southern regions of the United States as hurricanes commonly affect only these regions. Table 1 presents summary statistics for each county characteristic in both the hurricane exposed counties and unexposed counties. For each plant characteristic, the table reports both the mean and standard deviation (in parentheses, below the mean). The last column reports the difference in means, (with the t statistic in parentheses). The hurricane counties are very similar to the control group of counties, with the exception of county wage and the average plant age in the county. Given the imbalance in these characteristics, all regressions will control for these characteristics lagged by one year.

Plant-Level: Spillovers Effects within Exposed Firms

The plant-level sample to estimate the hurricane's indirect effects via spillovers within the firm includes 350,000 plant-year observations in non-hurricane counties spanning the years 1995 to 2014.

The sample is selected in four steps. First, I exclude plants whose information is imputed from administrative records rather than directly collected (Foster et al., 2008). Second, I follow Giroud and Mueller, 2015; by keeping plants that have a minimum of two consecutive years of data and limit the sample to manufacturing "firms", since detailed plant-level data is available only for manufacturing plants. Manufacturing "firms" are identified by computing the total number of employees for each firm in the LBD, which also includes non-manufacturing plants owned by a firm, and then limits the sample to firms with at least 90% of total employees in the manufacturing sector.[35] Third, I only keep exposed firms that have less than 100% of their establishments in disaster counties, as the analysis of within firm spillovers across disrupted and undisrupted counties is possible only within partially-exposed firms. Fourth, I drop observations before 1995 because the SED only records hurricane data after this period.

Table 3 provides summary statistics separately for each plant in the Spillover plants, Remaining plants and the full sample. For each plant characteristic, the table reports both the mean and standard deviation (in parentheses, below the mean). For the most part, the “Spillover" plants are evidently bigger than control plants on an average. This imbalance in the sample is not surprising as the sample selection mechanically picks spillover plants owned by big hurricane-exposed-firms with a large geographical spread (firms that have less than a 100% of its establishments in a disaster county). On an average, the spillover group of plants have 408 employees and invest 9% of their capital stock in capital expenditures, whereas the remaining plants have 86 employees and invest about 12% of their capital stock. Given the imbalance in size, all regressions will control for lagged plant shipments as a measure of plant size, and the firm's establishment count as a measure of firm size so that the “Spillover" and “Control" group of plants are similar in size and owned by similarly sized parent firms.

5 Results

5.1 County-Level Direct Impact of Hurricanes

Table 4 presents the estimated county-level direct impact of hurricanes on employment, investment and material costs in disaster counties. Each outcome variable in Table 4 has two columns, where the second column includes a state-year fixed effect to eliminate any concerns that U.S. states can cope with the hurricane strikes differently.[36]

First, employment in directly hit counties falls by 5.8%-6.8% in columns (1) and (2). Relative to a mean of 3,065 manufacturing jobs in a typical disaster county, these im-

[35] The 90% cutoff (instead of 100%) addresses measurement issues arising from auxiliary establishments of the firm being assigned non-manufacturing industry codes, even though they support the firm's manufacturing plants (Giroud and Mueller, 2015).

[36] For example, some states may have more capable governers than others to secure federal funds from FEMA to finance post-disaster rehabilitation processes.

pacts correspond to a decrease of about 211 manufacturing jobs after a typical hurricane strike in the county. This reduction in employment is consistent with hurricanes as a labor supply shock, as wages increase by 1.2%-1.7% (For wages, see Appendix Table C1, Columns (1) and (2)).[37]

Figure 2 explores the dynamics of the local treatment effect in two years before and five years after the county's hurricane year. The negative employment impacts begin in the year after the hurricane and persist for the five years after the hurricane strike.

These employment results are consistent with prior studies that estimate the direct impacts of disasters on local labor markets. Labor supply is found to be negatively affected by hurricanes (Belasen and Polachek, 2009), because of increased mortality risks and diminished amenity values upon disruptions to the local area, which cause out-migration to go up, house prices to drop (which tempers the out-migration rate) and poverty to rise (as poor people stay back) in equilibrium (Boustan et al., 2017). Post disaster transfer payments also come in the form of non-place based programs, such as unemployment insurance and income maintenance programs (Deryugina, 2016). Such non-place based programs may also cause people not to stay back in disaster areas.

Next, investment in exposed counties rises by 0.9 percent points after a typical hurricane strike (columns (3) and (4) in Table 4). Relative to the mean investment rate of 9% in a typical disaster county, this impact corresponds to a 10% increase in the manufacturing investment rate. The rebuilding occurs as these storms primarily destroy capital in disaster counties, which suggests that hurricanes do not completely depress investment opportunities locally. This amounts to approximately $4.5 million in capital expenditures, which is 1% of the county's manufacturing capital stock rebuilt after the hurricane episode. However, this rebuilding may not reflect a complete reinstallation and rebound in production. Material procurements and shipments in disaster counties also fall by 5% and 6% respectively (For shipments, see Appendix Table C1, Columns (3) and (4)). Figure 2 explores the dynamics of the local treatment effect of hurricanes on investment and procurement costs. Rebuilding happens immediately after the disaster strikes, while material costs begin to fall two years after the hurricane strike.

[37]Hurricane shocks to labor supply can manifest either as a uniform shock across the wage distribution, or as a disproportionate shock to lower-wage workers which can also increase the average wage among remaining employees in the county. The Federal Reserve Bank of Atlanta's macroblog has some evidence that sheds light on this point.

These estimates of the hurricane's direct investment effects may be interpreted as a *net* increase in the rate of physical capital investment (Skidmore and Toya, 2002), as the estimate captures both a positive and negative investment shock in the local area. On the one hand, hurricane exposure translates into positive investment shock if capital is damaged and the marginal product of capital increases. On the other hand, hurricanes may also hurt investment opportunities locally by hurting liquidity availability, which increases the adjustment costs of capital. In this case, any post-disaster reconstruction would then entail building'lesser but resilient' infrastructure, even as the future risk of hurricanes hurt the long run expected return to physical capital in the local area.

Overall, the county-level direct effects of hurricanes are harmful to manufacturing activity in the local area, by adversely affecting local labor supply, material procurements and shipments, aided by some captial reconstruction.[38]

5.2 Spillover Effects Within Firm Networks

Table 5 presents the estimated within-firm spillover effects of hurricanes to a typical "Spillover" establishment of the partially exposed firm. Each of the plant-level outcome variables in Table 5 has three columns, which differ from each other by the inclusion of additional fixed effects to facilitate comparison within the narrowly defined Industry or Industry-Year.

The estimated results show negative spillover effects across all outcome variables, and is statistically significant for employment. In columns (1) to (3), employment at the "Spillover" plant falls by 3.26% to 3.51% relative to a "Control" plant within the same county-year. This magnitude corresponds to about 13 jobs cut by the disaster exposed firm in the undisrupted establishment, relative to a mean of 408 employees in the plant. Column (2) estimates this differential impact by including a full set of industry-year fixed effects (industry narrowly defined at 4 digit NAICS level) to check for any upward bias in the spillover estimates from competition between the "Spillover" and "Control" plants; i.e., because the hurricane strike can simultaneously benefit the "Control" plant and hurt the "Spillover" plant. However, the estimated spillover effect re-

[38]Since the choice of a control group for hurricane affected counties is not obvious, I additionally perform matching upon county-observables using Coarsened Exact Matching (CEM). The results remain unchanged in Appendix Table C2, although the statistical significance on the investment and material cost results are lower.

mains almost unchanged across columns (1) and (2). The impact is slightly smaller but similar in Column (3), which includes a full set of industry fixed effects (4 digit NAICS level) to account for any time invariant industry characteristics that may impact the results. For example, both the “Spillover" and “Control" plants may be additionally impacted from supply chain exposure to other exposed firms. Column (3) alleviates this concern to the extent that plants within the same narrowly defined industries possess very similar supply chains linkages across geographies, and that these linkages are costly to change in the short run. The other columns pertaining to investment and labor productivity show statistically insignificant results in these headline estimates. Investment falls by 0.7 percentage points and labor productivity falls by 1% to 3%.

Figure 3 explores the dynamics of the estimated plant-level spillover effects within the firm. The time period spans the hurricane’s two year pre-period and five-year post-period. There are no significant differences between the spillover and control group of plants in the hurricane’s pre-period across all outcomes. The negative employment impacts begins in the year after the hurricane and continues falling gradually, only significant in the fifth year of the post-hurricane period. The gradual employment response by firms may be explained in two ways. First, firms may very slowly update their expectations about the vulnerability of their disaster area plants before readjusting inputs across their disrupted and undisrupted establishments. Delays in the settlement of insurance claims (Pryshchepa et al., 2015) can cause firms to adjust only after they are eventually compensated for their losses in the hurricane area. Secondly, long delays in federal assistance for disaster areas reparations may imply that firms adjust their expectations gradually, after assessing the extent of their longer term hurricane risks. Data from FEMA suggests that the average duration of public disaster assistance may last up to six years from the date the presidential disaster declaration is announced.

In addition to the identification concerns discussed in this section, Appendix B.2 includes further results on the estimated spillover effects. First, in order to understand if the environmental disasters and their dispersion within the firm network matter in the broader macroeconomy, it is important to determine if these negative spillover effects arise from multi-plant firms with or without a concentrated geographical dispersion. For this reason, I estimate the spillover effects for firms that operate in single or multiple states in the United States. Appendix Table C4 shows that the headline negative spillover effects on employment remain intact for multi-state firms, suggesting that these spillover effects spatially matter in the broader economy.

Next, I also check if these negative spillovers manifest within firms operating establishments in a single industry, or also within firms operating across multiple industries, to understand the industrial spread of these hurricane spillover effects. In Appendix Table C5, I find that the negative spillover manifest within firms operating establishments in both single and multiple industries (2 digit NAICS). The findings are similar to prior work by Lamont, 1997 which studies within-firm spillover effects in response to the 1986 oil price shock, and presents evidence of only cross-industry negative spillovers within-firms (i.e., within-firm propagation from oil to non-oil subsidiaries). This paper additionally shows that the within-firm spillover occur for firms that operate both single-industry and multiple-industry operations.

