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43 provide decision-makers with robust risk reduction strategies. A more pragmatic approach to disaster
44 risk reduction consists in building resilience in socio-ecological systems in order to strengthen their
45 ability to recover and adapt from adverse events of any kind (Linkov et al, 2014). Resilience
46 assessments allow scaling-up the analysis framework so as to both enhance recovery and reduce risk
47 while avoiding thoroughly accounting for the peculiarities of the initial hazard characteristics. As
48 such, they improve upon risk assessments to support decision-making under uncertainty.

49 Because they are the ultimate decision-makers of economic systems, businesses are a cornerstone in
50 building resilience of local economies. Their resilience, that is their ability to cope with new physical
51 and market conditions and maintain operations under stress, is crucial in the aftermath of extreme
52 events. They ensure the provision of goods and services that are essential to sustain livelihoods and
53 secure incomes for households, hastening thereby the recovery of entire communities. Measuring and
54 understanding their resilience to disaster risks is an important contribution to design efficient
55 resilience enhancement strategies (Smit & Wandel, 2006; Vincent, 2007). However, any attempt to
56 measure the economic resilience of businesses requires understanding their recovery process, which in
57 turn depends upon the economic impacts they are likely to suffer.

58 Economic impacts of natural disasters fall into two broad categories: direct impacts, which arise
59 directly from physical impacts, such as the cost of replacing a damaged building, and indirect impacts
60 which are second-order downstream effects that result from the diffusion of physical impacts across
61 the wider economic system, such as production loss due to water shortages caused by a damaged pipe
62 or increased production costs due to health related absenteeism (Hallegatte et al., 2011; Pelling et
63 al., 2002; Tierney, 2007). Because they have a straightforward and tangible effect on the economy and
64 are mostly covered by private insurances, it is standard practice to assess direct economic impacts in
65 the aftermath of natural disasters (André et al. 2013). Indirect economic impacts are however more
66 complex to capture. Hallegatte & Przulski (2010) provide a few explanations for this shortcoming,
67 among which the longer time span and larger spatial scale of indirect impacts or the fact that they vary
68 across sectors and economic agents. Yet, in the long-run, indirect impacts add to total economic
69 impacts of disasters to an extent that often exceeds direct physical damages (Rose & Liao, 2005;
70 Tierney, 1997). Thus, capturing these indirect impacts is of prime importance to measure economic
71 resilience in its entirety.

72 The literature on the assessment of indirect impacts and economic resilience of businesses is scarce.
73 Hallegatte (2008) developed an approach based on input-output tables to model economic impacts
74 through input supply and demand variations across economic sectors, accounting for propagations and
75 adaptive behaviors. Brozovic et al. (2007) developed a methodology that consists in compiling sector
76 specific (typology dependent) demand functions from different sources in order to assess the total
77 costs of water lifeline interruptions following severe earthquakes in California both for business and
78 residential water users. These approaches can be characterized as top-down or standardized normative
79 approaches that disregard the particularities of individual businesses within a sector. As pointed out by
80 Kajitani & Tatano (2009), such classical estimations of economic damages to production losses
81 account for restrictions of production capacity in an *ad hoc* manner but do not integrate vulnerability
82 and resilience of businesses to assess production capacity losses, although Hallegatte (2008) attempted
83 to integrate adaptive behaviors in its approach. This is partly due to the lack of a common
84 understanding of the multidimensional nature of economic resilience that differs from - but also
85 encompasses aspects of - vulnerability and adaptation. Omitting that resilience is not only sector
86 dependent but rather depend on individual characteristics that reflect the organization of the firm and
87 affect its ability to recover from a shock leads to frequent misinterpretations.

