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

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Job Market Paper
Current Version: November 11, 2017
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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. Additionally, I find that the adverse employment and investment spillovers only occur within resource-constrained firms, while productivity losses are consistent with mechanisms of 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.

*Any opinions and conclusions expressed herein are those of the author(s) and do not necessarily represent the views of the U.S. Census Bureau. All results have been reviewed to ensure that no confidential information is disclosed. I’m deeply indebted to Nicholas Bloom, Shai Bernstein, Pete Klenow and Lawrence Goulder for their support and guidance with this project. This paper has also been greatly benefited by comments from Jose Barrero, Steve Davis, Xavier Giroud, Caroline Hoxby, Brian Lucking, Megha Patnaik, Luigi Pistaferri, Cian Ruane, Isaac Sorkin, Stephen Teng Sun, and seminar participants at Stanford University. Financial support is gratefully acknowledged from the Stanford Graduate Fellowship through Stanford University’s Vice Provost for Graduate Education; and the Bradley Graduate and Post Graduate Fellowship through a grant to the Stanford Institute for Economic Policy Research.

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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 areas³, 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 can render the actual costs of hurricanes to be mismeasured by assessments solely focused on hurricane-affected areas.

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 disrupted and undisrupted plants within exposed firms can originate via production linkages from supply-chain integration (Joskow (1985), Atalay et al. (2014)), financial linkages within the firm’s internal capital market (Stein (1997), Gertner et al. (1994)), and managerial distraction arising from a limited executive time (Bandiera et al., 2011). These multi-plant firms account for a significant portion of economic activity,⁵ and are also vulnerable to hurricane exposure.⁶

One logical possibility is that if establishments within the firm are "independent," then plant ties within the firm are inconsequential to any spatial consequences of hurricane

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¹Insurance estimates are from press releases of RMS, Lloyd’s of London and Hiscox as of 09/13/2017.
²More 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) and NASA). Individual hurricanes will drop more precipitation in the future since warmer air can hold more water vapor Emanuel (2017).
³See Boustan et al. (2017), Strobl (2011) and Belasen and Polachek (2009).
⁴A 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".
⁵In 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)
⁶Big corporations are also vulnerable to disaster shocks. For example, Chevron Corporation on Friday, 2nd November 2012; blamed Hurricane Isaac (Category 1) for losses up to $2.58 billion in net income, $1.23 per share, and $5 billion in revenues.
shocks. This possibility emerges because establishments may operate their production, management, and financing 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 in the firm’s operations.

On the one hand, if divisions operate as substitutes within the exposed firm, the hurricane’s impacts may be spatially mitigated as the firm can reallocate activity away from its disrupted locations towards undisrupted divisions. This possibility arises if non-disaster units operate as substitutes along a horizontal supply chain (Vickery et al., 2003), and if the hurricanes only hurt businesses’ capacity in hurricane areas but not their customer demand. Moreover, if the hurricane also hurts depresses investment opportunities in disrupted regions, resource-constrained exposed firms may prefer to expand capacity in its undisrupted units while only partially rebuilding destroyed capacity in disaster areas (Stein (1997), Giroud and Mueller (2015)). As undisrupted regions become “winners” from reallocated economic activity, the effects of hurricanes will be overestimated by ignoring such spatial linkages within multi-plant firms.

On the other hand, if divisions operate as complements within the firm, the hurricane’s impacts may be spatially propagated if exposed businesses incur losses across both their disrupted and undisrupted locations. Such conditions may originate if plants within the firm operate as complements due to horizontal or vertical supply-chain ties (Joskow, 1985). Further complementary responses within the firm may arise if resource-constrained firms to scale down capacity across both disrupted and undisrupted areas in the hurricane post period (Gertner et al. (1994), Lamont (1997), Giroud and Mueller (2016)), or if the hurricane renders time-constrained top executives to be distracted (Schoar, 2002). As undisrupted regions are also adversely affected, the effects of hurricanes will be underestimated by ignoring such spatial linkages 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 U.S. manufacturing to every hurricane episode in the U.S. between 1995 and 2014. The U.S. Census Bureau also 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.  

The research design to quantify the indirect spatial impacts of hurricanes via firm internal networks proceeds in three steps. In the first step, I estimate the hurricane’s direct local impact to all manufacturing activity within disrupted counties. As the choice of a control group is not straightforward, I estimate the 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 prior findings of depressed local labor markets (Boustan et al. (2017), Strobl (2011), Belasen and Polachek (2009)) and only partial reconstruction and recovery in the hurricane post period (Hsiang and Jina (2014), Skidmore and Toya (2002)). Total manufacturing employment in a hurricane hit county falls by 6.8% and wages increase, which is consistent with a story of reduced labor supply. Although investment goes up by 0.9 percentage points, material procurement in disaster areas additionally falls by 5% and shipments are also depressed in the hurricane post period. These results suggest that manufacturing capital is only partially restored and does not correspond to a complete rebound in production. Overall, the hurricanes negatively impact manufacturing activity in disaster local areas.

In the second step, I estimate spillover effects within hurricane exposed firms by examining partially exposed multi-plant firms and studying the responses of their undisrupted establishments (illustrated in Figure 1). The undisrupted "spillover" establishments are compared to a control group of establishments 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 also falls in undisrupted plants by 0.7 percentage points. On the whole, these spillover estimates reflect complementarities in the responses of disrupted and undisrupted divisions within the average hurricane-exposed firm in the economy.

In the third step, I quantify the total indirect spatial impacts of hurricanes from economic linkages within the firm relative to the total local impacts estimated within a typical hur-

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8Additionally, 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.

9The results on county-level wages and shipments still await U.S. Census Bureau disclosure, and therefore report no magnitudes or statistics for these variables.
ricane county, by utilizing the above estimated county-level direct effects and plant-level spillover effects. For an average county hit by a hurricane, for every manufacturing job lost in that county, I estimate that 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. Additionally, I find that employment and capital expenditure losses occur only within small firms, while productivity losses originate only within undisrupted divisions without structured management practices. Most importantly, these findings indicate that the effects of hurricanes are potentially underestimated by focusing solely on disrupted areas, without considering the spatial implications of firm internal networks in the economy.

The paper then investigates the various mechanisms that spawn spatial propagation of hurricane impacts 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, while supply-chain ties do not significantly generate these negative spillovers.

First, I test for evidence of spillovers due resource-constraints that exposed firms may face in the aftermath of a hurricane, using firm size and age as a proxy for a firm’s resource constraints. The estimations present statistically significant negative spillovers on both employment and investments only in the smallest tercile of firms. These losses in the smallest firms are consistent with theories of risk smoothing within resource constrained firms in response to liquidity shocks (Gertner et al. (1994), Lamont (1997), Giroud and Mueller (2016)), as the smallest firms are more likely to be resource constrained from capital destruction upon hurricane exposure which lowers collateral values, increase moral hazard, and increase borrowing and participation costs.