5.3 Quantifying the Indirect Impacts of Hurricanes

Having estimated both the direct local effects and indirect within-firm spillovers of hurricanes, this section expresses the total indirect effects of hurricanes due to within-firm networks per unit of direct impact using the methodology presented in Section 4.2.

In the denominator of Equation (3), the estimated hurricane direct effects at the county-level amounts to 211 manufacturing jobs lost and $4.5 million spent in reconstruction in the disaster's aftermath. Each of these affected counties have on an average of 4.3 “Spillover" establishments due to the geographical spread of exposed firms ($\overline{\#\text{Siblings}}$ in the numerator of Equation (3)). This expression in the numerator scales up the plant-level spillover losses of 13 manufacturing jobs and US$347 million in capital expenditures.

For every manufacturing job lost in the disaster area, an additional 0.19 to 0.25 manufacturing jobs are lost across the undisrupted counties in the United States due spatial linkages via plant ties within multi-plant firms. Similarly, for every dollar of reconstructed capital in the disaster county, an additional $0.06-$0.08 is lost across undisrupted counties in the United States due to within-firm spillover effects. These headline results form the most important contribution of this paper, and have two important implications. First, the impacts of hurricanes may be potentially underestimated by focusing solely on direct local impacts and overlooking economic linkages within firms. Second, there are potential channels of complementarities in the way establishments within the average exposed firm respond to the hurricane shock. The subsequent sections investigate the relevant channels of plant ties that are responsible for the spatial propagation of shocks within the firm.

5.4 Mechanisms of Within-Firm Spillovers

Resource Constraints: If the within-firm spillovers are consistent with mechanisms of resource constraints, the spillover effects must obtain in the smaller terciles of firm-size and firm-age.[39]

Table 6 presents heterogeneous within-firm spillovers of hurricanes by firm size, separated into three bins by terciles of firm employment. To alleviate concerns that smaller firms may mechanically have a larger revenue share disrupted by a hurricane, all the regressions control for the firm's number of establishments. Consistent with the mechanism explored here, the table presents statistically significant negative spillovers for both employment and investments only in the first tercile of firm size. There are no statistically significant effects on investments in the larger bins of firm size, while employment also falls in the second tercile.

The magnitudes are similar to the headline results of within-firm spillovers. Investment falls in the first tercile by 0.017 percentage points after the hurricane strike, corresponding to a 15% loss in the investment rate and $347,000 cut in capital expenditures. Similarly, employment also falls by 7.3% (13.6 jobs) in the smallest tercile. These losses in the smallest firms may be consistent with theories and empirical evidence of risk smoothing within financially constrained firms upon a liquidity shock to the firm, as in Gertner et al., 1994 and Giroud and Mueller, 2016. To the extent that the smallest exposed firms are more likely to be financially constrained, the negative investment spillovers may be explained by the ability of multi-plant firms to distribute their liquidity shocks from hurricane exposure across disrupted and undisrupted plants via their internal capital markets, while firms in larger terciles make up for their budget shortfalls by borrowing from the external capital market. The additional employment losses in the second tercile of firm size may be explained by other mechanisms among some bigger firms such as supply chain ties, which will be explored in the next section. Using firm age bins in Appendix Table C3 obtains negative spillovers effects on

[39]Common measures of financial constraints generally tend to identify resource constrained firms as those that are smaller, younger and faster growing than unconstrained firms (Farre-Mensa and Ljungqvist, 2016).

all outcome variables in the middle tercile of firm age, and no statistically significant effects for the youngest or the oldest firms.

Supply Chain: Table 7 reports the heterogeneous spillover effects of hurricane strikes within firms that are supply chain integrated and firms that are not. Supply chain integration is defined as an indicator variable *SupChain*, which equals one if plants within the firm report material procurements and transfers from other plants within the same firm. As we see in the table, there is no meaningful heterogeneity along the supply chain dimension. There are three explanations for this result. First, there are very few firms in the data that report supply chain ties across their establishments, and are among the bigger firms in the size distribution. This is consistent with prior evidence from Atalay et al., 2014 and Ramondo et al., 2016 that within firm input-output relationships are a minor dimension by which plants are interconnected, and that supply chain relationships dominate between-firm relationships rather than ties within the firm. Second, it could also be the case that supply chains adjust relatively quickly, which may be lost in the annual time dimension of the census data. Last, there is a concern that plants do not reliably report their material procurements within the firm, which creates measurement error in the supply chain definition.

Managerial Distraction: Hurricane episodes require the exposed firms' top executives to divert their limited managerial time towards the firm's disrupted establishments. Given that CEO time is limited, the resulting inattention towards other unaffected operations in the hurricane's aftermath may potentially hurt their performance if these establishments are poorly managed at the plant-level. To be consistent with this hypothesis, the negative spillover effects of hurricanes must only occur among establishments without explicit management practices.

Table 8 presents the heterogeneous response of non-disaster plants within the exposed firm, depending on their managerial quality at the plant-level. It presents two coefficients, one which is the spillover effects on the omitted management score category, and the other which is spillover indicator interacted with a continuous measure of the establishment's management score. Establishment-level management scores range between zero and one, with an average of 0.56 and a standard deviation of 0.15. The sample size in the estimations drops to 75,000 plant-year observations across 1995-2014 as it only includes firms surveyed in the MOPS survey.

Consistent with the mechanism of CEO distraction, Columns (5) and (6) present clear evidence of a productivity fall that is only limited to poorly managed establishments within the exposed firm. "Spillover" establishments with managerial quality below one standard deviation of the mean managerial score have a productivity fall of 23%, while the productivity impact is zero for establishments with structured management practices (managerial quality above one standard deviation of the mean). The evidence is robust to controlling for the interaction of Spillover by lagged firm size, which ensures that the well-managed plants do not reflect bigger parent firms that can employ more talented plant managers.

Interestingly, Columns (1) to (4) demonstrate statistically insignificant impacts for employment and investment, respectively. To the extent that labor and capital reallocations will always be a result of conscious decisions of the firm management and not distracted decisions, limited managerial time must only affect the productivity of the incumbent undisrupted plants that aren't well managed.

The evidence is consistent with managerial distraction an important mechanism of disaster spillovers within the firm. Real world reports of managerial distraction after hurricane Irma include quotes on Forbes Magazine from the CEO of Blue Dog Business Service, Ron Eliot Dichter, "*One of the things that really stood out with this last storm, Irma, is that watching the cone of uncertainty regarding the hurricane's path is a surefire recipe for production not happening in the office. It became almost as distracting as March Madness and bracket picking. There wasn't a conversation that happened that didn't ultimately turn to where this was storm going.*"

The evidence of negative productivity spillovers within firms with distracted top executives may be termed as a *Broken-Toy Effect*, analogous to the *New-Toy Effect* documented in Schoar, 2002. Studying episodes of corporate diversification among conglomerates, Schoar, 2002 demonstrates that shifts in management focus towards newly acquired divisions causes productivity declines to its incumbent firms. While Schoar, 2002 does address concerns that the *New-Toy Effect* reflects distracted management rather than endogenous corporate strategies, the exogenous nature of hurricanes in this paper's setting additionally lends clarity on the adverse productivity consequences of distracted management within large multi-plant firms. These findings also relate to literature on the allocation of CEO time, a scarce resource, which has implications for the firm's governance and performance due to the CEOs' limited span of control (Malmendier and Tate, 2009; Bandiera et al., 2011). Overall, these results suggest that the quality of management practices at the establishment-level is crucial to determining a firm's overall performance (Bennedsen et al., 2006; Bloom and Van Reenen, 2010).

6 Conclusion

This paper demonstrates that the economic consequences of environmental disasters are potentially underestimated by overlooking spatial linkages within multi-plant firms, between their disrupted and undisrupted establishments. For a typical county hit by a hurricane in the United States, for every job lost upon exposure, I estimate that an additional 0.19 to 0.25 jobs are lost across the undisrupted distant regions from spatial propagation within multi-plant firm networks. These negative spillovers within the exposed firm are found to originate from resource constraints and managerial distraction in the hurricane's aftermath, but not necessarily from supply chain linkages within the firm.

In order to position these findings in the aggregate, the extent of underestimation also depends on the extent to which inter-firm and inter-regional linkages in the economy spatially mitigate or propagate disaster shocks. Thus, the within-firm dimension explored here is a small piece in the larger picture. Regarding the between-firm dimension, evidence by Boehm et al., 2015 and Barrot and Sauvagnat, 2016 also shows spatial propagation of disasters via supply chain linkages. However, it remains an open question if between-firms product market rivalry could potentially mitigate these impacts as competing undisrupted firms may exploit new opportunities from business stealing. This is an important area of future research to pursue in the context of natural disasters and their indirect effects via business linkages.

These findings have important policy implications. First, the transmission of disasters via economic linkages has important implications for estimates of the social cost of carbon, which is a measure of the economic harm from climate change's impacts (expressed as the dollar value of the total damages from emitting one ton of carbon dioxide into the atmosphere). This paper's evidence of spatial propagation suggests that the current central estimate of $40 per ton may be potentially far lower than the true costs of carbon pollution. Second, given the vast rehabilitation finances channeled exclusively towards directly hit regions, the evidence in this paper suggests that fiscal assistance must also assess the disasters' economic implications for undisrupted regions. Third, the findings of shock propagation to undisrupted counties suggest that our traditional difference-in-difference estimates of the direct impacts of disasters are potentially underestimated, because the control groups in these empirical settings may also face indirect disruptions from economic linkages. Last, from a climate justice point of view, many studies have documented the unequal burden of global warming across countries at the global-level, with poor countries facing the brunt of unmitigated climate change (Burke et al., 2015, IMF World Economic Outlook 2017). This paper additionally shows evidence of the unequal impacts of hurricanes across-businesses within a country, with smaller firms more prone to spreading the adverse impacts of hurricanes across regions. As smaller firms are more likely to be resource constrained, government policies must provide small firms with better access to finance and disaster-insurance, for both pre-disaster adaptation and post-disaster recovery. Adaptation policies must encourage investments in climate-smart infrastructure in disaster-prone areas, while post-disaster aid must be well-targeted and quickly implemented to maintain investment opportunities for firms located in disaster areas.