88 This paper presents a complementary approach to standard, sector-typology based approaches
89 described above in order to assess and investigate the processes and factors underlying individual
90 economic resilience of businesses. Its ambition is to make the best use of the available theory in a very
91 pragmatic goal: measuring and understanding the resilience of businesses in order to provide public
92 policies with recommendations for building resilient economies. We first develop an explicit
93 conceptual framework of the economic resilience of individual businesses that integrates and clarifies
94 the relationships between resilience, adaptation and vulnerability. We then develop an aggregated
95 indicator of economic resilience that addresses some of the current scientific and technical obstacles
96 regarding the measurement of economic resilience at individual scale. The strength of our
97 methodology lies in its ability to scientifically ground an operational measurement of microeconomic
98 resilience that accounts for both the individual ability to cope with potential impacts and the timing of
99 recovery. As an illustration, the indicator is then applied to businesses of the Urban Community of
100 Central Martinique. Located in the French West Indies, this overseas territory encompasses many
101 factors of vulnerability commonly censused in isolated islands (IPCC, 2014; Pelling & Uitto, 2001).
102 Most of its infrastructures and activities are concentrated on the coastline which is subject to
103 increasing natural hazards due to climate changes (e.g. erosion, submersion, rising sea-level) (Hess et
104 al., 2008; Pelling, 2010; UNFCC, 1992; UNISDR, 2005). Moreover, insularity makes lifeline services
105 particularly prone to cut-offs and outages, especially in the event of a natural disaster. As for economic
106 impacts, they are likely to be significant because the economy of the French West Indies is mostly
107 made of small businesses, often thinly capitalized and individually owned, that do not benefit from
108 strong support functions to help them anticipate and cope with potential impacts.

109 This research focuses on the microeconomic resilience of businesses to lifeline service interruptions,
110 and as such, does not account for macroeconomic effects of natural disasters that pertain to the overall
111 systemic resilience of the economy. However, the concepts and indicators produced may contribute to
112 adapt production functions in macroeconomic models such as CGE models as suggested by Rose &
113 Liao (2005) who argue that classical models do not account for resilience and as such, tend to either
114 overestimate (e.g. when adaptations are not accounted for), or underestimate (e.g. when a systematic
115 return to equilibrium is considered after a long period of time), the effects of natural hazards on the
116 economy. Concentrating on microeconomic processes allows our analysis to focus on the intrinsic
117 ability of individual businesses to recover and adapt to a given degraded situation, disregarding the
118 characteristics of the event that generates damages and indirect market effects such as dropping
119 demand or increasing supply prices. It focuses on private businesses that are operated for profit, as
120 opposed to public sector and non-profit organizations. This includes all types of business
121 proprietorship, irrespective of their sector, size and turnover.

122 The present paper is organized as follows. We develop a conceptual framework for economic
123 resilience and describe its theoretical foundations in section 2. We then propose in section 3 an
124 original methodology to measure and assess the economic resilience of individual businesses. Results
125 of the application of this indicator-based approach are presented in section 4. In particular, the socio-
126 economic drivers of economic resilience are investigated using a linear regression model. Section 5
127 discusses the interests and the limits of our methodology and section 6 concludes by presenting a set
128 of future perspectives to this work.

129 **2. Conceptual framework for the economic resilience of individual businesses**

130 Building on existing literature, we suggest a conceptual framework that highlights the composite
131 nature of economic resilience at the microeconomic level (Fig. 1). This framework clarifies the

132 relationships existing between vulnerability, adaptation and resilience. In doing so, it provides an
133 analytical basis that is consistent with approaches developed in both risk and economic conceptual
134 models (Sedan et al, 2013; Aulong et al, 2011; Hallegatte & Przyluski, 2010).

135 **2.1. Vulnerability**

136 Natural disaster risks result from the interaction of (1) a hazard, that is the potential occurrence of a
137 natural or human-induced physical event that may cause damage, harm or adverse effects, (2) the
138 exposure, that is the presence of stakes (e.g. people, assets, resources) in places and settings that could
139 be adversely affected; and (3) the vulnerability, which is the propensity or predisposition of
140 individuals, communities and the environment to be adversely affected (IPCC, 2014). Focused on
141 hazard as the triggering mechanism, vulnerability is commonly defined in the literature on disaster
142 risks as the sensitivity of exposed elements to hazards (Papathoma-Köhle et al., 2011) or as the degree
143 to which a system is likely to experience damages due to its exposure to a hazard (Turner et al., 2003).
144 Social science literature offers a wider vision of the concept, including also non-hazard related forces
145 (contextual parameters) influencing vulnerability (Adger, 2006; Fussel & Klein, 2006; Gallopin, 2006;
146 Kelly & Adger, 2000). The last IPCC report¹ recognizes vulnerability as a multidimensional
147 propensity or predisposition that depends not only upon the character and intensity of the hazard to
148 which a system is exposed, but also upon its lack of capacity to adapt, its sensitivity or susceptibility to
149 harm, and its social, economic and institutional organization and development pathways (IPCC, 2014).
150 This interpretation acknowledges that, by enhancing coping capacities, adaptation is a mean to reduce
151 vulnerability (Pelling, 2010), and that vulnerability is directly connected to the intrinsic characteristics
152 of individuals and communities (Bassett & Fogelman, 2013; Birkmann, 2006; Kelly & Adger, 2000;
153 IPCC, 2012). In this paper, we understand vulnerability as a *multidimensional pre-existing condition*
154 *driven by both hazard and non-hazard related factors that jointly determine the predisposition to be*
155 *adversely affected by a disaster*. In line with recent literature (Angell and Stokke, 2013; Birkmann et
156 al., 2013; Menoni et al., 2002; Pascale et al., 2010), we split vulnerability into three main dimensions:
157 *physical (or material) vulnerability* that relates to the physical resistance of an element exposed to a
158 hazard (e.g. the resistance of a building to an earthquake); *systemic (or functional) vulnerability* that
159 depends on the functional organization of a system (e.g. the importance of a road section in the overall
160 transportation network given its spatial distribution and actual use by city-dwellers); and *socio-*
161 *economic vulnerability* that pertains to the intrinsic socio-economic characteristics and abilities of
162 individuals (e.g. the propensity of a business to get help from its professional network).