Next, regarding supply chain linkages within the firm, I identify firms to be supply-chain linked if their divisions report material procurements and transfers from within the firm and test the heterogeneous spillover impact of hurricanes for exposed firms with and without supply chain ties. The evidence weakly suggests that only employment losses occur in supply chain linked firms. The lack of a statistical power may arise either because of measurement error in the plant reports of material procurements within the firm, or because there are very few large firms in the data report supply chain ties across their divisions. The latter possibility is consistent with prior evidence from Atalay et al. (2014) and Ramondo et al. (2016) that the ownership of vertically linked affiliates is not related

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10 Firm size and age are inversely associated with 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).

11 See Appendix A.4.1 for a detailed literature review on hurricanes as liquidity shocks.
to the transfer of goods within the boundaries of the firm.

Last, the results suggest that managerial distraction is another driver of hurricane spillovers within the firm since these episodes require top executives to divert their limited time towards the firm’s disrupted divisions. I utilize measures of managerial quality at the establishment-level from the Managerial and Organizational Practices Survey (MOPS), and study the differential response of undisrupted divisions with and without structured management practices. I find that productivity falls by 23% only for undisrupted divisions without explicit structured management practices, while there are no productivity losses for divisions that follow structured management practices. This Broken-Toy Effect originating within firms with distracted top executives is analogous to the New-Toy Effect documented in Schoar (2002). The evidence is robust to ensure that the is not just explained by well-managed firms that are also bigger 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 macroeconomy via economic linkages within the firm. Such indirect disaster effects either remain unaccounted for in prior microdata investigations that evaluate only the direct local impact of natural disasters, or remain hidden as an aggregate effect in country-level studies of environmental shocks.

Second, this paper speaks to a burgeoning literature in macroeconomics that studies the propagation of local shocks throughout the economy via economic linkages. 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

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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).


15 See Hsiang and Jina (2014); Burke et al. (2015).

non-public establishment-level microdata provides a valuable setting where input-output synergies are just one among many other channels of interactions between divisions within the firm. This paper is also closely related to a growing literature on the propagation of local shocks propagate via firms’ internal networks. Both Lamont (1997) and Giroud and Mueller (2016) study spillover effects within the firm from divisional interlinkages via the internal capital markets of resource-constrained firms. This paper explores many additional channels responsible for spatial propagation 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 firm internal organization by deciphering various mechanisms responsible for the spatial propagation of hurricanes within firms. These mechanisms include supply chain ties, resource constraints, limited CEO time and and the quality of management practices. Most notably, the evidence of managerial distraction spawning productivity losses within the firm (Broken-Toy Effect) is analogous to the New-Toy Effect documented in Schoar (2002). This paper’s contribution lies in utilizing exogenous hurricane shocks as a setting to establish the adverse productivity consequences of distracted management within the firm.

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

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


20 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.
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”\textsuperscript{21} 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. Since such detailed information on inputs, capital expenditures and output 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 establishment corporate affiliations in the LBD aid in constructing all plant linkages within each firm.

Furthermore, two supplementary Census datasets at the establishment-level are merged into the above constructed plant-level panel using establishment identifiers. First is the Commodity Flow Survey (CFS), which records establishment shipments data. Since being initiated in 1993, the survey has been subsequently conducted during Census Years. It includes a random sample of an establishment’s shipments in four periods (1 period per quarter could last 1 or 2 weeks). Each establishment generally reports 20-40 shipments per period, and establishments with fewer than 40 shipments during the period tend to report everything. For each shipment, it records the originating establishment, destination

\textsuperscript{21}“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”.

zip code, commodity, mode of transport, dollar value, and weight (quantity). Establish-
ments broadly belong to Mining, Manufacturing, and Wholesale, while select retail and
services establishments are also included, totally covering approximately 400 SIC indus-
tries\textsuperscript{22}. Second is the Management and Organizational Practices Survey (MOPS) in the
U.S. Census data, which is a mandatory government management survey supplementing
the ASM. The MOPS was first conducted in 2010, and data has subsequently been rec-
collected every five years. The survey covers over 30,000 plants across more than 10,000
firms\textsuperscript{23}.

B. Hurricane Data

Information on hurricane strikes is collected from the Storm Events Database (SED), com-
piled by the U.S. Department of Commerce’s National Oceanic and Atmospheric Admin-
istration (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 phenom-
ena, even if it does not cause any major disruptions as mentioned in point (1)\textsuperscript{24}; (3) The
event is a rare unusual weather phenomena that generates media attention, such as sig-
nificant 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 since January 1996, 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 hurricanes from the SED is collapsed to the
county-year aggregation, and merged into the longitudinally linked ASM-CMF panel of
manufacturing establishments.

\textsuperscript{22}See the CFS description details in Atalay et al. (2014)
\textsuperscript{23}See the MOPS description in Bloom et al. (2017) and Buffington et al. (2016)
\textsuperscript{24}Cutoffs may be classified into two broad categories - (a) a physical characterisitic 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.
3 Plant Ties Within the Firm and Hurricane Spillovers

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 mitigation or propagation of disasters 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, 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’s network of plants. The nature of spatial spillovers within the firm (positive or negative) are then governed by the extent to which the exposed firm’s divisions respond as substitutes or complements to the hurricane disruption.

This section explores linkages that arise between between disrupted and undisrupted operations of exposed firms due to the resource allocation process within constrained firms (Stein (1997), Gertner et al. (1994)), supply-chain linkages (Joskow (1985), Atalay et al. (2014)) and the limited managerial time of top executives (Bandiera et al. (2011), Malmendier and Tate (2009)).

First, resource constraints within the firm’s internal capital market may cause plants within the exposed firm to respond as substitutes or complements to the hurricane disruption. On the one hand, if hurricanes only destroy capital in exposed areas but do not hurt investment opportunities, plants may respond as complements as resource constrained firms may spread these losses across disrupted and undisrupted regions (Gertner et al. (1994), Giroud and Mueller (2016)). Appendix Figure B1 illustrates this case, where capital destruction provides firms the incentive to rebuild capacity as the marginal returns to invest are higher in disrupted areas. However, resource constrained firms may only be able to partially tap the external market to reconstruct their destroyed capacity. There-

\[\text{As a budgetary authority, the firm is capable of both organizing external finance and pooling internal resources from its various divisions. As a strategic authority, the firm’s CEO then allocates these combined funds in an internal capital market to its individual plants. This setup of the firm reflects the way large and complex firms like General Electric organize their production and financing operations. While they operate hundreds of plants, only the firm issues bonds, borrows from banks or raises equity (Kehrig and Vincent, 2016).}\]
fore, these firms resort to rebuild their capital by mobilizing internal resources from their undisrupted divisions by the amount of the budget shortfall, until the marginal returns to invest are equalized across exposed and unexposed divisions.\textsuperscript{26,27} On the other hand, if hurricanes destroy both capital and investment opportunities in the exposed areas, the exposed firms divisions may respond as substitutes. This case, illustrated in Appendix Figure B2, occurs because resource constrained parent firms will only rebuild capacity only outside disrupted areas until the marginal returns to invest across its exposed and unexposed divisions are equalized (\textit{Stein (1997), Giroud and Mueller (2015)}).