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Appendix

A Hurricanes and Economic Activity

A.1 Brief History and Description

Hurricanes are severe tropical storms that form in the waters of the Atlantic and eastern Pacific oceans, with winds that exceed 74 miles per hour. A hurricane's formation and trajectory are stochastic and difficult to predict more than a few days in advance, which makes a county's exposure exogenous in its timing, intensity, and duration (Hsiang and Jina, 2014; Baker and Bloom, 2013). Hurricanes are frequent, and the U.S. has about 1.75 hurricanes on an average every year (Averages are based on http://www.aoml.noaa.gov/hrd/tcfaq/E19.html). The large territorial coverage that hurricanes can randomly disrupt make them very important. Their reach not only includes coastal regions from Texas to Maine, but also an extensive inland area affected either by floods or by high winds. Most U.S. establishments are exposed to them either directly, or by floods, heavy rain, and high wind accompanying hurricanes (Dessaint and Matray, 2015), and these storms are known to cause severe damages (Pielke, 2005).

Between 1996-2014, 17 hurricanes made landfall in the United States. Table A1 lists each hurricane's year of landfall, name, intensity on the Saffir-Simpson Scale (ranging from one (low) through five (high)), and the extent of property damages caused. The least damaging of them was Hurricane Arthur, a category two storm, that caused US$3.25 million in total damages, while the most damaging was Hurricane Katrina (category 3) that accounted for US$108 billion in total losses. The association between storm intensity and property damages is not strongly positive, because a hurricane's damage is not only governed by just wind speed, but also by its windspan and the density of population and wealth concentrated along exposed areas. For example, Hurricane Sandy, a category one storm, accrued very large damages due to its record windspan spanning 1,100 miles and covering the entire seaboard from Maine to Florida. Alternatively, Hurricane Bertha was a category 3 storm that passed over scarcely populated areas along the Mid-Atlantic states, North Carolina and New England. That being said, two out of three hurricanes have inflicted damages of at least US$ 1 billion or more. This is because any hurricanes are extreme storms, and are only classified as one upon breaking the 74 mph windspeed barrier.

A.2 Hurricanes vs. Other Extreme Weather Events

Natural disasters may generally be categorized in two groups. The first is climatic or meteorological events such as droughts, floods, heatwaves, tropical storms/hurricanes, etc.; and the second is geological events such as earthquakes, volcanoes, avalanches and sinkholes. The impacts of global warming are clearly understood to increase the intensity (and probably frequency) of meteorological events. However, it is unclear if warmer climates directly impact geological events, in addition to any complex interactions that exist between climatic and geological events.

While this study is interested in all meteorological disasters relevant to climate change, the choice of hurricanes is motivated by their clear definitions of onset, high frequency and territorial coverage, stochastic trajectory and predictive difficulty, and severity of damages. This lends empirical convenience to identify the impacts; i.e. hurricanes are a very tight shock that are clean to measure in terms of timing and geographic impact. Equivalently, it would implicitly be an instrument variable strategy of studying the impact of all natural disasters using hurricanes as an instrument. Implicitly, hurricanes provide a clean source of causal variation, and the resulting estimations using hurricanes strikes may be used as a stand-in for a more general result. Regarding their link to climate change, there is a growing consensus that, around the world, the hurricanes's strength and associated rainfall levels are likely to increase (Knutson et al., 2010; Seneviratne et al., 2012; Christensen et al., 2013). Observational data show a marked increase in hurricane activity in the Atlantic since the 1970's (Emanuel, 2007).

A.3 Hurricanes and Firms

The hurricane impacts the firm and the local economy in various ways. Most directly, the hurricane damages the exposed firm's capital in the disaster area, like buildings, machinery or inventories.The hurricane also hurts the local economy by disrupting local transportation, power and infrastructure, which disallows employees and managers to commute and work. Depending on the sector of operation, hurricanes can be different treatments for different businesses. On one hand, non-tradable sectors such as restaurants, hotels and retail supermarkets will primarily face disruptions to both their supply- and demand-side, since they locate close to the customer base they serve. On the other hand, predominantly tradable sectors like manufacturing will face disruptions mostly to their supply-side or operations, since they service the demand of a customers base located either inside or outside their local area. In the manufacturing sector, its very nature makes facilities and employees susceptible to disasters, because a range of risks unique to manufacturing, such as equipment malfunction, chemical spills and leaks, and employee injuries.

Insuring Disaster Risk: Firms can buy insurance to offset disaster risk, but coverage is far from complete. Froot, 2001 shows that hurricane insurance premiums are much higher than the value of expected losses, because of the market power enjoyed by the small number of catastrophe reinsurers. Garmaise and Moskowitz, 2009 provide evidence that such inefficiencies in the hurricane insurance market lead to firms only partially covering their risk, which hurts both bank financing and firm investment. Also, while both the public and private sector offer insurance against losses arising from hurricane strikes, the volume of insurance claims relative to the volume of total damages suggests that only about half of all firms take out such policies (Henry et al., 2013). Pryshchepa et al., 2015 show that delays in the settlement of insurance claims imply that even those firms that are insured against hurricane losses can experience financial (rather than economic) distress until they are eventually compensated for their losses.

Disaster Relief & Assistance: Post disaster relief programs come from various sources such as the federal government and its agencies like the Federal Emergency Management

Agency (FEMA), state and local-level agencies, federal and National Guard soldiers, non-governmental organizations, charities, and private individuals. A county can receive specially targeted federal disaster aid if the U.S. president declares a disaster in the county. Federal money flows into these areas in the form of either public assistance for reparations of public structures, or private assistance towards individuals and businesses such as grants, subsidized loans, unemployment insurance and tax relief. The Federal Emergency Management Agency (FEMA) also provides personnel, legal help, counseling, and special unemployment payments for those left unemployed by a disaster. Two-thirds of these funds were dispersed through unemployment insurance and income maintenance programs that are not tied to the recipient's location. Although long-term recovery spending is provided in some cases, most disaster-specific transfers to individuals occur within six months of a declaration, and most public infrastructure spending occurs within two to three years (Deryugina, 2016).

Strategic Locational Choice: Firms could manage their risks by locating away from disaster vulnerable areas, which may induce some selection issues regarding the kind of multi-plant firms analyzed in this paper. Indeed, since land does not stay unused, there will be a slight skew of activity on vulnerable lands that is more hurricane resistant. As the probability of hurricanes go up, this skew will get much stronger. There is also some historical precedent for this - factories built in hurricane prone areas will be more aware of their risks and better insure themselves, and some others may locate far away from coastal regions to protect themselves (like Disneyland in Orlando, Florida). However, global warming has made the risk of extreme weather events more intense/likely. Thus, any selection on geographical dispersion based on a persistent perception of climate change may not be perfect over time. In fact, Rappaport and Sachs, 2003 and Pielke, 2005 document that U.S. economic activity has overwhelmingly concentrated over time at its ocean and Great Lakes coasts, even with the imminent threats of rising sea-levels and severely destructive disasters.

This selection is also governed by the value of land in equilibrium. Imagine hurricanes are more common in some areas than others. Then, the value of land will be depressed in more vulnerable areas, because it is less valuable. In an extreme case, if hurricanes are really common, then it would push down the value of land to zero and firms would find it worthless to locate there.[40] But in reality, hurricanes are not that common at the county-level, because they can hit a wide area with a stochastic trajectory. However, given that they all possess some risk of disaster exposure, the selection on manufacturing and locational choice is then driven by the alternative use of land in hurricane counties. One one hand, if the alternative use of land is unaffected by hurricanes, then only manufacturing would move away from these areas and cause some selection. On the other hand, if the alternative use of land is equally depressed by hurricanes for any kind of activity, then it just reduces the value of the land. In equilibrium, firms would just use the land and the price would just offset by falling.[41]

[40] A good example is California and its risk of earthquake exposure. If there was no earthquake risk, property prices would've been higher. However, the risk induces firms not undertake activities that require large brick buildings, or expensive capital. Thus there will be some amount of selection on the sort of capital being built.

[41] Boustan et al., 2017 documents that land prices fall in response to natural disaster exposure.

A.4 Impact of Hurricanes within Disaster Areas

A.4.1 Predictions on Investment

The impact of hurricanes on county-level investment depends on the extent to which hurricanes hurt the firm's liquidity relative to improving or depressing investment opportunities. Therefore, this section considers two cases - first, hurricanes as liquidity shocks; and second, hurricanes as shocks to investment opportunities. The final estimated impact of hurricanes on county-level investment in Equation (1) is to be interpreted as "net" investment losses or gains that embody these two forces.

Regarding firm liquidity, hurricanes are found to be a negative shocks to firms in five distinct ways. Firstly, borrowing costs increase upon exposure because hurricanes - (a) hurt firm collateral value by destroying capital in the form of damaged buildings, machinery and other assets; and (b) increase monitoring and moral hazard problems that diminish a lender's maximum leverage tolerance. Secondly, as collateral values fall and monitoring costs go up, lenders raise interest rates and reduce loan amounts (Cerqueiro et al., 2014). Thirdly, hurricanes also increase the participation costs of seeking finance from the external capital markets. Exposed firms end up exerting more effort by applying to more financial institutions and by spending more time completing credit applications, due to a strain on the available pool of credit servicing post-disaster financial needs (Collier et al., 2016; Hosono et al., 2016; Chavaz, 2014). Fourth, hurricanes cause a sudden shock to the perceived liquidity risk of managers, who increase the amount of corporate cash holding in response and further hurt the amount of internal cash flow available to firms (Dessaint and Matray, 2015). Lastly on insurance, both insurance take-up in the disaster's pre-period and insurance payouts in the post-period are imperfect. Only about half of all firms take out disaster policies (Henry et al., 2013), because of high premiums (Froot, 2001), trade-offs to utilize productive resource towards production or towards disaster mitigation (Collier et al., 2016), and long delays in settling insurance claims (Pryshchepa et al., 2015).