163 **2.2. Adaptation**

164 Adaptation is the process of adjustment to actual or expected disasters or stresses and their effects
165 (IPCC, 2014). Spread through climate change policies, the concept of adaptation has been largely
166 dissected and debated in the literature (Bassett & Fogelman, 2013; Pelling, 2010; Smit & Wandel,
167 2006). Together with mitigation, it is one of the two main strategies used to reduce disaster risks.
168 However, unlike mitigation that focuses on reducing the root cause of a potential upcoming disaster
169 (i.e. before it occurs, such as the strengthening of buildings), adaptation actions apply to both actual
170 and expected events and may be implemented before, during and after a disaster. Depending on their
171 intent, scale, timing and purpose, they can be classified into many categories (e.g. incremental versus
172 transformational, private versus public, hard versus soft, autonomous versus planned) (Basset et al.,
173 2013; Biagini et al., 2014; Hallegatte, 2009; Park et al., 2012; Pelling, 2010; Smit et al., 2000;
174 Tompkins & Eakin, 2012). In particular, their timing of implementation allows distinguishing
175 *anticipatory* or *pro-active* adaptations that are deliberate decisions to prepare for potential effects (e.g.

¹ The advances in conceptualizing vulnerability between IPCC's Third and Fifth Assessment Reports are a noteworthy evidence of the progress the scientific community achieved in understanding the complexity of this concept.

176 having a generator at disposal to cope with potential power cuts, i.e. ex-ante) from *reactive* adaptations
177 that are carried out in response to a specific event (e.g. buying a generator once the power is off, i.e.
178 ex-post) (Fankhauser et al., 1999). Despite the diversity of their definitions and rationales, most
179 scientists agree that adaptation actions are manifold, both technological and behavioral (incl.
180 organizational), and that they aim at reducing risks and fostering coping capacities. In our conceptual
181 framework, adaptation is defined as *any adjustment or transformative process that allows either pre-*
182 *event risk reduction, in-time or post-event risk coping*. We consider as crucial the distinction between
183 pro-active and reactive adaptations, with pro-active adaptations being a driver of the wider concept of
184 vulnerability.