Second, the supply chain structure within exposed firms may cause plants to respond as substitutes or complements to the hurricane disruption. This intuition is illustrated by a simple model of plant interdependencies within a multi-plant firm in Appendix B, where the elasticity of substitution governs the negative or positive spillover effect. On the one hand, substitutability between disrupted and undisrupted operations of exposed firms may manifest along a horizontally structured supply chain (\textit{Vickery et al., 2003}) with divisions producing similar products. In this case, economic activity would be reallocated to non-disaster areas upon hurricane disruptions to the firm. On the other hand, complementarities between the exposed firms divisions may occur from supply-chain ties via horizontal integration (\textit{Vickery et al., 2003}) or vertical integration (\textit{Monteverde and Teece (1982), Masten (1984), Joskow (1985)}).\textsuperscript{28} In this case, disaster shocks would propagate to the firm’s undisrupted divisions.\textsuperscript{29}

Lastly, CEO distraction upon disaster exposure can cause divisions within the exposed firm to respond as complements. This occurs because top executives may be required to over-invest their limited time (\textit{Bandiera et al. (2011), Malmendier and Tate (2009)}) on

\begin{itemize}
  \item \textsuperscript{26}Firms with no resource constraints may borrow from the external market to finance the rebuilding, with no implications of any spillover effects within the firm.
  \item \textsuperscript{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 (\textit{Gertner et al. (1994), Stein (1997)} and \textit{Inderst and Müller (2003)}).
  \item \textsuperscript{28}Examples of complementarities along a horizontal supply chain include the manufacturing of tables and chair, or bottles and caps in two separate divisions. Complementarities could alternatively arise from interdependencies along a vertically integrated supply chain.
  \item \textsuperscript{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 (\textit{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.
\end{itemize}
disrupted divisions in disaster areas. As a result, poorly managed undisrupted divisions would perform worse upon withdrawn CEO attention, and cause hurricane shocks to propagate via the firm network. The negative spillover effects may be termed a "Broken-Toy Effect", along the lines of 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 disasters via firm internal networks, and the mechanisms that spawn spillovers within the firm.

These indirect impacts are quantified in three steps. First, Section 4.1 estimates the total direct impact of disasters to all manufacturing activity within disrupted local areas. This step sets the baseline to quantify the magnitude of spatial propagation via plant linkages internal to the firm. Second, Section 4.2 presents methodology to identify plant-level spillover effects within partially exposed firms. Third, Section 4.3 employs these two estimates to quantify the indirect spatial impacts of disasters across the economy’s undisrupted regions, relative to the direct effects within a typical disaster county.

Lastly, Section 4.4 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 on "all" manufacturing activity (both single- 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).

\[
y_{c,t} = \alpha_c + \alpha_t + \sum_{j=-2}^{5} \beta_j^{Exposure} Exposure_{c,t-j} + \gamma'X_{c,t-1} + \epsilon_{c,t} \tag{1}
\]

³⁰Schoar (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 divisions.
In Equation 1, \( y \) is the dependent variable of interest. Fixed effects \( \alpha_c \) and \( \alpha_t \) absorb any time-invariant characteristics particular to each county and year respectively. "Exposure" is a 0-1 indicator variable equals one if county \( c \) witnesses a hurricane in year \( t - j \), where \( j \in [-2, 5] \) is the time window around the hurricane’s onset in year \( t \). \( X \) is a vector of time varying county characteristics in the past year. The coefficients of interest are \( \{ \beta_j^{\text{Exposure}} \}_{j=-2}^5 \), measure the dynamic impact of hurricane disruptions 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 investment, employment, and material costs. 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. Employment is the logarithm of the number of employees in the county. Material Costs are the logarithm of the total cost of materials and inputs procured by plants in that county. 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 matched 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 coefficients \( \{ \beta_j^{\text{Exposure}} \}_{j=-2}^5 \), whether positive or negative, is non-trivial. Investment may be positively impacted if the hurricane improves investment opportunities in the county, or may be depressed if hurricanes hurt firm-liquidity and investment opportunities in disaster local areas (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). Therefore, the final estimated impact of hurricanes on county-level outcomes in Equation (1) is to be interpreted as "net" investment or employment impact.
4.2 Spillover Effects Within Firm Networks

This section presents the empirical methodology to investigate the role of plant-level linkages within the firm in propagating or absorbing hurricane shocks. The purpose of this exercise is to assess a disaster’s total cost by additionally accounting spillovers 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 four establishments located across many counties. Firm A owns two plants ($p^A_1$ and $p^A_2$) in County C1 and the rest ($p^A_3$ and $p^A_4$) in County C2, while Firm B owns two plants ($p^B_1$ and $p^B_2$) in County C2. When County C1 is unexpectedly struck by a hurricane, Firm A becomes "Exposed" as it owns a fraction of plants located in the disaster county C1, while Firm B continues to be "Un-Exposed" on that account. The disrupted plants of exposed Firm A are then called "Direct Hit" plants, while its undisrupted plants are called the "Spillover" plants.

I estimate the hurricane disruption’s spillover effects within the exposed Firm A’s plant network, by comparing the exposed Firm A’s "Spillover" plants ($p^A_3$ and $p^A_4$) to a "Control" group of unexposed but similar plants ($p^B_1$ and $p^B_2$) located within the same non-disaster County C2, and similar in age and size, operating in the same industry, and owned by a similarly sized parent firm (Firm B).

The following difference-in-differences specification estimates the disaster’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).

$$y_{p,f,c,t} = \alpha_p + \alpha_{ct} + \sum_{j=-2}^{5} \beta_j^{Spillover} Spillover_{p,f,c,t-j} + \gamma' X_{p,f,c,t-1} + \epsilon_{p,f,c,t} \tag{2}$$

In Equation 2, $y$ is the dependent variable of interest. Fixed effect $\alpha_p$ absorbs any time-invariant characteristics particular to each plant. Fixed effect $\alpha_{ct}$ 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 plants within the same county. "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. $X$ 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 coefficients of interest are $\{\beta_j^{Spillover}\}_{j=-2}^5$, which measure the dynamic "Spillover" impact.
of hurricane disruptions for the exposed firm’s undisrupted plants. 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 primarily Investment, Employment and Labor Productivity. 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. Employment is the logarithm of the number of employees. Labor productivity is the log 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 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 larger geographical spread. The regression 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 methodology. Firstly, natural disasters must affect the undisrupted "spillover" plants only through the firm internal network. However, local shocks to undisrupted counties that coincide with hurricane strikes elsewhere may hurt non-disaster plants in addition to within-firm spillovers. Examples include disaster neighboring counties or other counties linked by transportation infrastructure that could also suffer from hurricanes. To alleviate this issue, the full set of county-year fixed effects in the regressions absorb any impact that is common to all non disaster plants. As an additional robustness check, I also exclude disaster neighbor counties from the regressions and re-estimate the spillover effects.