Regarding investment opportunities, whether or not hurricanes improve or depress returns to invest is an empirical question. On one hand, hurricane exposure may translate into a positive investment shock because capital damage increases both the marginal product of capital as well as reconstruction demand. On the other hand, investment opportunities may fall upon hurricane exposure, because adjustment costs of capital also go up (a negative liquidity shock increases the opportunity cost of resources taken away from production), reconstruction may only entail building back lesser but resilient infrastructure, and disaster risk hurts the long run expected return to physical capital (Skidmore and Toya, 2002). Therefore, hurricanes may cause the *net* rate of physical capital investment to go up or down, depending on how these forces play out.

A.4.2 Predictions on Employment

The impact of hurricanes on county-level employment depends on the degree to which hurricanes hurt local labor supply relative to improving or depressing local labor demand. Therefore, this section considers two cases - first, hurricanes as labor-supply shocks; and second, hurricanes as shocks to labor-demand. The final estimated impact of hurricanes on county-level employment in Equation (1) may be interpreted as either losses or gains in “net" employment, as the local treatment effect is a reduced form that embodies the all these forces.

Local labor supply is found to be negatively impacted by hurricanes (Belasen and Polachek, 2009), because of increased mortality risks and diminished amenity values upon disruptions to the local area, which cause out-migration to go up, house prices to drop (which tempers the out-migration rate) and poverty to rise (as poor people stay back) in equilibrium (Boustan et al., 2017). Post disaster transfer payments also come in the form of non-place based programs, such as unemployment insurance and income maintenance programs (Deryugina, 2016). Such non-place based programs may also cause people not to stay back in disaster areas.

Local labor demand's response to hurricane exposure is an empirical question. On one hand, labor demand shifts positively, because businesses substitute away from physical capital towards labor if disaster risk reduces the expected return to physical capital (Skidmore and Toya, 2002). Additionally, establishments may increase labor demand to fill vacancies that arise, because people either migrate out of disaster areas or do not go to work due to private property and public infrastructure damages. On the other hand, local labor demand could also fall because firms leave the local area, or because wages rise in response to a negative shift in labor supply (Belasen and Polachek, 2009). Overall, hurricanes may cause *net* employment to go up or down, depending on the way demand and supply forces play out in the disaster counties' local labor markets.

B A Model of Plant Interdependencies Within the Firm

B.1 Resource Constraints and Spillover Effects

The nature of spatial spillovers within a resource constrained firm (positive or negative) are governed by the extent to which the firm's operations respond as substitutes or complements in the firm's resource allocation process. These responses depend on the extent to which the hurricane disrupts investment opportunities in the disaster area.

Consider a firm that has two establishments: one in Jefferson county, Louisiana, and another in Cook county, Illinois. Appendix Figures B1 and B2 plot each establishment's capital allocation on the x-axis and turnover on the y-axis.

The firm also faces resource constraints, which limits the extent to which the firm can borrow from the external markets to finance their projects. Since the firm faces resource constraints, the capital allocations of both plants are below its first best optimal level.

Now, say a hurricane hits only Jefferson county, Louisiana. This hurricane may either not destroy investment opportunities in Jefferson (Case 1), or may depress investment opportunities in Jefferson county (Case 2).

In Case 1, if the Jefferson hurricane only destroys capital but does not hurt investment opportunities locally (Panel A in Appendix Figure B1), the hurricane provides firms the incentive to rebuild capacity in Jefferson county as the marginal returns to invest are higher than in undisrupted Cook county. However, resource constrained firms can only partially tap external markets to reconstruct destroyed capacity in Jefferson. Therefore, these firms make up for their budget shortfalls by mobilizing internal resources from their undisrupted Cook county establishments, until the marginal returns to invest are equalized across exposed and unexposed establishments (Appendix Figure B1, Panel B). Such complementary responses within the firm gives rise to a *negative* spillover effect (Gertner et al., 1994; Giroud and Mueller, 2016), which spatially propagates the shock within the firm dimension.[42] [43]

In Case 2, if the hurricane destroys both capital and investment opportunities in Jefferson county (Appendix Figure B2, Panel A), the resource constrained parent firm will rather rebuild capacity in undisrupted Cook county whose marginal returns to invest are higher than in the exposed county. This rebuilding occurs until the marginal returns to invest across its exposed and unexposed establishments are equalized (Appendix Figure B2, Panel B). Such substitute responses between the firms exposed and unexposed plants gives rise to a *positive* spillover effect (Stein, 1997; Giroud and Mueller, 2015), which spatially mitigates the shock within the firm dimension.

B.2 Supply Chain Linkages and Spillover Effects

The nature of spatial spillovers within the firm (positive or negative) are then governed by the extent to which the firm's operations interact as substitutes or complements in the production process.

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This intuition is illustrated by a simple model of plant interdependencies within a multi-plant firm. Consider a firm F that operates two divisions, A and B, located in separate geographies. Each of these divisions produces output y_A and y_B. The firm's total production Y_F is then a combined homogeneous output of its individual operations, aggregated by a Constant Elasticity of Substitution (CES) production function

$$Y_F = \left[\alpha_A y_A^{\frac{\sigma-1}{\sigma}} + \alpha_B y_B^{\frac{\sigma-1}{\sigma}} \right]^{\frac{\sigma}{\sigma-1}} \tag{7}$$

where Y_F is the firm's total output; y_A and y_B are each division's individual outputs, respectively; α_A and α_B are share parameters, with $\alpha_A + \alpha_B = 1$; and σ is the elasticity of substitution

[42]Firms with no resource constraints will borrow from the external market to finance the rebuilding, with no implications of any spillover effects within the firm.

[43]The coinsurance function of internal capital markets from combining divisional cash flows benefit multi-plant organizations by increasing debt capacity, achieving resource allocative efficiency, and enjoying tax benefits. Thus, internal capital markets provide insurance for divisional cash flow risks in the presence of imperfect capital markets. Therefore, the same coinsurance benefit of a firm's internal capital market translates into contagion within the its network of plants from co-insuring the adverse liquidity shock Gertner et al. (1994); Stein (1997); Inderst and Müller (2003).

that determines the degree of substitution between operating divisions A and B.

Each division A and B within the firm produces outputs y_A and y_B using labor (l) as a variable input, and capital (k) as a fixed input within a cobb-douglas production function given below:

$$y_i = A k_i^{\gamma} l_i^{1-\gamma} \qquad \forall i,j \in \{\text{A,B}\} \ \& \ i \neq j \tag{8}$$

Given the wage rate w for labor and rental rate r for capital, the optimal prices $\{p_A, p_B\}$ of divisional outputs $\{y_A, y_B\}$ to firm F is set to the marginal cost (MC) of producing an extra unit of divisional output. In the short run, each divisions's marginal costs measured by the labor margin is given by:

$$p_i = MC_i = \frac{w}{(1-\gamma)\left(\frac{k_i}{l_i}\right)^{\gamma}} \qquad \forall i,j \in \{\text{A,B}\} \ \& \ i \neq j \tag{9}$$

Given a vector of prices $\{p_A, p_B\}$ to operate divisions A and B, the firm chooses each division's production levels $\{y_A, y_B\}$ to minimize its total operating costs, subject to a production constraint.

$$\begin{aligned} \min_{y_A, y_B} & \; p_A y_A + p_B y_B \\ \text{s.t.} & \;\; \overline{Y_F} = \left[\alpha_A y_A^{\frac{\sigma-1}{\sigma}} + \alpha_B y_B^{\frac{\sigma-1}{\sigma}}\right]^{\frac{\sigma}{\sigma-1}} \end{aligned} \tag{10}$$

Solving the firm's optimization problem yields the following optimal output levels for each division $i \in \{A, B\}$

$$y_i^*(p_i, p_j, \alpha_i, \alpha_j, \sigma) = \frac{\left(\frac{p_i}{\alpha_i}\right)^{-\sigma}}{\left[\alpha_i\left(\frac{p_i}{\alpha_i}\right)^{1-\sigma} + \alpha_j\left(\frac{p_j}{\alpha_j}\right)^{1-\sigma}\right]^{\frac{\sigma}{\sigma-1}}} \times \overline{Y_F} \qquad \forall i,j \in \{\text{A,B}\} \ \& \ i \neq j \tag{11}$$

and the firm's cost function to operate at the optimal output levels $\{y_A^*, y_B^*\}$

$$C^*(p_A, p_B, \alpha_A, \alpha_B, \sigma) = \left[\alpha_A^{\sigma} p_A^{1-\sigma} + \alpha_B^{\sigma} p_B^{1-\sigma}\right]^{\frac{1}{1-\sigma}} \times \overline{Y_F} \qquad \forall i,j \in \{\text{A,B}\} \ \& \ i \neq j \tag{12}$$

Now consider a hurricane that disrupts operations in plant j. When a hurricane hits division j, it destroys the capital stock of division j. The depletion of division j's capital stock raises the firm's short run cost of operating division j, or p_j, because

$$\frac{\partial p_j}{\partial k_j} = \frac{\partial MC_j}{\partial k_j} = \frac{-\alpha}{(1-\alpha)} w k^{-\alpha-1} L^{\alpha} < 0 \qquad \forall i,j \in \{\text{A,B}\} \;\; \& \;\; i \neq j \tag{13}$$