185 **2.3. Resilience**

186 Resilience results from both adaptation actions and vulnerability. Often described as the opposite of
187 vulnerability, the concept of resilience has recently become a buzzword in the disaster risk literature.
188 Used in various ways by ecological, psychological or social sciences to reflect the ability of a system
189 to respond to disturbances, self-organize, learn and adapt, the concept is subject to multiple
190 interpretations (Alexander, 2013; Folke, 2006; Manyena, 2006; Reghezza-Zitt et al. 2012; Rose, 2009;
191 Saunders & Becker, 2015; Turner, 2010). A review of the recent literature on resilience can be found
192 in Hosseini et al. (2016) and Bergström et al. (2015). IPCC describes resilience as the capacity of
193 social, economic, and environmental systems to cope with a hazardous event, responding or
194 reorganizing in ways that maintain their essential function, identity, and structure, while also
195 maintaining the capacity for adaptation, learning, and transformation (IPCC, 2014). Thus, resilience
196 takes place in the post-disaster response and recovery phases. It is driven by adaptive capacity since it
197 relies on actions carried out to reduce the impacts of specific events or to transform to better cope with
198 these events. But it differs from vulnerability in that it pertains to post-disaster outcomes and only
199 becomes operational in the aftermath of an event, when vulnerability characterizes a pre-existing
200 condition. However, resilience can also be strengthened prior to a disaster by pro-active measures that
201 increase the capacity of a system to cope with upcoming effects. To clarify this time-related duality,
202 Rose (2009) identifies two components of economic resilience: inherent and adaptive resilience.
203 *Inherent resilience* pertains to abilities that were part of the system prior to disasters. It is resilience
204 already built in the system (e.g. the ability to use inventories in case of supply outages). *Adaptive*
205 *resilience* arises out of ingenuity under stress and pertains to decisions made during and in the
206 aftermath of disasters (e.g. the ability to substitute inputs given newly available materials) (Rose,
207 2004; Rose et al., 2013; Tierney, 2007). Together, inherent and adaptive resilience enable individuals
208 and communities to avoid potential losses by returning as quickly as possible to an equilibrium state,
209 may it be steady or dynamic. Based on the definition proposed by Rose (2009), we define economic
210 resilience as *the capacity to absorb an initial shock through pro-active adaptation, and to respond and*
211 *adapt afterwards through reactive adaptation, so as to maintain function and hasten recovery, as well*
212 *as to be in a better position to reduce losses from future disasters*. This definition is consistent with
213 Birkmann et al. (2013) who differentiate the concept of resilience into a *coping part* that deals with the
214 'here and now' capacity and resort to a set of actions currently available to those at risk and an
215 *adaptation part* that deals with the longer-term process of learning and reorganizing. However, it goes
216 behind by considering that the equilibrium state in which the system returns may or may not be the
217 pre-existing (or current) state. This echoes the recent distinction made by Manyena et al. (2011)
218 between bouncing back and forward after a shock. Initially used as a *bounce back* notion measuring
219 the propensity of a system to return to its previous equilibrium in order to preserve its overall stability
220 (Holling, 1973; Timmerman, 1981), resilience can also be considered as a *bounce forward* notion
221 allowing a system to come back stronger and move on by rebuilding itself and hereby changing from
222 the original state (Manyena et al., 2011).

223 Building on the literature background presented upfront, we suggest a conceptual framework that
224 provides an analytic setting for resilience assessments at individual scale (Fig.1). Our framework
225 highlights the essential place of time in the resilience concept. It distinguishes two periods in coping
226 with disaster risks: (i) the short term, also called immediate aftermath, when impacts of disasters are
227 strongly felt and coping capacity depends on the inherent resilience already built in the system that
228 relies upon pre-existing vulnerability and pro-active adaptation measures, (ii) the medium term, also
229 called reactive period, when the business has organized and implemented measures to deal with the
230 impacts and where the adaptive resilience expresses. Adaptive resilience depends upon the magnitude
231 of the impacts felt in the short to medium terms as well as the reactive adaptations undertaken in
232 response to these impacts. Overall long-term economic resilience is the aggregated inherent and
233 adaptive resilience. In this paper, we focus on the economic dimension of resilience. Other types of
234 physical or systemic resilience could also be investigated using the same framework. However, this
235 work falls outside the scope of this paper.

236 *Fig.1. – Approximately here*

237 **3. Material and method**

238 **3.1. Background on indicators of economic resilience**

239 Measuring economic resilience is not a trivial exercise. It faces three main difficulties. First, resilience
240 is a composite measure of adaptation actions, pre-existing vulnerability and actual impacts on business
241 activities, which in turn depend on the magnitude of the hazard and the exposure of the business.
242 Therefore, any attempt to provide a complete and integrated resilience indicator should encompass its
243 *multidimensional nature*. Second, it pertains to characteristics and actions existing and occurring
244 before, during and after a disaster. Therefore, indicators should account for the *dynamic of the process*.
245 Third, resilience is driven by individual socio-economic characteristics and behaviors, some of which
246 are made manifest only when individuals are faced with a disaster. Relevant indicators should account
247 for *individual choices*.

248 Two main approaches can be distinguished in building business-level economic resilience indicators.
249 A first approach consists in characterizing an indicator of resilience with an *a priori* (deductive)
250 approach. It calculates indexes based on a set of publicly available observed characteristics of firms.
251 Eidsvig et al. (2014) and Oxford Metrica (2015) built business resilience to supply chain disruption
252 indexes at country level combining economic, risk quality and supply chain factors, each described
253 using three drivers. The nine drivers combined with equal weights enable to calculate a resilience
254 index. However, these approaches cannot account for post-disaster reactive adaptations nor for
255 differences in individual firm behaviors, and as such do not fit our concept. A second literature strand
256 relies on a more empirical approach and consists in calculating a microeconomic economic resilience
257 indicator as a measure of the ex-post economic impact of disasters. Such an approach has been
258 developed by Rose (2009). Differentiating static economic resilience defined as the ability to maintain
259 function after a shock from dynamic economic resilience defined as the speed at which an entity
260 recovers from a shock, Rose (2009) suggests measuring direct static economic resilience (DSER) as
261 the extent to which actual change in business output deviates from its likely maximum in the aftermath
262 of a given disaster:

