Proposal 3: Firm adaptation and production networks: Structural evidence from extreme weather events in Country x

PRIMARY IGC THEME: ENERGY & ENVIORNMENT

GRANT TYPE: FULL RESEARCH GRANT

BUDGET: £64,240

PROJECT DURATION: 3 YEARS

SUMMARY

Climate change presents a global threat to human populations and economic growth. One important manifestation of climate change is through the increased likelihood of extreme weather events. In this project we aim to understand the response of firms and their supply networks to extreme weather events, more specifically floods, in Country X. We seek to estimate impacts on firms that are directly affected, firms indirectly affected through disruptions to vertical linkages or factor markets, and the structure of firm supply networks themselves. A particular focus of our analysis is the extent to which firms make adaptive decisions in the aftermath of extreme weather events that may help to limit their exposure to future such events.

The project's approach combines a micro-founded structural general equilibrium model with novel datasets. To measure firm outcomes, we have obtained and georeferenced monthly microdata on the near-universe of formal firm-to-firm sales transactions of firms from VAT data. To measure firms' exposure to floods, we combine three datasets: (i) satellite flood maps; (ii) georeferenced flood risk measures based on state-of-the-art hydrological models; (iii) high-frequency geospatial data from GPS trackers installed on over commercial trucks, which yields accurate data on supply routes, traffic conditions and flood-related road closures.

We will first use these datasets to provide reduced-form evidence on the responses of firms and their supply network structures to natural disaster events. We will then interpret the elasticities estimated from these regressions in a structural spatial general equilibrium model to understand the general equilibrium impacts of shocks on all firms in the network and run counterfactuals to understand the importance of different adaptation margins for firm-level and aggregate outcomes. Understanding the magnitude of these adaptation decisions is crucial in trying to anticipate how costly climate change will be and in designing appropriate policy responses.

RESEARCH DESIGN

The proposed methodology for the project combines micro-founded structural econometric models with a series of novel datasets, georeferenced at a fine geographical resolution, described below:

1. To measure firm sales outcomes and disruptions to supply chains, we have obtained and georeferenced microdata on the near-universe of formal firm-to-firm sales transactions of local firms. These data are available from the government [source details anonymized by the IGC for this example]. These data provide monthly transaction-level data reported by VAT-registered firms containing sales, purchases, imports, exports, VAT amounts paid and key characteristics of the transacting firms. The full data span the period 20XX to 20XX, with VAT amounts paid also available dating back to 20XX. Importantly, the data also contain detailed information on each firm's registered address and business premises, which we have used to geocode firms in the data at a fine geographical resolution.

2. To measure the extent to which supply routes are affected by extreme weather events, we have purchased high-frequency geospatial data from GPS trackers installed on over 15,000 commercial trucks from an original equipment manufacturer. These data show the location and speed of the vehicles travelling on country's road network at a very high frequency from 20XX to the present, comprising 6 billion observations. These allow us to construct accurate data on supply routes, traffic conditions, flood disruptions, and adaptation of firms' shipping routes from these data.

3. Georeferenced data on extreme weather and natural disaster events in Country X over our study period have been obtained from publicly available sources. These geospatial datasets can be combined with the georeferenced data on firm locations and supply routes as above to identify at a high geographical resolution firms and infrastructure that were exposed to extreme weather events over the study period. Our primary source of flooding data is georeferenced satellite data on flood events and extents from the UNOSAT Flood Portal of the United Nations Institute for Training and Research. Areas affected by earthquakes are obtained by combining USGS earthquake data with georeferenced 'ShakeMaps', a product of the USGS Earthquake Hazards Program in conjunction with regional seismic networks which allow for estimation of affected areas by providing maps of ground motion and shaking intensity. The fine geographical resolution of the datasets allows us to construct the extent of flood- and earthquake-related disruptions to firms and road networks.

We have now collected and georeferenced these datasets. The proposed activities over the period covered by this proposal focus on analysis of these datasets to understand the response of firms and their networks to natural disasters, and important margins of adaptation. There are two key components of this analysis: (i) examining reduced form evidence on the responses of firms and their supply network structures to natural disaster events in Country X; and (ii) interpreting the elasticities estimated from these regressions in a structural spatial general equilibrium model to understand the general equilibrium impacts of shocks on all firms in the network and run counterfactuals to understand the importance of different adaptation margins. The methodologies proposed for each of these sections are described in more detail below.

(i) Reduced form analysis

We first explore firms' responses to extreme weather events by running reduced-form regressions of firm decisions (in particular adaptive decisions such as exit, location, industry, supplier choice, supply routes, but also total sales and purchase values) on variables capturing the direct and indirect exposure to floods. The granular spatial and temporal resolution of our data allow us to run these regressions at the level of individual firms and firm pairs at the monthly, quarterly and annual level. The availability of the firm-to-firm transaction data over a time period spanning 20XX-20XX also allows us to consider the persistence of effects over several years (longer than is generally possible in the extant literature), an effect of particular interest since persistent responses may be indicative of changes in firms' expectations about future natural disaster events. As part of this proposal, we are also asking for resources to investigate extending the data to more recent time periods to study the impact of and adaptation to a more recent natural disaster in Country X.