Secondly, product market rivalry between the spillover and control establishments can overestimate the spillover impact. I address this concern by both including and excluding
industry 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 by including industry fixed effects.

Lastly, the counterfactual control group to estimate spillover effects may have exposure to disaster exposed firms, via shipments to either disaster counties or or non-disaster siblings of directly hit plants. While this concern only underestimates the spillover effects, I re-estimate the regressions by removing any establishments in the control group that report shipments to disaster exposed firms in the Commodity Flow Survey.

4.3 Quantifying the Indirect Impacts of Hurricanes

For a typical county hit by a hurricane, for every job or dollar change upon exposure, the total additional indirect impacts of hurricanes across other non-disaster counties from spillovers within the firm is given by the ratio

\[
\frac{\text{Spillover Impact (Plant)} \times \#\text{Siblings (Hurricane County)}}{\text{Direct Impact (Hurricane County)}}
\]

(3)

The denominator in Equation 3 is the estimated county-level change in total manufac-
turing investment or employment from direct hurricane exposure. This denominator is obtained by multiplying the county-level estimate of hurricane impact (\(\beta^{\text{Exposure}}\)) with the pre-hurricane county-level mean of the respective outcome variable (\(\bar{y}_c^{\text{pre-period}}\)).

The numerator is the estimated average plant-level spillover effect for a typical unexposed sibling within partially exposed firms, obtained by multiplying the plant-level within-
firm spillover estimate (\(\beta^{\text{Spillover}}\)) with the pre-hurricane plant-level mean of the respective outcome variable for the spillover division (\(\bar{y}_{p,f,c}^{\text{pre-period}}\)). These plant-level spillovers are then scaled up by the average number of "Spillover" siblings that a typical disaster county is connected with.

On the whole, the ratio quantifies a hurricane’s total indirect spatial impacts incurred across the macroeconomy upon disruptions to a typical hurricane-county, arising from plant ties within firm internal networks.
4.4 Mechanisms driving Within-Firm Spillovers

This section provides the methodology to investigate the mechanisms that spawn spillovers within the firm network. These mechanisms include plant linkages via financial ties within the firm’s internal capital market, supply-chain synergies within the firm, and managerial distraction.

4.4.1 Financial Constraints:

Plants are financially linked within a firm via an internal pool of resources of the firm’s many divisions, called the internal capital market. Upon hurricanes exposure, firms that face damages to their capital stock may find it harder to access external financing due to damaged collateral, increased moral hazard and higher participation costs.\(^{31}\) While financially unconstrained firms can make up for their budget shortfalls by borrowing from the external market, financially constrained firms will be unable to tap the external market to shore up their budgets. Therefore, firms with limited liquidity in the internal capital market will smooth-out the adverse impact of hurricanes across their disrupted and undisrupted divisions until they equalize the marginal returns to invest across their divisions (Gertner et al. (1994), Giroud and Mueller (2016)).

I test this hypothesis by estimating the heterogeneous impact of hurricanes by firm size (measured by firm employment). Firm size is inversely associated with 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).

I define a variable \(\text{FirmSize}_f\) which categorizes firms by terciles of firm employment. The heterogeneous spillover effects are then estimated by interacting \(\text{Spillover}\) in Equation (4) with the measure of firm size bins \(\text{FirmSize}_f\).

\[
y_{pfct} = \alpha_p + \alpha_{ct} + \beta' \text{Spillover}_{p|fct##\text{FirmSize}_f} + \gamma' \mathbf{X}_{pfct-1} + \epsilon_{pfct} \tag{4}
\]

where \(\text{Spillover}\) is a pooled indicator that equals one for all undisrupted plants of exposed firms, during 5 years after the firm’s first treatment. \(\beta'\) is a vector of estimates for the spillover effect for each tercile of firm size. Since theories of financial constraints

\(^{31}\)See Appendix A.4.1 for evidence on disasters as liquidity shocks to the firm.
consider smaller firms to be associated with liquidity constraints, the negative spillover effects must obtain in the smallest tercile of firm size.

4.4.2 Supply Chain:

Plant may be linked within within the firm due to supply chain relationships, either horizontal or vertical in nature. Therefore, disaster shocks to a certain fraction of the firm may propagate to its other divisions via the supply chain. This mechanism is particularly relevant as firms adopt lean inventory and made-to-order manufacturing processes which may lend them vulnerable to idiosyncratic shocks.

I test this mechanism by transforming the same hurricane into different treatments, depending on whether the firm is supply-chain linked or not. A firm \((f)\) is defined to be supply-chain linked using an indicator variable \(\text{SupChain}_f\), which equals one if the firm’s divisions report a positive value of materials and transfers sourced from its sibling divisions within the same firm. The heterogeneous spillover effects are then estimated by interacting \(\text{Spillover}\) in Equation (5) with \(\text{SupChain}_f\).

\[
y_{p,f,c,t} = \alpha_p + \alpha_{ct} + \beta_1 \text{Spillover}_{p,f,c,t} + \beta_2 \text{Spillover}_{p,f,c,t} \times \text{SupChain}_f + \beta_3 \text{SupChain}_f + \gamma' X_{p,f,c,t-1} + \epsilon_{p,f,c,t}
\]

where \(\text{Spillover}\) is a pooled indicator that equals one for all undisrupted plants of exposed firms, during 5 years after the firm’s first treatment. \(\beta_1\) 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 multi-plant firms, then the estimate \(\beta_1 + \beta_2\) must be positive or negative respectively.

4.4.3 Managerial Distraction:

In the event of hurricane disruptions, the CEO may have to divert a disproportionate amount of attention towards disrupted operations, because of the nature of disruption or the politics of the job. Due to limited managerial time and span of control, the resulting CEO inattention towards undisrupted operations may cause negative spillovers if undisrupted divisions are poorly managed.
To investigate this hypotheses, I utilize each division’s management score obtained from the Management and Organizational Practices Survey (MOPS) in the U.S. Census data\textsuperscript{32}. The management score is the unweighted average of every individual score 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 the quality of divisional 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.

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

$$y_{p,f,c,t} = \alpha_p + \alpha_{ct} + \beta_1 Spillover_{p,f,c,t} + \beta_2 Spillover_{p,f,c,t} \times Mgmt_{p,f} + \beta_3 Mgmt_{p,f} + \gamma' X_{p,f,c,t-1} + \epsilon_{p,f,c,t}$$ \hspace{1cm} (6)

$\beta_1$ estimates the spillover effect for plants with no structured management category, and $\beta_2$ estimates the differential spillover effect for divisions with structured management. If CEO distraction upon hurricane exposure incites spatial propagation within firms due to poorly managed undisrupted divisions, then the estimates $\beta_1 < 0$ and $\beta_1 + \beta_2 = 0$ must obtain.

### 4.5 Sample Selection and Summary Statistics

#### County Level: Direct Impact of Hurricanes

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

The sample includes all manufacturing divisions of single-plant and multi-plant firms, excludes those plants whose information is imputed from administrative records rather than directly collected. The sample keeps states located in the northeast and southern regions

\textsuperscript{32}See the MOPS description in Bloom et al. (2017) and Buffington et al. (2016)
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 lagged county characteristics of wage and age.