$$DSER = \frac{(\% \Delta DY_m - \% \Delta DY)}{\% \Delta DY_m}$$

263 With:

264 - $\% \Delta DY_m$, the maximum percent change in direct output that could result from a disaster if
265 businesses had no coping capacity;

266 - $\% \Delta DY$, the actual percent change in direct output that reflects and integrates the resilience
267 options that firms implemented to minimize impacts.

268 This indicator has been adopted by various authors (Chen et al., 2015; Cox et al., 2011). Its main
269 challenge involves quantifying $\% \Delta DY_m$ as this is a theoretical figure that is *per se* not measurable,
270 unless in extreme fully destructive disasters where the maximum percent change is 100% (e.g. firms
271 going out of business after the 9/11 attacks in the United States) (Rose & Brock, 2010; Hosseini et al,
272 2016). To overcome this pitfall, Kajitani and Tatano (2009) define a resilience indicator as the ratio of
273 production capacity during the impacted period over the baseline production capacity. Although
274 straightforward to compute, this ratio does not account for the vulnerability component of the
275 resilience since it does not differentiate businesses that are initially little impacted from those that are
276 strongly impacted but whose adaptations succeeded in reducing overall impacts compared to a
277 baseline scenario. A misinterpretation with a direct relationship between resilience and production
278 capacity would tend to characterize a firm as resilient if it had nothing to do in the face of an event
279 (i.e. a firm that is not vulnerable). As such, this indicator does not fully comply with the definition of
280 the economic resilience consisting in emphasizing on the capacity to recover after an event and to
281 reorganize. Darnhofer (2010) suggests to measure economic resilience in the farming sector as the
282 inverse of the cost incurred by the firm because of the event. This is consistent with the view that
283 vulnerability is the opposite of resilience and supports the idea of taking a monetary impact on the
284 output as a measure of resilience although it does not account for the multidimensional nature of the
285 process.

286 One of the main limits of these measures of economic resilience is that they integrate vulnerability and
287 resilience components with a global impact measure, which does not allow isolating the ultimate
288 economic impact from the inherent vulnerability component. This illustrates the difficulty to maintain
289 the two concepts of vulnerability and resilience separate as soon as it comes to metrics. In our
290 perspective, this is of interest to really understand the process of individual resilience whose added
291 value as an analytical concept stems from its ability to capture not only the predisposition to be
292 affected but also the rebound capacity when faced with a destructive event.

293 3.2. Metrics of economic resilience

294 Based on the previous literature review, we suggest measuring economic resilience (ER) of individual
295 businesses to lifeline service interruptions with an integrated indicator that accounts for long-term
296 impacts and pre-existing vulnerability separately. ER is measured as:

$$297 \left\{ \begin{array}{l} ER = 1 - \frac{Ltl}{S} \\ Ltl = Stl \times t \times \sigma \\ Stl = \Delta Y + OMI + NMI \\ ER > 0 \end{array} \right. \quad (1)$$

298 With:

- 299 - ΔY , the percentage change in business turnover during the event;
- 300 - OMI , the other market impacts incurred by businesses during the event (e.g. increasing
301 production costs, penalties dues to non-compliance with commercial contracts);
- 302 - NMI , the non-market impacts incurred by businesses during the event (e.g. increasing
303 painfulness of work, damages to reputation, stress of the workforce);
- 304 - t , the recovery period, that is the length of time that separates the occurrence of the event from
305 the return to normalcy of business activities;

- 306 - σ , the equilibrium state, that is an indicator of the new level of activity reached by businesses
307 in the long-run;
- 308 - S , the sensitivity, that is the level of dependence of business activities to the lifeline service
309 under study ;
- 310 - LtI , the long-term economic impacts of the disaster;
- 311 - StI , the immediate (short-term) economic impacts of the disaster.