As a result, the nature of spillover effects within the firm - positive or negative - is determined by the change in the firm's expenditure share on plant i, upon an increase p_j. This is given below:

$$\begin{aligned} \frac{\partial}{\partial p_j}\left(\frac{p_i y_i^*}{C^*}\right) &= (\sigma-1) p_i \underbrace{\left(\frac{p_i p_j}{\alpha_i \alpha_j}\right)^{-\sigma}}_{>0} \underbrace{\left[\alpha_A^{\sigma} p_A^{1-\sigma} + \alpha_B^{\sigma} p_B^{1-\sigma}\right]^{-2}}_{>0} \qquad \forall i,j \in \{\text{A,B}\} \;\; \& \;\; i \neq j \\ \implies \quad \frac{\partial}{\partial p_j}\left(\frac{p_i y_i^*}{C^*}\right) &= \begin{cases} < 0\,, & \text{if } \sigma < 1 \\ = 0\,, & \text{if } \sigma = 1 \\ > 0\,, & \text{if } \sigma > 1 \end{cases} \end{aligned} \tag{14}$$

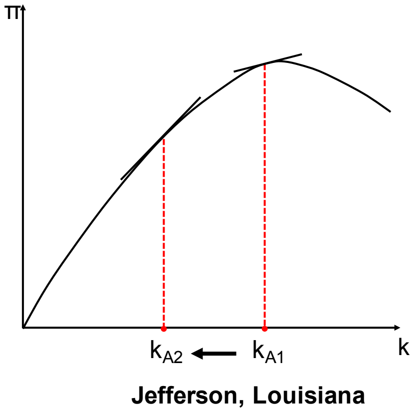
Equation 14 demonstrates that the nature of spillover effects within the firm is determined by the degree of substitutabity between its operations i and j. When $\sigma = 1$, any change in the firm's relative operating costs p_i/p_j from an increase in p_j will be matched by a proportional change in outputs y_i/y_j that keeps the firm's relative expenditure shares on both operations constant. However, when $\sigma < (>)1$, any change in the firm's relative operating costs p_i/p_j results in a less (greater) than proportional change in outputs y_i/y_j, which reduces (increases) the firm's expenditure share in division i. At the extremes, $\sigma = 0$ is the Leontief case on one hand, where the divisions are perfect complements to each other, and disruptions to plant j devastates the firm's operations in both i and j. On the other hand, $\sigma = +\infty$ is the perfect substitutes case, and the firm can continue production with operation j. Therefore, the extent of negative/positive spillover effects within the firm from disruptions to division j, depends on the degree of complementarity/substitutability between the two operations i and j.

Appendix Tables and Graphs

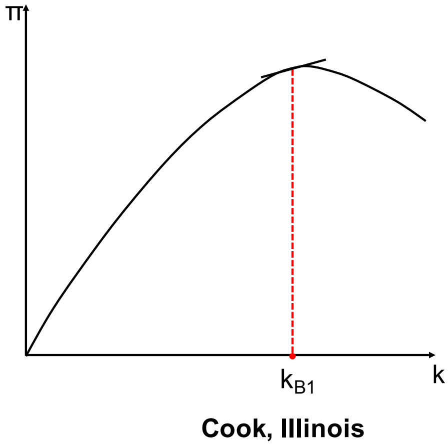
Table A1: U.S. Hurricanes that made Landfall: 1996 - 2014

Year	Hurricane	Saffir-Simpson Category (Scale 1-5)	Property Damage (in US$ billion)
1996	Fran	3	$3.20
	Bertha	2	$0.33
1997	Danny	1	$0.10
1998	Bonnie	2	$1.00
	Earl	1	$0.08
	Georges	2	$9.72
1999	Bret	3	$0.02
	Floyd	2	$6.90
	Irene	1	$15.60
2002	Lili	1	$0.93
2003	Claudette	1	$0.18
	Isabel	2	$5.37
2004	Alex	1	$0.01
	Charley	4	$15.10
	Gaston	1	$0.13
	Frances	2	$9.80
	Ivan	3	$18.80
	Jeanne	3	$6.80
2005	Cindy	1	$0.32
	Dennis	3	$2.20
	Katrina	3	$108.00
	Rita	3	$12.00
	Wilma	3	$21.00
2007	Humberto	1	$0.05
2008	Dolly	1	$1.10
	Gustav	2	$4.30
	Ike	2	$29.50
2011	Irene	1	$15.60
2012	Isaac	1	$2.40
	Sandy	1	$71.40
2014	Arthur	2	$0.003

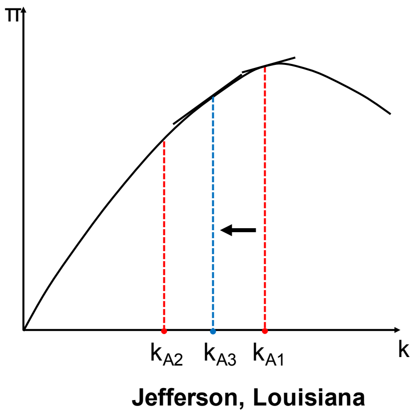
Source: National Hurricane Center of the National Oceanic and Atmospheric Administration (NOAA), U.S. Department of Commerce.



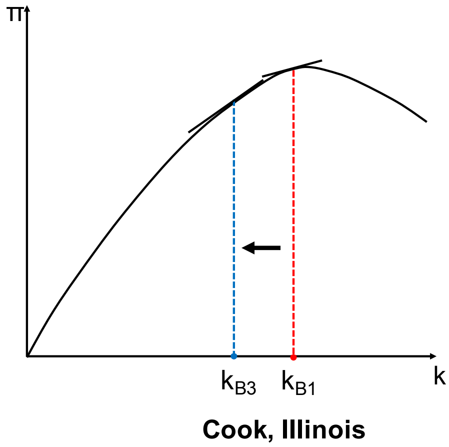
(A) Capital Destruction by Hurricane, Investment Opportunities Unaffected



(A) No Hurricane



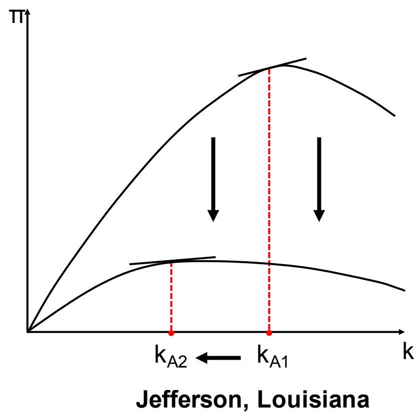
(B) Partial Rebuilding (Constrained Borrowing)



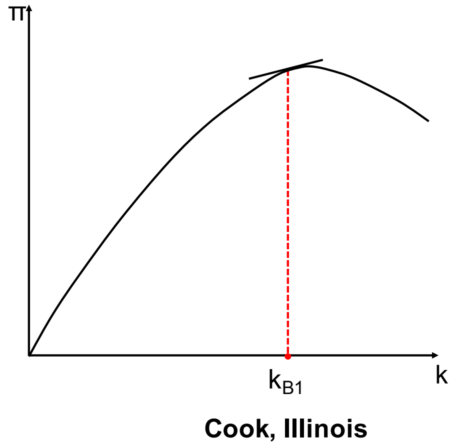
(B) Negative Spillover Effect

Figure B1: Spillovers Within Firms: Resource Constraints (Case 1)

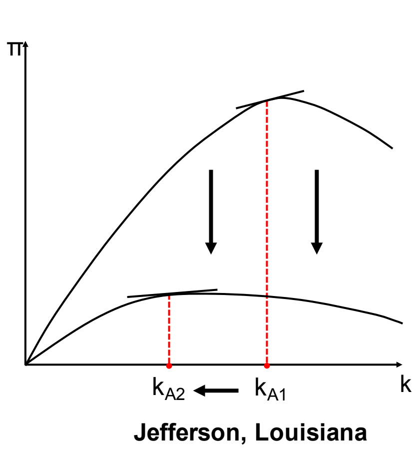
This figure illustrates the case where hurricane disruptions cause **negative** spillover effects within exposed firms that face resource constraints.
In Panel A, the resource constrained firm's pre-hurricane capital allocations $\{k_{A1}, k_{B1}\}$ across Area 1 and Area 2 are below the first best optimal level, with the marginal returns to invest equalized across the two divisions.
Consider Case 1: When the hurricane only destroys capital in Area 1 (from k_{A1} to k_{A2}) but does not hurt investment opportunities in Area 1, the marginal returns to rebuild in Area 1 is higher than in Area 2 (See Panel A).
In response, the borrowing constrained firm may only be able to partially rebuild capacity in Area 1. In order to equalize the marginal returns to invest across its disrupted and undisrupted divisions, the resource constrained firm can rebuild lost capital in Area 1 by mobilizing internal resources (from Area 2) by the budget shortfall, until the marginal returns to invest are equalized across Area 1 and Area 2. Panel B illustrates this new post-hurricane capital allocations at $\{k_{A3}, k_{B3}\}$.



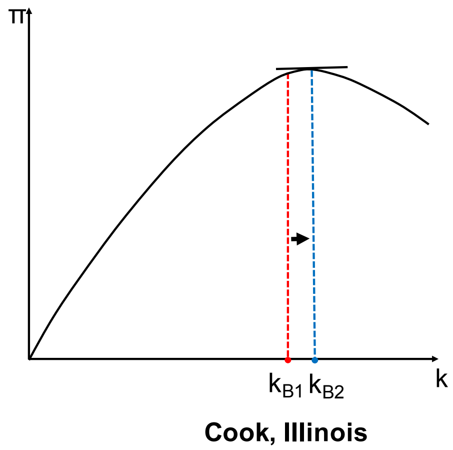
(A) Capital and Investment Opportunities destroyed by Hurricane



(A) No Hurricane



(B) No Rebuilding



(B) Positive Spillover Effect

Figure B2: Spillovers Within Firms: Resource Constraints (Case 2)

This figure illustrates the case where hurricane disruptions cause **positive** spillover effects within exposed firms that face resource constraints.