**Plant-Level: Spillovers Effects within Exposed Firms**

The plant-level sample to estimate the hurricane’s spillover effects 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 (3). 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 are only available for the firm’s manufacturing plants. The latter is performed 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 whose plants in the CMF/ASM account for at least 90% of the firm’s total employees. Third, I only keep exposed firms that have less than 100% of their establishments in disaster regions, as the analysis of within firm spillovers across disrupted and undisrupted counties is only possible 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 group, Control group 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 group is evidently bigger than control plants on an average. This imbalance in the sample is not surprising because the sample selection mechanically obtains spillover plants that belong to big hurricane-exposed firms with a large geographical spread. This is a result of including firms that have less than a 100% of its establishments in a disaster

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33 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).
county. On an average, the spillover group of plants have 408 employees and invest 9% of their capital stock in capital expenditures, whereas the control group 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.

5 Results

5.1 County-Level Direct Impact of Hurricanes

Table 4 presents the estimated county-level impact of hurricane strikes on employment, investment and material costs in disaster counties. First, employment in exposed counties falls by 6.8% percent in columns (1) and (2), corresponding to a decrease of about 211 manufacturing jobs after a typical hurricane strike in the county. 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.

The employment results are consistent with prior studies that estimate that 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.

Next, investment in exposed counties rises by 0.9 percent points after a typical hurricane strikes (columns (3) and (4) in Table 4), which corresponds to a 10% increase in the investment rate as these storms primarily destroy the capital stock in disaster counties. The rebuilding amounts to $4.5 million in capital expenditures, which is 1% of manufacturing capital stock rebuilt after a typical hurricane strike. However, this rebuilding may not correspond to a complete reinstallation and rebound in production, as aggregate material procurement in disaster areas falls by 5% in the hurricane post period. 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.

These investment results may be interpreted as a net increase in the rate of physical capital investment, consistent with predictions in Skidmore and Toya (2002). On one hand, hurricane exposure translates into positive investment shock as capital damage increases both the marginal product of capital as well as reconstruction demand. On the other hand, hurricanes also hurt investment opportunities by causing a negative liquidity shock, which increases the adjustment costs of capital. This causes reconstruction to only entail building back lesser but resilient infrastructure, but hurts the long run expected return to physical capital due to hurricane risk.

Overall, the hurricanes depress economic activity in the disaster local areas. Manufacturing employment in local labor markets is down by 211 jobs and material procurement by $38.2 million, even as $4.5 million in capital expenditures are spent to rebuild manufacturing capital stock.34

## 5.2 Spillover Effects Within Firm Networks

Table 5 presents the estimated plant-level spillover effects of hurricanes on employment, investment and labor productivity within the partially exposed firm. As shown in column (1), employment at the spillover plant falls by 3.26% and is statistically significant. This corresponds to about 13 jobs cut by the disaster exposed firm in an undisrupted division. Column (2) includes a full set of industry fixed effects (4 digit NAICS) to check for any upward bias in the spillover estimate due to product market rivalry between the spillover and control plants. To the extent that the two groups of plants are rivals within the same narrowly defined industry, hurricane exposure may simultaneously benefit the control group as it hurts the spillover group and would manifest by including the industry fixed effect. However, the estimated spillovers remain unchanged across columns (1) and (2). Columns (3) and (4) similarly finds that investment falls by 0.7 percentage points, although statistically insignificant. This corresponds to a fall of 0.8% of investment in the hurricane post period, that is 0.7% of plant’s capital stock. There is no impact on labor productivity in the non disaster plants, as seen in columns (5) and (6). Labor productivity is measured as the ratio of each plant’s value added to employment. Since these plants

34Since 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 C1, although the statistical significance on the investment and material cost results are lower.
cut employment in the disaster plants, the lack of impact on productivity per employee suggests there may also some fall in the value-added of these plants.

Figure 3 explores the dynamics of the estimated plant-level spillover effects within the firm. The time period spans the hurricane’s three 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. The negative employment impacts begins in the year after the hurricane and continues to get negative, but only significant in the fifth year of the post-hurricane period. The patterns suggest that the negative employment spillovers are more of a gradual response, which may be explained in two ways. First, the gradual response may arise because firms update their expectations about the vulnerability of their disaster area plants before readjusting inputs across their disrupted and undisrupted divisions. The gradual update of expectations may be spawned by delays in the settlement of insurance claims (Pryshchepa et al., 2015), causing firms to adjust only after they are eventually compensated for their losses. Additionally, 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. These long delays in public assistance for disaster areas reparations may suggest that firms adjust their expectations gradually, after assessing the extent of their longer term hurricane risks. The second reason for the gradually significant negative impact may reflect heterogeneity in the implications of hurricanes to economic activity in undisrupted regions, even as negative spillovers manifest on an average. For example, the Wall Street Journal reported that Hurricane Harvey’s aftermath boosted car manufacturing in Detroit, as widespread flooding damaged many cars in both residential and retail locations.

The estimated within-firm spillover effects are robust to various concerns. As seen in Table 5, the county-year fixed effects ensure that the estimated plant-level spillover effects do not originate from any other local shocks that independently affect non-disaster plants, in addition to plant ties within the firm. The estimates are also robust to overestimation concerns due to product market rivalry between the spillover group and control group of plants, checked by the inclusion/exclusion of industry fixed effects. The estimates are robust to between-firm supply-chain ties that negatively impact the control group and bias the spillover estimates towards zero, because the estimates remain unchanged upon excluding plants that ship to zip codes associated with divisions of exposed firms. Appendix C additionally shows that the spatial spillovers does not only reflect local spillovers, as they occur within firms with divisions spread across multiple states. Appendix C also shows that the negative within-firm spillovers also manifest in firms operating in both single
and multiple industries (2 digit NAICS). This result further builds on early evidence from Lamont (1997) of negative spillovers only within multi-industry firms - in their non-oil divisions upon disruption to the oil producing plants.

5.3 Quantifying the Indirect Impacts of Hurricanes

Table 9 quantifies the indirect spatial costs of hurricanes arising from spillovers within the internal network of multi-plant firms in the economy. The calculations follow methodology presented in Section 4.3.

Each quantity in Table 9 is the total hurricane impact across undisrupted counties in the economy, divided by the total impact of hurricanes within disaster local counties. The numerator is obtained from the plant-level estimates of spillovers within firms (Section 5.2 above), multiplied by the average number of undisrupted siblings affiliated to a typical disaster county via disrupted parent firms. There are about 4.3 spillover plants on an average per hurricane affected county in the US. The denominator is obtained from the county-level estimated direct impact of hurricanes (Section 5.1 above).

Column (1) shows that 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. The result demonstrates that the impacts of hurricanes are spatially dispersed in the economy, and may be underestimated by focusing solely within disaster areas and ignoring linkages within firms. Column (2) shows that capital expenditures are also cut across undisrupted regions, for every dollar of reconstruction in the disaster area. This figure is however not statistically significant in the headline estimations.