312 Here, economic resilience is defined as an aggregated indicator of the overall economic impacts
313 suffered by a business following a disaster, given its pre-existing vulnerability to the disaster. Its
314 calculation requires computing two economic impact indexes successively: (i) an aggregated
315 *immediate* economic impact index (StI) that accounts for the strength of the impact during the disaster
316 and encompasses three indicators (change in turnover, other market impacts and non-market impacts),
317 and (ii) an aggregated *long-term* economic impact index (LtI) that accounts for the overall impact of
318 the disaster once business operations returned to normalcy and encompasses three indicators
319 (immediate economic impacts, recovery time and equilibrium state). StI includes both market and
320 non-market impacts. Amongst market impacts, demand-side effects resulting in changes in turnover
321 (ΔY) are distinguished from supply-side effects resulting in additional costs for businesses (i.e.
322 monetary damages) (OMI). ER also accounts for pro-active and reactive adaptation actions. Since it
323 depicts the effects of the disaster, given the inherent characteristics of the business, the StI component
324 already captures the effect of pro-active adaptation actions. As for reactive adaptations, we consider
325 that they allow reducing the duration of the impacts which is captured by the recovery time
326 component (t). The nature of the equilibrium state reached by businesses once their activity has
327 returned to normalcy is captured by an indicator (σ) that differentiates bouncing back from bouncing
328 forward profiles. When understanding and assigning values to these metrics, a particular attention has
329 to be given to avoiding double counting (see also how this is handled for a specific case in our
330 illustration). To avoid double counting of pro-active adaptations that are already embodied in the
331 resilience indicator through StI , we only keep in the formula the sensitivity component (S) of
332 vulnerability, sensitivity being defined as the vulnerability from which pro-active adaptations are
333 removed. In our case, sensitivity is approximated by the root cause of the impact, namely the level of
334 dependency of business activities to lifeline services, disregarding any pro-active adaptation that could
335 have been implemented to reduce this sensitivity (e.g. having a water tank at disposal in case of water
336 outages). Double counting may also arise from overlapping between ΔY , NMI and OMI . For instance,
337 some non-market impacts may affect turnover (e.g. increasing stress of the workers may impact
338 productivity). However, all these components are isolated in the formula in order to acknowledge that
339 the impact that they capture should be accounted for in their essence (e.g. stress is per se a “damage”
340 to the employee) and not only because they have an effect on turnover. Figure 2 illustrates the
341 performance profiles of businesses during and after an event in a dynamic way. It enables to illustrate
342 several parameters of the economic resilience indicator and relates to the conceptual framework
343 presented upfront.

344 In order to demonstrate the interest of the indicator in understanding factors of resilience, we develop
345 two econometric models that investigate the dependence of economic resilience to a set of individual
346 characteristics (explanatory variables). It is assumed that the economic resilience of individual
347 businesses depends on their demographics (e.g. economic sector, turnover, number of employees),
348 their operating characteristics (e.g. indebtedness, inventories), their owner’s characteristics (e.g. age,
349 level of education), and the pro-active and reactive adaptations they are likely to implement when
350 affected by a disaster.

351

Fig.2. – Approximately here

352 **3.3. Illustration**

353 **3.3.1. Case study presentation**

354 Economic resilience was assessed for individual businesses of the Urban Community of Central
355 Martinique (UCCM). Martinique is an overseas region of France located in the Caribbean Sea and part
356 of the archipelago of the French West Indies. Due to its geographic location in the Central Lesser
357 Antilles subduction zone, its volcanic origin and tropical climate, it is particularly prone to natural
358 disasters; in particular earthquakes, hurricanes, landslides, floods and volcanic eruptions. In 2007,
359 hurricane Dean caused major damages to buildings and infrastructures. Its total cost was estimated to
360 more than 500 M€, including about 102 M€ attributable to the repair of networks and infrastructures
361 (mostly electricity supply and roads), and 97 M€ to business losses in the industrial, commercial and
362 craft sectors, with many businesses suffering temporary operating losses of one to two weeks (Babre et
363 al., 2007). Later the same year, an earthquake of magnitude 7.4 on the Richter scale occurred on the
364 island. Damages were mostly material and included several building collapsing and power outages.
365 Besides its geographic location, Martinique is also particularly vulnerable to disaster risks due to the
366 concentration of most of its population, infrastructures and economy within the relatively small
367 perimeter of the UCCM. Located on the Caribbean coast, the UCCM encompasses four municipalities
368 and accounts for 42% of the population and 56% of the total number of businesses registered on the
369 island. Its economy is mainly made of small enterprises, with no or very few employees, exercising
370 mostly in the services, tourism, transport and construction sectors, and focused on local markets².
371 Moreover, the UCCM territory concentrates many critical lifelines and infrastructures whose
372 functioning is crucial to small businesses. Yet, insularity makes those services particularly prone to
373 cut-offs and outages, especially in the event of a natural disaster.