In Panel A, the resource constrained firm's pre-hurricane capital allocations $\{k_{A1}, k_{B1}\}$ across Area 1 and Area 2 are below the first best optimal level, with the marginal returns to invest equalized across the two divisions.

Consider Case 2: When the hurricane both destroys capital and investment opportunities in Area 1 (k_{A1} to k_{A2}), the marginal returns to rebuild in Area 1 is lower than in Area 2 (See Panel A).

In response, the borrowing constrained firm will then choose to rebuild capacity in Area 2, until the marginal returns to invest across its disrupted (Area 1) and undisrupted divisions (Area 2) are equalized. Panel B illustrates the new post-hurricane capital allocations at $\{k_{A2}, k_{B2}\}$.

Table C1: County-Level Impact of Hurricanes (A)

	Log(Wage)		Log(Shipments)	
	(1)	(2)	(3)	(4)
Exposure (5 years)	0.0128*	0.0177**	-0.0628*	-0.0589*
	(0.0076)	(0.0083)	(0.0321)	(0.0349)
Observations	24,964	24,964	24,964	24,964
R-squared	0.8256	0.8295	0.9232	0.9258
County Fixed Effects	Yes	Yes	Yes	Yes
Year Fixed Effects	Yes		Yes	
State-Year Fixed Effects		Yes		
Control Variables	Yes	Yes	Yes	Yes

Notes: Exposure is an indicator that equals one if the county witnesses a hurricane in its county in that year and five years after. Log(Wage) is the logarithm of total county's single and multi-plant wage per employee. Log(Shipments) is the logarithm of total county's single and multi-plant shipments. Sample period is 1995 to 2014. p-value significance: * $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$.

Table C2: County-Level Impact of Hurricanes (B)

	Log(Employment)		Investment		Log(Materials)	
	(1)	(2)	(3)	(4)	(5)	(6)
Exposure (5 years)	-0.0665**	-0.0907***	0.0077*	0.0054	-0.0676*	-0.0584
	(0.0298)	(0.0344)	(0.0045)	(0.0055)	(0.0409)	(0.0441)
Observations	24,964	24,964	24,964	24,964	24,964	24,964
R-squared	0.9629	0.9642	0.5986	0.6088	0.9702	0.9728
County Fixed Effects	Yes	Yes	Yes	Yes	Yes	Yes
Year Fixed Effects	Yes		Yes		Yes	
State-Year Fixed Effects		Yes		Yes		Yes
Control Variables	Yes	Yes	Yes	Yes	Yes	Yes
Dep Var Mean	3,065.1	3,065.1	0.09	0.09	841,461	841,461
CEM Matching	Yes	Yes	Yes	Yes	Yes	Yes

Notes: Exposure is an indicator that equals one if the county witnesses a hurricane in its county in that year and five years after. Log(Employment) is the logarithm of total county's single and multi-plant manufacturing employees. Investment is the ratio of county-level capital expenditures divided by the past year's capital stock. Log(Materials) is the logarithm of one plus county aggregate cost of materials procured. Sample period is 1995 to 2014. p-value significance: * $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$.

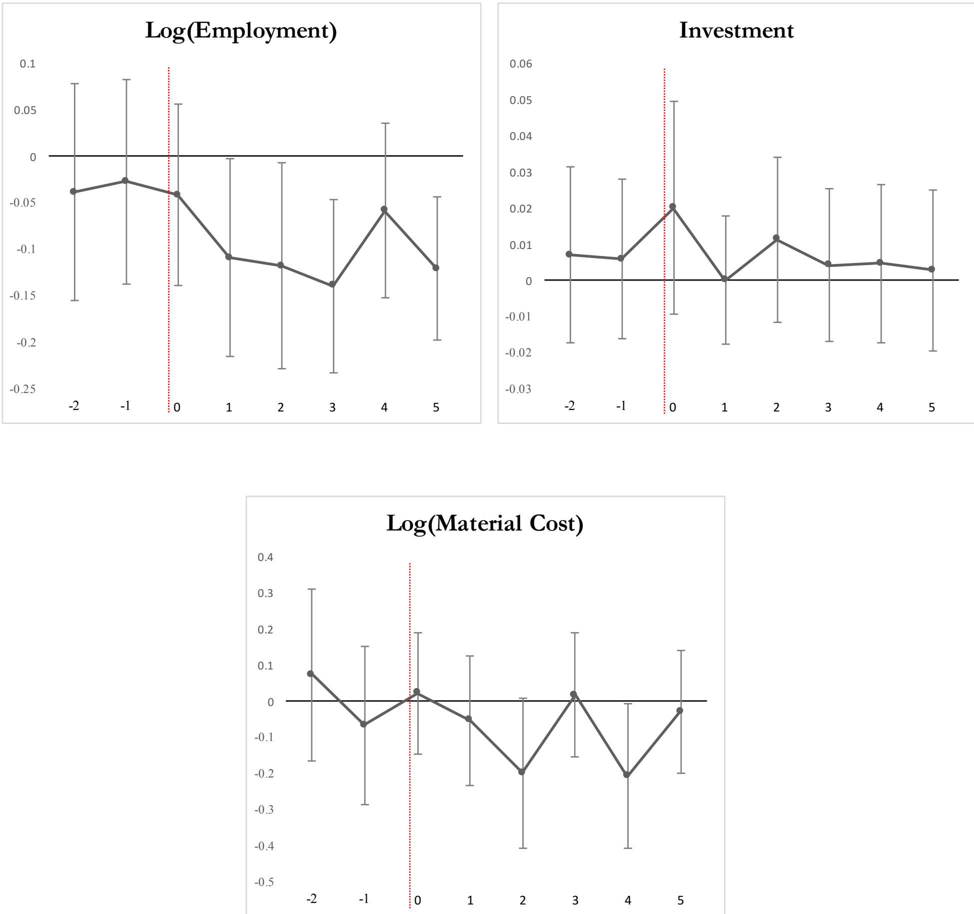


Figure C1: County-Level Impact of Hurricanes

These figures present the estimated dynamic impact of hurricanes at the county-level on all single-plant and multi-plant manufacturing activity in disrupted counties, two years prior and five years after hurricane exposure. The estimates are expressed relative to a counterfactual group of unexposed counties from the northeastern and southern states of the United States that are equally susceptible to hurricane strikes. Standard errors are clustered at the county-level.

Table C3: Spillovers within Firms: Heterogeneity by Firm Age

	Log(Employment)	Investment	Log(Labor Prod)
	(1)	(2)	(3)
Spillover (Firm Age Tercile 1)	0.0451	-0.0392	0.0877
	(0.0762)	(0.0301)	(0.0696)
Spillover (Firm Age Tercile 2)	-0.1040***	-0.0909***	-0.0824***
	(0.0090)	(0.0035)	(0.0109)
Spillover (Firm Age Tercile 3)	-0.0271	-0.0021	0.0445
	(0.0329)	(0.0136)	(0.0413)
Observations	350,000	310,000	310,000
R-squared	0.9332	0.4326	0.7244
Plant & County-Year FE	Yes	Yes	Yes
Controls	Yes	Yes	Yes

Notes: Spillover is an indicator variable that equals one for all the undisrupted divisions after the exposed parent firm's first hurricane exposure. Each tercile of firm age is bins of firm age. Investment is capital expenditures divided by last year's capital stock. Log(Labor Prod) is the logarithm of one plus value added divided by employment. Sample period is 1995 to 2014. p-value significance: * $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$.

Table C4: Spillovers within Firms: Heterogeneity by Firm State-Spread

	Log(Employment)	Investment	Log(Labor Prod)
	(1)	(2)	(3)
Spillover (Multi-State Firms)	-0.0321**	-0.0066	-0.0237
	(0.0159)	(0.0066)	(0.0362)
Spillover (Single-State Firms)	-0.0596	-0.0287	0.006
	(0.1033)	(0.0233)	(0.1926)
Observations	350,000	310,000	310,000
R-squared	0.9381	0.382	0.6195
Plant Fixed Effects	Yes	Yes	Yes
County-Year Fixed Effects	Yes	Yes	Yes
Controls	Yes	Yes	Yes

Notes: Spillover is an indicator variable that equals one for all the undisrupted divisions of partially exposed firms, after the exposed parent firm's first hurricane exposure. Heterogeneity is by each firm's state count. Log(Employment) is the log number of plant employees. Investment is capital expenditures divided by last year's capital stock. Log(Labor Prod) is the logarithm of one plus value added divided by employment. Sample period is 1995 to 2014. p-value significance: * $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$.

Table C5: Spillovers within Firms: Heterogeneity by Firm Industry-Spread

	Log(Employment)	Investment	Log(Labor Prod)
	(1)	(2)	(3)
Spillover (Single-Industry Firms)	-0.1006**	-0.0199	0.0514
	(0.0480)	(0.0180)	(0.0851)
Spillover (Multi-Industry Firms)	-0.0299*	-0.0062	-0.0344
	(0.0173)	(0.0068)	(0.0378)
Observations	350,000	310,000	310,000
R-squared	0.938	0.382	0.6195
Plant Fixed Effects	Yes	Yes	Yes
County-Year Fixed Effects	Yes	Yes	Yes
Controls	Yes	Yes	Yes

Notes: Spillover is an indicator variable that equals one for all the undisrupted divisions of partially exposed firms, after the exposed parent firm's first hurricane exposure. Heterogeneity is by each firm's industry count (2 digit NAICS). Log(Employment) is the log number of plant employees. Investment is capital expenditures divided by last year's capital stock. Log(Labor Prod) is the logarithm of one plus value added divided by employment. Sample period is 1995 to 2014. p-value significance: * $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$.