5.4 Mechanisms of Within-Firm Spillovers

Financial Constraints (by Firm Size): Table 6 explores heterogeneous spillover effects of hurricanes by firm size, separated into three bins by terciles of firm employment.

Columns (1) and (2) study employment and investment respectively, and present statistically significant negative spillovers on 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, which can arise from larger firms being more likely to be supply chain integrated.
Investment falls in the first tercile by 0.017 percentage points in the undisrupted plant 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). Hurricanes have been found to adversely affect firm liquidity by destroying capital in the form of damaged buildings, machinery and other assets. This leads to lower collateral values, higher moral hazard, and a resulting increase in borrowing and participation costs. 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 divisions 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 additionally come from supply-chain linkages among bigger firms, which will be explored in the next section.

On the whole, Table 9 indicates that these employment spillovers within the first tercile of firms accounts for about 0.04 to 0.05 manufacturing jobs lost across undisrupted counties in the United States, per manufacturing job lost in a typical disaster county. Similarly, for every dollar reconstructed in disaster counties, about 6 cents to 8 cents are lost across the undisrupted macroeconomy due to spillover effects within the smallest firm group. In the second tercile, employment losses across the undisrupted economy amount to about 11%-15% of the total disaster area employment losses.

**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 column (1), employment falls in both categories of firms by about 3%, but is statistically significant for supply chain linked firms (only at the ten percent level). The lack of a statistical power may arise for two reasons. Firstly, 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 and biases the result downward. Secondly, even if we assume that the $SupChain$ measure is moderately reliable, there are very few

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35See Appendix A.4.1 for a detailed literature review on hurricanes as liquidity shocks.
firms in the data that report supply chain ties across their divisions, 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. Even then, this is still an important dimension, as the employment spillovers within supply-chain integrated firms account for about 0.17-0.23 jobs lost across undisrupted counties in the United States (See Table 9). Column (2) similarly presents results for investment spillovers between firms with and without supply-chain links. The results suggest that investment does not fall for supply chain linked firms, and is limited to the omitted category alone. Given that our measure of supply chain linkages is correlated with size, the results suggest that investment spillovers are possibly limited to smaller firms that may face financing constraints. The evidence in Table 6 of investment and employment losses limited to smallest firm size terciles, and employment alone falling in the second tercile helps reconcile the supply chain results. Column (3) presents results for labor productivity, and does not have any significant heterogeneity along the firm’s supply chain dimension.

Managerial Distraction: Hurricane episodes require the exposed firms’ top executives to divert limited managerial time towards the firm’s disrupted divisions. The resulting CEO distraction to the firm’s undisrupted segments may cause a Broken-Toy Effect, hurting performance even without any impacts to labor and capital inputs. Table 8 presents the heterogeneous response of non-disaster plants within the exposed firm, depending on the managerial quality of its undisrupted plants. 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 division’s management score. Divisional management scores range between zero and one, with an average of 0.056 and a standard deviation of 0.15.

Column (3) presents clear evidence of a Broken-Toy Effect that is limited to poorly managed divisions within the exposed firm. Productivity falls by 23% for divisions without structured management practices, or those with managerial quality below one standard deviation of the mean managerial score. However, the productivity impact is approximately zero for divisions with structured management practices, or those with 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 Broken-Toy Effect is not just explained by well managed firms that are also bigger firms. While performance falls for poorly managed divisions, Columns (1) and (2) demonstrate statistically insignificant
impacts for employment and investment, respectively. The results suggest that the negative investment and employment spillovers the within hurricane exposed firms do not respond to whether the firms possess structured management practices or not.

The evidence suggests that managerial distraction is an important mechanism of disaster spillovers within the firm. Real world reports of managerial distraction after hurricane Irma include quotes on Forbes Magazine from 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."

This paper’s evidence of a Broken-Toy Effect originating within firms with distracted top executives is 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 the paper does address concerns of the New-Toy Effect more likely reflecting 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 the firm. These findings also relate to literature on the allocation of CEO time which is 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, the results suggest that managers are key to determining a firm’s performance (Bennedsen et al. (2006), Bloom and Van Reenen (2010)).

6 Conclusion

This paper demonstrates that the economic consequences of environmental disasters are underestimated by evaluations that typically focus within disaster local areas, because of spatial linkages across disrupted and undisrupted regions within multi-plant firm networks. 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 firm are found to originate from plant-interconnections via financial ties within the firm’s internal capital market, supply-chain synergies within the firm,
and managerial distraction. Overall, these results indicate that we considerably underes-
timate the effects of hurricanes by ignoring inter-regional linkages emerging within firm
networks.

In terms of the aggregate indirect effects of hurricanes, the within-firm spatial propagation
examined in this paper may be an under-estimate or an over-estimate, depending on the
nature of inter-firm and inter-regional linkages in the economy. On one hand, if firms ad-
ditionally propagate these shocks via between-firm along the supply chain (Boehm et al.
(2015), Barrot and Sauvagnat (2016)), then my results are an under-estimate of the indirect
costs of hurricanes. On the other hand, my results may be an overestimate if disrupted
and undisrupted firms are product market rivals, causing competing undisrupted firms
to exploit new opportunities and thus mitigate these indirect hurricanes costs.

These findings have important policy implications for inequality and disaster assistance
policies. First, the transmission of disaster impacts via economic linkages suggests that
natural disasters can be less local than they seem, even in large economies. Given the
vast rehabilitation finances channeled exclusively towards directly hit regions, the evi-
dence in this paper suggests that fiscal assistance must also assess the disasters’ economic
implications for undisrupted regions. Second, the depression of local economic commu-
nities due to more frequent natural disasters could exacerbate regional inequality, which
is traditionally explained through the lens of globalization, technological change, firm-
agglomerations, footloose capital, and falling tendency towards relocations (Takahashi
et al., 2013). In order to mitigate the role of climate change in amplifying regional inequal-
ity, policies must encourage investments in climate-smart infrastructure and disaster aid
must be well-targeted to support affected households that cannot migrate away. Third,
from a climate justice point of view, many studies have documented the unequal bur-
den 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 Out-
look 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 ad-
verse 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.

References


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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 are known to cause severe damages (Pielke, 2005).

Between 1996-2012, 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, here is a growing consensus that, around the world, the strongest hurricanes 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 outside their local area. Additionally, the very nature of manufacturing 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 greater 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. But in reality, hurricanes are not that common at the county-level, because they can hit a wide area with a stochastic trajectory (CITATION). 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.

**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

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36A 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.

37Boustan et al. (2017) documents that land prices fall in response to natural disaster exposure.
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 tempts 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

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.