374 **3.3.2. Data collection**

375 Because our approach requires aggregating a set of observed variables to build an indicator, it involves
376 recovering a large range of business-level information. Neither public statistical nor private insurance
377 databases provide such disaggregated and specific data. Therefore, we resort to an ex-ante business
378 survey that is particularly fitted to gather site-specific information on individual businesses. It also
379 enables collecting data for a hypothetical equal hazard scenario – here, the disruption of lifeline
380 service networks – which allows comparing economic impacts disregarding hazard exposure. This
381 would not be possible with a post-event survey that would collect information from firms that were
382 differently impacted because they were originally differently exposed to the hazard according to their
383 geographic location.

384 Our methodology includes a two-step data collection process consisting in a series of face-to-face
385 interviews with local decision makers, natural hazard experts and individual businesses, and in the
386 Internet dissemination of an on-line questionnaire to individual businesses (see Appendix for details).
387 Interviews were carried out in order to fine-tune the design of the questionnaire in light of empirical
388 information. They helped characterize how network interruptions impact firm activities (e.g. which
389 technical, economic and organizational processes are likely to be affected at firm level) and pre-

² The important share of small businesses in Martinique results from the island's high unemployment rate (about 20% in 2014), especially among young people, whose struggle to find a steady employment often leads them to start their own company.

390 identify a set of adaptation actions likely to be implemented by businesses to cope with these impacts
391 and recover from the shock.

392 The questionnaire focused on the economic impacts resulting from the interruption of lifeline services
393 provided by critical networks in the event of natural disasters. In line with recent local events, two
394 interruption scenarios were exposed to respondents disregarding the natural hazard causing the
395 interruption as well as potential side and macroeconomic effects: an interruption of the drinking water
396 network for one week and an interruption of the electricity network for two days. The questionnaire
397 aimed to collect data in order to (i) calculate individual economic resilience, and (ii) understand the
398 drivers of economic resilience that are embodied in the peculiar characteristics of businesses (e.g.
399 economic sector, annual turnover, geographic location, diversification of activities) and likely to
400 explain their ability to cope with network interruptions. It was designed using *Limesurvey*³, a free and
401 open source on-line survey application. Because it is an eco-friendly, inexpensive, easy to administrate
402 and use process, the questionnaire was disseminated exclusively on the Internet. It was e-mailed from
403 July to October 2015 to businesses registered by three local economic institutions and to members of
404 twenty representative local business associations⁴. It was also publicized on social media (Facebook®,
405 Viadeo® and LinkedIn®). To maximize the response rate, a lottery incentive was eventually added to
406 the survey⁵.

407 Questions were designed so as to recover each component of the resilience indicator. Every metric is
408 thus directly recovered from a question of the survey (Table 1). Indicators were constructed as
409 follows:

- 410 - The change in turnover (ΔY) is directly provided by respondents and expressed in percentage
411 of baseline turnover over the length of the event ;
- 412 - The recovery time (t) is the ratio of the duration of the impacts to the duration of the event,
413 both quantities being expressed in days⁶;
- 414 - The equilibrium state (σ) is a coefficient that is 1 if the level of activity of the business
415 suffered no impact after one year (bounce back profile), 0.5 if activity increased (bounce
416 forward profile) and 1.5 if activity decreased;
- 417 - The other market impacts (*OMI*) and non-market impacts (*NMI*) are qualitative weighted
418 indicators computed as $\sum_i I_i * w_i$, with I_i a binary variable taking 1 if impact i was suffered by
419 the business and 0 otherwise, and w_i a weighting factor accounting for the importance of each
420 impact i on business operations (Table 1);
- 421 - The sensitivity (S) is a qualitative weighted indicator computed as $\sum_a S_a * w_a$, with S_a a
422 binary variable taking 1 if the service is used for the type of activity a (e.g. network water
423 used for production, sales, well-being) and 0 otherwise, and w_a a weighting factor accounting
424 for the importance of each activity a on business operations (Table 1).

³ LimeSurvey: An Open Source survey tool /LimeSurvey Project Hamburg, Germany. <http://www.limesurvey.org>

⁴ Based on public data, a particular attention was paid when selecting business associations in order to target similarly each economic sector so as to ensure that the sample be representative of the general structure of the case study economy.