Main Tables and Graphs

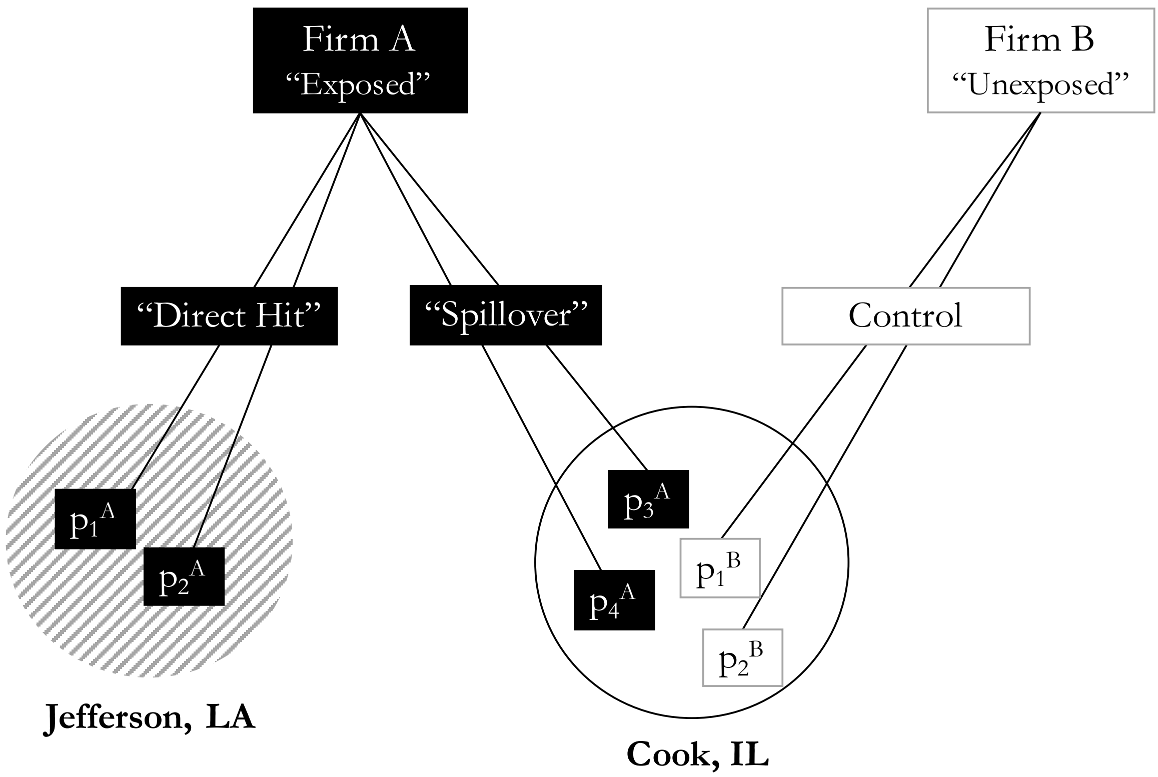


Figure 1: Illustration of Empirical Methodology

The figure illustrates the empirical strategy to identify within-firm spillovers from disaster exposure. Firm A is "Exposed" as it owns a fraction of establishments in a disaster-hit Jefferson county in Louisiana. Firm A's disrupted units are called "Direct Hit" plants and undisrupted units are called "Spillover" plants. Spillover effects within Firm A are estimated by comparing the A's "Spillover" plants located in the undisrupted Cook county, Illinois, to a control group of similar plants in Cook county that belong to the unexposed Firm B.

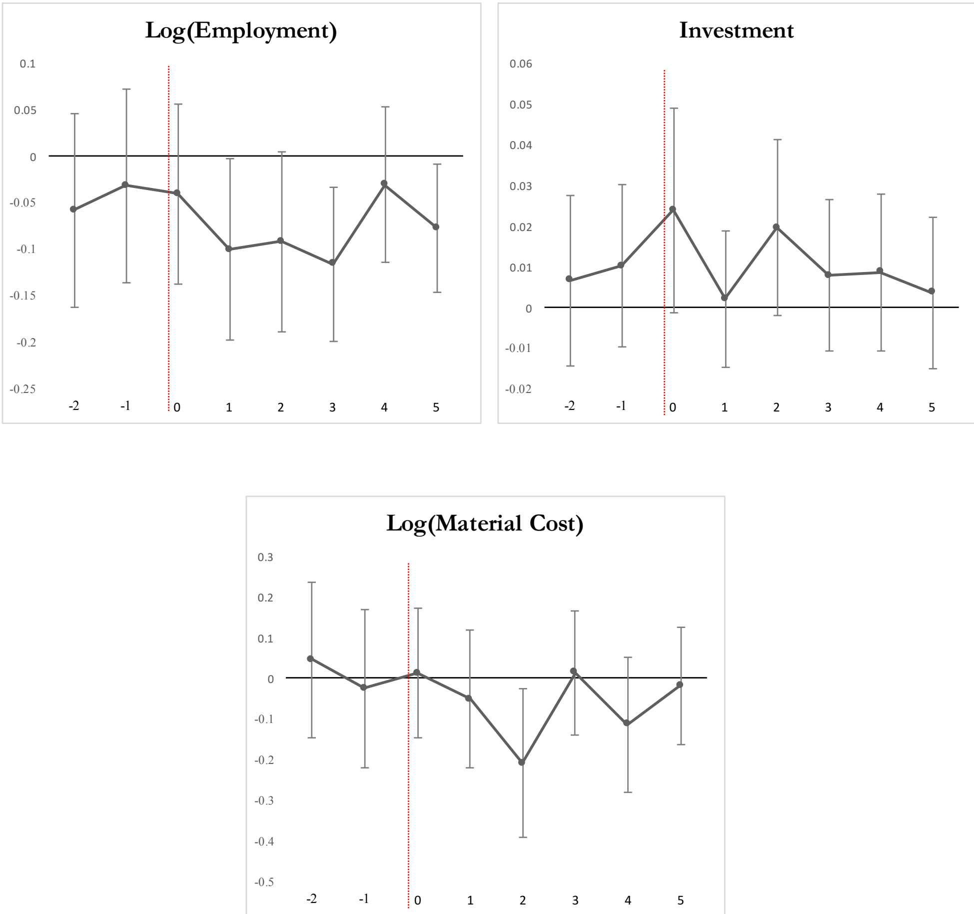


Figure 2: County-Level Impact of Hurricanes

These figures present the estimated dynamic impact of hurricanes at the county-level on all single-plant and multi-plant manufacturing activity in disrupted counties, two years prior and five years after hurricane exposure. The estimates are expressed relative to a counterfactual group of unexposed counties from the northeastern and southern states of the United States that are equally susceptible to hurricane strikes. Standard errors are clustered at the county-level.

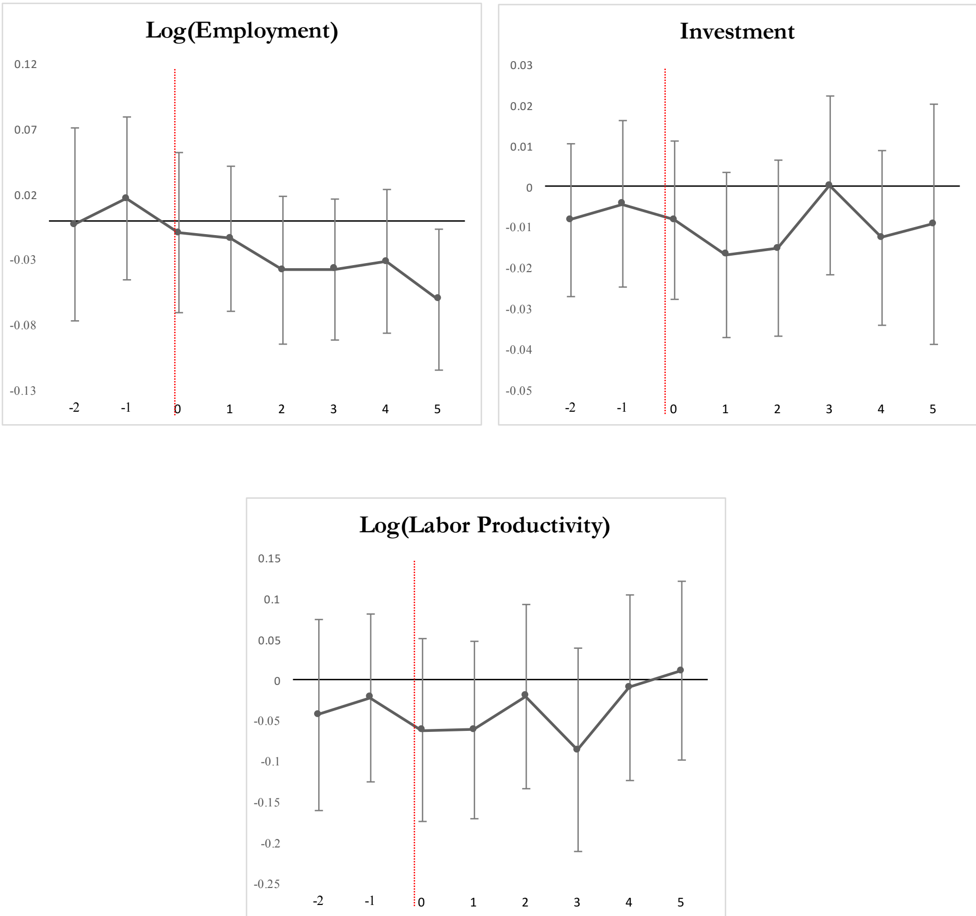


Figure 3: Plant-Level Estimation of Hurricane Impact

These figures present the estimated plant-level dynamic spillover effects of hurricane exposure within multi-plant manufacturing firms, two years prior and five years after hurricane exposure. The identification strategy follows the intuition in Figure 1.