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

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

(7)

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

$$y_i = Ak_i^{\gamma}l_i^{1-\gamma} \quad \forall i, j \in \{A, B\} \ & \ i \neq j$$

(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 division’s marginal costs measured by the labor margin is given by:

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

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

$$y^*_i(p_i, p_j, \alpha_i, \alpha_j, \sigma) = \frac{\left(\frac{p_i}{\alpha_i}\right)^{-\sigma}}{\left[\alpha_i \left(\frac{p_i}{\alpha_i}\right)^{-\sigma} + \alpha_j \left(\frac{p_j}{\alpha_j}\right)^{-\sigma}\right]^{1/\sigma}} \times Y_F \quad \forall i, j \in \{A, B\} & i \neq j$$

and the firm’s cost function to operate at the optimal output levels $\{y^*_A, y^*_B\}$

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

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

$$\frac{\partial p_j}{\partial k_j} = \frac{-\alpha}{(1-\alpha)}w_k^{-\alpha-1} < 0 \quad \forall i, j \in \{A, B\} & i \neq j$$

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:

$$\frac{\partial}{\partial p_j} \left(\frac{p_jy^*_j}{C^*}\right) = (\sigma - 1)p_j \left[\frac{p_j}{\alpha_j}\right]^{-\sigma} \left[\alpha_A p_A^{1-\sigma} + \alpha_B p_B^{1-\sigma}\right]^{-2} \quad \forall i, j \in \{A, B\} & i \neq j$$

$$\Rightarrow \frac{\partial}{\partial p_j} \left(\frac{p_jy^*_j}{C^*}\right) = \begin{cases} < 0, & \text{if } \sigma < 1 \\ = 0, & \text{if } \sigma = 1 \\ > 0, & \text{if } \sigma > 1 \end{cases}$$

Equation 14 demonstrates that the nature of spillover effects within the firm is determined by the degree of substitutability 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 $j$.

C Additional Results and Robustness

Plant-Level Spillovers within Exposed Firms

The Geographical Dispersion of Multi-Plant Firms: 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. Table C2 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.

The Industrial Dispersion of Multi-Plant Firms: Earlier work by Lamont (1997) presents evidence of negative spillovers of the 1986 oil price shock within multi-industry firms. That is, investments fall in their non-oil divisions upon disruption to the firms’ oil producing plants. In this paper, the negative spillover effects of hurricanes are not just limited to multi-industry divisions alone. As indicated in Table C3, negative employment spillovers from hurricane disruptions manifest within firms operating in both single and multiple 2 digit NAICS industries.

Disaster Neighboring Counties: The locational choice of a firm may not be solely determined by the county where production is conducted, but by the prospects of advantageous access to infrastructure in a surrounding county. Therefore, establishments located in disaster neighboring counties may partially bear some consequence of hurricane exposure, and cause contamination to either the control group of plants or to the spillover group of plants. The county-year fixed effects absorb such concerns in the regressions. Moreover, such confounds will only cause the spillover estimates to be attenuated. In additional robustness, I omit plants located in disaster neighbor counties, as well as all divisions affiliated to such plants through their firm’s networks. The exclusion of such locations and plants does not change the negative spillover effects estimated beforehand.

Firm’s County Dominance: Plants owned by multi-plant companies may or may not be the dominant businesses in the county that absorb a large share of the county’s labor force. Could the large spillover effects on employment and investment arise from a few firms that accrue for a large share of non-disaster county activity? I accordingly test for the heterogeneity of spillover effects by the firm’s share of employment in spillover counties and obtain negative results for both non-dominant and dominant firms in non-disaster counties.
Appendix Tables and Graphs
<table>
<thead>
<tr>
<th>Year</th>
<th>Hurricane</th>
<th>Saffir-Simpson Category (Scale 1-5)</th>
<th>Property Damage (in US$ billion)</th>
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<tr>
<td>1996</td>
<td>Fran</td>
<td>3</td>
<td>$3.20</td>
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<td></td>
<td>Bertha</td>
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<td>1999</td>
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<td>Floyd</td>
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<td></td>
<td>Irene</td>
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<td>Lili</td>
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<td></td>
<td>Katrina</td>
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<td>2007</td>
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<td></td>
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<td>2014</td>
<td>Arthur</td>
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Figure B1: Spillovers Within Firms: Resource Constraints

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 \(\{k_{A3}, k_{B3}\}\).
Figure B2: Spillovers Within Firms: Resource Constraints

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

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<th>Log(Employment)</th>
<th>Investment</th>
<th>Log(Materials)</th>
</tr>
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<tr>
<td></td>
<td>(1)</td>
<td>(2)</td>
<td>(3)</td>
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<tr>
<td>Exposure (5 years)</td>
<td>-0.0665**</td>
<td>-0.0907***</td>
<td>0.0077*</td>
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<td></td>
<td>(0.0298)</td>
<td>(0.0344)</td>
<td>(0.0045)</td>
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<td>Observations</td>
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<td>24,964</td>
<td>24,964</td>
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<td>R-squared</td>
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<td>County Fixed Effects</td>
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<td>Year Fixed Effects</td>
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<td>State-Year Fixed Effects</td>
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<td>CEM Matching</td>
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</tbody>
</table>

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.

Table C2: Spillovers within Firms: Heterogeneity by Firm State-Spread

<table>
<thead>
<tr>
<th></th>
<th>Log(Employment)</th>
<th>Investment</th>
<th>Log(Labor Prod)</th>
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<td></td>
<td>(1)</td>
<td>(2)</td>
<td>(3)</td>
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<tr>
<td>Spillover (Multi-State Firms)</td>
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<td>-0.0237</td>
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<td>(0.0362)</td>
</tr>
<tr>
<td>Spillover (Single-State Firms)</td>
<td>-0.0596</td>
<td>-0.0287</td>
<td>0.006</td>
</tr>
<tr>
<td></td>
<td>(0.1033)</td>
<td>(0.0233)</td>
<td>(0.1926)</td>
</tr>
<tr>
<td>Observations</td>
<td>350,000</td>
<td>310,000</td>
<td>310,000</td>
</tr>
<tr>
<td>R-squared</td>
<td>0.9381</td>
<td>0.382</td>
<td>0.6195</td>
</tr>
<tr>
<td>Plant Fixed Effects</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
</tr>
<tr>
<td>County-Year Fixed Effects</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
</tr>
<tr>
<td>Controls</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
</tr>
</tbody>
</table>

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

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 county C1. 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 county (C2), to a control group of similar plants in county C2 that belong to the unexposed Firm B. The hurricane’s direct impact on Firm A’s "Direct Hit” divisions in the disaster county C1 is estimated by comparing them to a control group of similar unexposed plants located in regions that are equally vulnerable to hurricanes.
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.
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

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

Notes: This table presents means and standard deviations of county-level characteristics. The Pre-hurricane period spans the three years before the county’s first hurricane. Shipments, Capital Stock, Capital Expenditures, Employment, and Wages are county-level aggregates of the county’s 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 the total wage per manufacturing employee, calculated as payroll divided by employment. Plant Age is the average age of establishments in the county. Share of 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

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

Notes: 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 divisions. p-value significance: * p < 0.10, ** p < 0.05, *** p < 0.01.
Table 3: Establishment-Level Summary Statistics

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

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. All figures are sample means. Sample period is 1995-2014.