Our main set of reduced-form regressions are event study regressions, i.e. regression of outcome variables (at the firm x month level) on a set of time-to-event dummies, as well as cross-sectional and time fixed effects. To capture the role of the degree of treatment intensity, we will interact the time-to-event dummies with a measure of flood severity in the local vicinity of the firm's location. Equivalent specifications will also be run using earthquake rather than flood exposure.

These specifications allow us to test, for instance, how far firms in affected areas experience differential rates of exit; lower sales; and/or move to a different location in the aftermath of extreme weather events. We will also be able to investigate potential adaptive responses by examining, for instance, how far firms that move to a different location move to areas characterized by a lower risk of extreme weather events.

Corresponding specifications that draw on the network structure of the transaction-level data will then be used to examine network-level adaptive responses. For instance, for seller- (buyer-) level regressions, we can consider whether flood exposure results in changes in the shares of sales to (expenditures from) buyers (sellers) in flooded or flood-prone regions, as well as how such effects impact firm outcomes such as total sales and survival probability. This will also allow us to analyse indirect impacts, for instance whether firms that have customers or suppliers in affected locations undertake adaptive responses such as moving to safer locations or shifting the balance of firms' customers or suppliers towards those that are less susceptible to extreme weather events.

By combining the firm data with the GPS data on supply routes and transport network disruptions, we will also be able to examine impacts when the road to a supplier or customer is disrupted by the extreme weather events, even though neither the firm nor their trading partners are in an affected area. Another set of regressions will look at heterogeneity in responses; particularly whether firms in poorer areas or rural areas exhibit different adaptation behaviour. Interactions of flood severity with ex-ante flood risk will inform us about the mechanisms at play.

(ii) Structural analysis

The second part of the analysis will then interpret the different elasticities estimated from these reduced form regressions in a structural spatial general equilibrium model. This will allow us to investigate the quantitative importance of different margins of firm responses and to run counterfactuals. The exact margins of firms' choices and adjustments to be included in the model will depend on those margins that we find to be operational according to the reduced-form regressions. Firms may, for instance, potentially face a location choice, a choice of industry, a choice of suppliers and customers and a choice of supply routes. Trade is costly and extreme weather events may affect labour productivity in flooded areas as well as these trade costs. Our structural spatial general equilibrium model will allow us to quantify the importance of changes in firm expectations for mitigating the cost of future extreme weather events. Through the lens of the model and using the elasticities calibrated from the extreme weather shocks, we would also be able to use counterfactual simulations to assess the importance of and interactions with other types of transport network disruptions, for instance resulting from conflict and other frictions, for aggregate economic activity.

Our structural model-based approach allows us to study questions that it is not possible to address using reduced-form analysis. Such questions include, for instance: Do the observed adaptation patterns point to the presence of frictions that could be corrected through policy? How far does observed adaptation reduce the economy's exposure to subsequent extreme weather events? How sensitive is the aggregate economy to bottlenecks in the supply chain network, and how exposed are these bottlenecks to disruptions caused by climate change? What is the impact of policies that protect key segments of the road network or increase supply chain diversification among key firms in the firm network? The answers

to these questions are key when attempting to make supply chains more resilient to the threats imposed by climate change.

IGC EVALUATION

This proposal was ranked very highly by all the reviewers with a potential to produce knowledge that would have great interest among academics and policy makers. The project was completely aligned with the research strategy, with a clear question, good data, careful plan of analysis and had great policy implications.

PROPOSAL SUMMARY & RESEARCH QUESTION

The proposal summary was very succinct and set the context, research question, project's approach and policy implications very clearly for the reviewer. Some of the strengths of the summary are outlined below:

1. **Context and research question:** The proposal started by stating a critical issue and how the research question was relevant in this context. The research question was clearly defined: how do firms and their supply networks respond to extreme weather events, particularly floods, and to what extent do firms make adaptive decisions to mitigate future risks.
2. **Research design:** The research team provided a clear outline of the theoretical model planned for this project. The proposal summary detailed the three main datasets that would be combined and included a brief overview of the empirical analysis to be used. Providing such an overview of the research design in the project summary ensured that reviewers understood the research team had thoroughly considered the project details.

RESEARCH DESIGN

The research design for this project was clearly outlined with great details on the datasets combined, robust empirical model, and clear identification strategy. Some of the specific strengths are outlined below:

1. **Comprehensive datasets:** The research team provided comprehensive details of high-frequency and high-resolution data that was combined and georeferenced for the purpose of this project. Proposal aimed to analyse these datasets to understand the response of firms and their networks to natural disasters, and important margins of adaptation.
2. **Innovative experimental design: T**he experimental design was very robust and innovative. Reduced-form analysis was used to examine firm responses to natural disasters, and these findings were used in a structural model to understand general equilibrium impacts. The structural model-based approach allowed the researchers to study questions, particularly on adaptive patterns, that were not possible to answer using reduced-form analysis.
3. **Identification strategy:** The proposal outlined a clear plan to measure the impacts of extreme weather events on firms and their supply networks using detailed, georeferenced datasets. By leveraging microdata on firm transactions, GPS data from commercial trucks, and georeferenced flood and earthquake data, the project aimed to identify both direct and indirect effects of natural disasters.

The research design of this proposal was very sound, reassuring the reviewers that there is a solid foundation to analyse the relevant research question and hypothesis outlined in the proposal.