Table 1: Pre-Hurricane Balancing Table of County Characteristics

Characteristics	Hurricane County mean (sd)	Unexposed County mean (sd)	Difference mean (t-test)
Shipments	1,277,663.8	1,199,061	78,602.8
	(2,344,488.2)	(2,084,460.7)	(0.76)
Capital Stock	506,327.6	479,092.9	27,234.7
	(897,173.8)	(799,402.2)	(0.69)
Real Capital Expenditures	39,188.0	39,279.4	-91.41
	(76,269.4)	(70,885.4)	(-0.03)
Investment	0.094	0.105	-0.011
	(0.111)	(0.128)	(-1.77)
Employment	3,065.1	3,262	-196.9
	(4,306.7)	(4,772.9)	(-0.84)
County Wage	34,604.3	37,706.7	-3,102.4***
	(13,158.9)	(12,888.9)	(-4.89)
County Plant Age	15.8	16.89	-1.082***
	(5.105)	(5.504)	(-4.01)
County Multi-Unit Plants	0.655	0.667	-0.0121
	(0.271)	(0.253)	(-0.97)

Notes: This table presents means and standard deviations of county-level characteristics, in the pre-hurricane period spanning the three years before the county's first hurricane. Shipments, Capital Stock, Capital Expenditures, Employment, and Wages are county-level quantities of manufacturing plant characteristics. Shipments are the county-level aggregate of all plants' total shipments. Investment is ratio of county-level real capital expenditures to county-level capital stock in the previous year. County Wage is total payroll divided by employment. Plant Age is the average age of establishments in the county. County Multi-Unit Plants is the average fraction of multi-unit establishments in the county. p-value significance: * $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$.

Table 2: Pre-Hurricane Balancing Table of Plant and Firm Characteristics

Characteristics	Spillover Group mean (sd)	Control Group mean (sd)	Difference in Means mean (t-test)
Plant Age	17.69	18.06	-0.366
	(8.752)	(9.604)	(-1.44)
Plant Shipments	99249	17899.1	81349.9***
	(199322.2)	(67659.5)	(43.70)
Firm Age	23.47	18.75	4.725***
	(5.202)	(9.541)	(18.77)
Firm Establishment Count	21.76	1.284	20.47***
	(24.23)	(2.192)	(283.87)

Notes: The pre-hurricane period refers to the three years prior to the firm's first hurricane strike. Firm Age is calculated as the age of the firm's oldest plant in the LBD. Firm Employment the total employment across the firm's plants. p-value significance: * $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$.

Table 3: Establishment-Level Summary Statistics

	Spillover Plants	Remaining Plants	All Establishments
Shipments	99249	17899.1	18253.1
	(199322.2)	(67659.5)	(68988)
Capital Stock	61647.2	8412.9	8660.6
	(211181.1)	(51035.4)	(53037.6)
Capital Expenditures	4290.1	854.5	869.5
	(17724.9)	(9481.3)	(9535.3)
Investment	0.0898	0.117	0.117
	(0.125)	(0.181)	(0.181)
Employment	408.9	86.04	87.51
	(617.9)	(171.5)	(177.4)
Labor Productivity	168.5	103.2	103.5
	(1224.7)	(625.8)	(629.7)
Management Score	0.65	0.566	0.566
	(0.12)	(0.153)	(0.152)

Notes: Spillover Plants are all the undisrupted establishments of partially exposed firms, and the Remaining Plants are all undisrupted establishments owned by firms with no disaster exposure. Sample period is 1995-2014.

Table 4: County-Level Impact of Hurricanes

	Log(Employment)		Investment		Log(Materials)	
	(1)	(2)	(3)	(4)	(5)	(6)
Exposure (5 years)	-0.0588**	-0.0688**	0.0090**	0.0088*	-0.0643*	-0.0469
	(0.0281)	(0.0309)	(0.0045)	(0.0050)	(0.0379)	(0.0407)
Observations	24,964	24,964	24,964	24,964	24,964	24,964
R-squared	0.9202	0.923	0.2614	0.2769	0.9668	0.9694
County Fixed Effects	Yes	Yes	Yes	Yes	Yes	Yes
Year Fixed Effects	Yes		Yes		Yes	
State-Year Fixed Effects		Yes		Yes		Yes
Control Variables	Yes	Yes	Yes	Yes	Yes	Yes
Dep Var Mean	3,065.1	3,065.1	0.09	0.09	841,461	841,461

Notes: Exposure is an indicator that equals one if the county witnesses a hurricane in that year and five years after. Investment is the ratio of county-level capital expenditures divided by the past year's capital stock. Employment is the logarithm of total county's single and multi-plant manufacturing employees. Materials is the total material inputs procured by manufacturing plants in the county. Standard errors are clustered at the county-level. Sample period is 1995 to 2014. p-value significance: * $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$.

Table 5: Plant-Level Spillover Effects within Firms

	Log(Employment)			Investment			Log(Labor Prod)		
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
Spillover	-0.0334**	-0.0351*	-0.0326**	-0.0074	-0.0067	-0.0074	-0.0268	-0.0087	-0.0283
	(0.0159)	(0.0158)	(0.0158)	(0.0065)	(0.0065)	(0.0065)	(0.0361)	(0.0362)	(0.0362)
Observations	350,000	350,000	350,000	310,000	310,000	310,000	310,000	310,000	310,000
R-squared	0.9380	0.9398	0.9382	0.3820	0.3953	0.3825	0.6195	0.6973	0.6201
Plant Fixed Effects	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
County-Year Fixed Effects	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Industry-Year Fixed Effects		Yes			Yes			Yes	
Industry Fixed Effects			Yes			Yes			Yes
Controls	Yes	Yes	Yes	Yes	Yes	Yes			
Dep Var Mean	408.9	408.9	408.9	0.09	0.09	0.09	168.5	168.5	168.5

Notes: Spillover is an indicator variable that equals one for all the undisrupted plants of partially exposed firms, after the exposed parent firm's first hurricane exposure and five years after. Log(Employment) is the log number of plant employees. Investment is capital expenditures divided by last year's capital stock. Log(Labor Prod) is the logarithm of one plus value added divided by employment. Standard errors are clustered at the county-level. Sample period is 1995 to 2014. p-value significance: * $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$.

Table 6: Spillovers within Firms: Heterogeneity by Firm Size

	Log(Employment)	Investment	Log(Labor Prod)
	(1)	(2)	(3)
Spillover (Firm Size Tercile 1)	-0.0733**	-0.0170**	-0.0796
	(0.0293)	(0.0078)	(0.0541)
Spillover (Firm Size Tercile 2)	-0.0802***	0.0004	0.0366
	(0.0262)	(0.0134)	(0.0513)
Spillover (Firm Size Tercile 3)	-0.0211	-0.0109	-0.028
	(0.0269)	(0.0085)	(0.0817)
Observations	350,000	310,000	310,000
R-squared	0.9382	0.382	0.6196
Plant Fixed Effects	Yes	Yes	Yes
County-Year Fixed Effects	Yes	Yes	Yes
Controls	Yes	Yes	Yes

Notes: Spillover is an indicator variable that equals one for all the undisrupted plants of partially exposed firms, after the exposed parent firm's first hurricane exposure and five years after. Each tercile is the tercile of firm size, which is firm total employment. Log(Employment) is the log number of plant employees. Investment is capital expenditures divided by last year's capital stock. Log(Labor Prod) is the logarithm of one plus value added divided by employment. Standard errors are clustered at the county-level. Sample period is 1995 to 2014. p-value significance: * $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$.

Table 7: Spillovers within Firms: Heterogeneity by Supply Chain Linkages

	Log(Employment)	Investment	Log(Labor Prod)
	(1)	(2)	(3)
Spillover	-0.029	-0.0271***	-0.0601
	(0.0310)	(0.0090)	(0.0601)
Spillover x SupChain	-0.0059	0.0286**	0.0469
	(0.0390)	(0.0116)	(0.0762)
Observations	350,000	310,000	310,000
R-squared	0.9382	0.3825	0.6201
Plant & County-Year Fixed Effects	Yes	Yes	Yes
Controls	Yes	Yes	Yes

Notes: Spillover is an indicator variable that equals one for all the undisrupted plants of partially exposed firms, after the exposed parent firm's first hurricane exposure and five years after. Supchain is an indicator if the firm has internal supply chain ties. Log(Employment) is the log number of plant employees. Investment is capital expenditures divided by last year's capital stock. Log(Labor Prod) is the logarithm of one plus value added divided by employment. Standard errors are clustered at the county-level. Sample period is 1995 to 2014. p-value significance: * $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$.

Table 8: Spillovers within Firms: Heterogeneity by Managerial Quality

	Log(Employment)		Investment		Log(Labor Prod)	
	(1)	(2)	(3)	(4)	(5)	(6)
Spillover	-0.0212	-0.0308	-0.018	-0.0128	-0.5605**	-0.5276*
	(0.1234)	(0.1260)	(0.0537)	(0.0537)	(0.2733)	(0.2693)
Spillover x Mgmt Score	-0.0319	-0.0654	0.0136	0.0322	0.8225**	0.9380**
	(0.1897)	(0.1936)	(0.0828)	(0.0852)	(0.4131)	(0.4250)
Observations	75,000	75,000	75,000	75,000	75,000	75,000
R-Squared	0.9502	0.9502	0.4186	0.4186	0.6013	0.6013
Plant & County-Year Fixed Effects	Yes	Yes	Yes	Yes	Yes	Yes
Controls	Yes	Yes	Yes	Yes	Yes	Yes
Spillover x FirmSize Controls		Yes		Yes		Yes

Notes: Spillover is an indicator variable that equals one for all the undisrupted plants of partially exposed firms, after the exposed parent firm's first hurricane exposure and five years after. Mgmt Score is each plant's management score from Management and Organizational Practices Survey (MOPS) from Bloom et al., 2017. Log(Employment) is the log number of plant employees. Investment is capital expenditures divided by last year's capital stock. Log(Labor Prod) is the logarithm of one plus value added divided by employment. Standard errors are clustered at the county-level. Sample period is 1995 to 2014. p-value significance: * $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$.