Table 4: County-Level Impact of Hurricanes

<table>
<thead>
<tr>
<th></th>
<th>Log(Employment)</th>
<th>Investment</th>
<th>Log(Materials)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>(1)</td>
<td>(2)</td>
<td>(3)</td>
</tr>
<tr>
<td>Exposure (5 years)</td>
<td>-0.0588**</td>
<td>-0.0688**</td>
<td>0.0090**</td>
</tr>
<tr>
<td></td>
<td>(0.0281)</td>
<td>(0.0309)</td>
<td>(0.0045)</td>
</tr>
<tr>
<td>Observations</td>
<td>24,964</td>
<td>24,964</td>
<td>24,964</td>
</tr>
<tr>
<td>R-squared</td>
<td>0.9202</td>
<td>0.923</td>
<td>0.2614</td>
</tr>
<tr>
<td>County Fixed Effects</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
</tr>
<tr>
<td>Year Fixed Effects</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
</tr>
<tr>
<td>State-Year Fixed Effects</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
</tr>
<tr>
<td>Control Variables</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
</tr>
<tr>
<td>Dep Var Mean</td>
<td>3,065.1</td>
<td>3,065.1</td>
<td>0.09</td>
</tr>
</tbody>
</table>

Notes: Exposure is an indicator that equals one if the county witnesses a hurricane in its county 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. 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

<table>
<thead>
<tr>
<th></th>
<th>Log(Employment)</th>
<th>Investment</th>
<th>Log(Labor Prod)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>(1)</td>
<td>(2)</td>
<td>(3)</td>
</tr>
<tr>
<td>Spillover</td>
<td>-0.0334**</td>
<td>-0.0326**</td>
<td>-0.0074</td>
</tr>
<tr>
<td></td>
<td>(0.0159)</td>
<td>(0.0158)</td>
<td>(0.0065)</td>
</tr>
<tr>
<td>Observations</td>
<td>350,000</td>
<td>350,000</td>
<td>310,000</td>
</tr>
<tr>
<td>R-squared</td>
<td>0.938</td>
<td>0.9382</td>
<td>0.382</td>
</tr>
<tr>
<td>Plant Fixed Effects</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
</tr>
<tr>
<td>County-Year Fixed Effects</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
</tr>
<tr>
<td>Industry Fixed Effects</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
</tr>
<tr>
<td>Controls</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
</tr>
<tr>
<td>Dep Var Mean</td>
<td>408.9</td>
<td>408.9</td>
<td>0.09</td>
</tr>
</tbody>
</table>

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. 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

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

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. 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

<table>
<thead>
<tr>
<th></th>
<th>Log(Employment)</th>
<th>Investment</th>
<th>Log(Labor Prod)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>(1)</td>
<td>(2)</td>
<td>(3)</td>
</tr>
<tr>
<td>Spillover</td>
<td>-0.029</td>
<td>-0.0271***</td>
<td>-0.0601</td>
</tr>
<tr>
<td></td>
<td>(0.0310)</td>
<td>(0.0090)</td>
<td>(0.0601)</td>
</tr>
<tr>
<td>Spillover x SupChain</td>
<td>-0.0059</td>
<td>0.0286**</td>
<td>0.0469</td>
</tr>
<tr>
<td></td>
<td>(0.0390)</td>
<td>(0.0116)</td>
<td>(0.0762)</td>
</tr>
<tr>
<td>Spillover + (Spillover x SupChain)</td>
<td>-0.0349*</td>
<td>0.0015</td>
<td>-0.0601</td>
</tr>
<tr>
<td></td>
<td>(0.0201)</td>
<td>(0.0082)</td>
<td>(0.0601)</td>
</tr>
<tr>
<td>Observations</td>
<td>350,000</td>
<td>310,000</td>
<td>310,000</td>
</tr>
<tr>
<td>R-squared</td>
<td>0.9382</td>
<td>0.3825</td>
<td>0.6201</td>
</tr>
<tr>
<td>Plant &amp; County-Year Fixed Effects</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
</tr>
<tr>
<td>Controls</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
</tr>
</tbody>
</table>

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. 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

<table>
<thead>
<tr>
<th></th>
<th>Log(Employment)</th>
<th>Investment</th>
<th>Log(Labor Prod)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>(1)</td>
<td>(2)</td>
<td>(3)</td>
</tr>
<tr>
<td></td>
<td>(4)</td>
<td>(5)</td>
<td>(6)</td>
</tr>
<tr>
<td>Spillover</td>
<td>-0.0212</td>
<td>-0.0308</td>
<td>-0.018</td>
</tr>
<tr>
<td></td>
<td>(0.1234)</td>
<td>(0.1260)</td>
<td>(0.0537)</td>
</tr>
<tr>
<td>Spillover x Mgmt Score</td>
<td>-0.0319</td>
<td>-0.0654</td>
<td>0.0136</td>
</tr>
<tr>
<td></td>
<td>(0.1897)</td>
<td>(0.1936)</td>
<td>(0.0828)</td>
</tr>
<tr>
<td>Observations</td>
<td>75,000</td>
<td>75,000</td>
<td>75,000</td>
</tr>
<tr>
<td>R-Squared</td>
<td>0.9502</td>
<td>0.9502</td>
<td>0.4186</td>
</tr>
<tr>
<td>Plant &amp; County-Year Fixed Effects</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
</tr>
<tr>
<td>Controls</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
</tr>
<tr>
<td>Treat x FirmSize Controls</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
</tr>
</tbody>
</table>

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. 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.
### Table 9: Quantifying Indirect Spatial Effects of Hurricanes

<table>
<thead>
<tr>
<th>Cases</th>
<th>Employment (jobs)</th>
<th>Capital Expenditures (US$)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>(1)</td>
<td>(2)</td>
</tr>
<tr>
<td>Aggregate</td>
<td>0.19 – 0.25</td>
<td>.</td>
</tr>
<tr>
<td>Firm Size Tercile 1</td>
<td>0.04 – 0.05</td>
<td>0.06 – 0.08</td>
</tr>
<tr>
<td>Firm Size Tercile 2</td>
<td>0.11 – 0.14</td>
<td>.</td>
</tr>
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<td>Firm Size Tercile 3</td>
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<tr>
<td>Supply Chain Linkages</td>
<td>0.17 – 0.23</td>
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</tbody>
</table>

Managerial Distraction  
Productivity Loss (Broken Toy Effect)

Notes: This table quantifies the indirect spatial costs of hurricanes arising from spillovers within the internal network of multi-plant firms in the economy. Each quantity is the total hurricane impact across undisrupted counties in the economy, divided by the total impact of hurricanes within disaster local counties. The total impact across undisrupted counties is obtained from the plant-level estimates of spillovers within firms, multiplied by the average number of undisrupted siblings affiliated to a typical disaster county via disrupted parent firms. Thus, each quantity presents the total additional indirect costs of hurricanes across other non-disaster counties per every job/dollar lost upon exposure in a typical hurricane county.