⁵ Respondents that would entirely fill the questionnaire were offered to participate in a lottery selecting randomly 30 winners of a Guide to the Local Geological Curiosities whose retail price is 19 €₂₀₁₅.

⁶ Here, we use a ratio in order to compare two events with different durations. If one was to analyze resilience among companies for a unique event, the sole use of the duration of the impact would be sufficient to capture recovery time. For the present case study, the use of a ratio allows differentiating the relative higher resilience of a business that suffers damages for a week after a one week water shortage from the lower resilience of a business that suffers damages for a week following an only two days electricity blackout.

426 **4. Results**

427 **4.1. Description of the sample**

428 Our sample contains 108 individual businesses whose main characteristics are presented in Table 2.
 429 Microenterprises – less than 10 employees and an annual turnover inferior to 2M€ – account for 64%
 430 of the sample, half of which are less than 8 years old. The service sector represents 80% of the sample.
 431 Respectively 74% and 94% of businesses depend on the drinking water and electricity networks for
 432 their operations. Interestingly, only 40% of businesses own their buildings which are also, for 35% of
 433 the sample, the ordinary residence of business owners. In line with the peculiarities of the UCCM
 434 economy, businesses are rather small enterprises, often thinly capitalized and individually owned.
 435 However, it has to be noted that our sample is quite modest with regard to the 29 000 businesses
 436 recorded in the perimeter of the UCCM in 2014. Therefore, this case study only aims to illustrate our
 437 method and the reader should be aware of the strong limits of our results as they are inferred from a
 438 small data set.

439 A set of 19 adaptation actions either currently implemented by businesses or likely to be implemented
 440 in the aftermath of lifeline service interruptions was identified through face-to-face interviews and
 441 assessed in the survey (Fig.3). Pro-active adaptations include inventories that enables keeping on
 442 producing even in case of default of the supplier, business interruption insurance, risk management
 443 procedures, membership in professional groups and well-functioning substitution solutions to the
 444 service network (e.g. private well for drinking water, power generator for electricity). During and after
 445 the shutdown, reactive adaptation actions are related to both supply (e.g. purchasing bottled water,
 446 changing procurement processes) and production activities (e.g. relocating operations, lengthening
 447 working hours). Although their relative frequency of implementation depends on the shutdown
 448 scenario investigated, all businesses but one already set up at least one pro-active adaptation and most
 449 of them would adopt both reactive and pro-active adaptations when faced with lifeline service
 450 interruptions. Owning a substitute to the electricity network is the most frequent pro-active adaptation
 451 implemented by businesses while the most frequent reactive adaptations in both scenarios are related
 452 to modulating working hours.

453 *Fig.3. – Approximately here*

454 **4.2. Calculation of economic resilience indicators**

455 Economic resilience of businesses as defined by (1) requires computing several indicators from raw
 456 data of the survey that are transformed according to the details presented in section 3.3. Results are
 457 summarized in Table 1 and 2. They apply to both the drinking water network shutdown (DWNS) and
 458 the electricity network shutdown (ENS) scenarios. Since the objective is to assess economic resilience
 459 with regard to lifeline service interruptions, indicators are computed only for businesses whose
 460 activities depend on the considered service⁷.

461 *Table 1. – Approximately here*

⁷ The sample does not contain complete data for all the variables required to compute economic resilience (some stem from non-mandatory questions of the questionnaire). Therefore, although the activities of respectively 80 and 102 businesses depend on drinking water and electricity, only 72 and 93 observations are used to assess economic resilience to DWNS and ENS.

462 **4.2.1.Change in turnover (ΔY)**

463 Most businesses declare that they would face a decrease in turnover during the interruption (51% of
464 businesses during the DWNS and 76% during the ENS). On average, turnover loss compared to
465 baseline turnover over the length of the event would reach 21% for the DWNS, that is on average
466 3320 €₂₀₁₅ per impacted business, and 32% for the ENS, that is on average 3440 €₂₀₁₅ per impacted
467 business⁸. No business would report an increase in turnover, neither during nor after the interruption.

468 **4.2.2.Other market impacts (OMI)**

469 Apart from changes in turnover, the other market impacts incurred by businesses that are investigated
470 in the questionnaire include production interruptions, sales interruptions, increasing production costs,
471 penalties due to non-compliance with commercial contracts and other impacts on revenues.
472 Respectively 60% and 64% of businesses would incur at least one of these market impacts during the
473 DWNS and the ENS. Using the weighting factors presented in Fig.3, OMI ranges on a scale from 0 to
474 9. On average, it is slightly higher for the ENS (2.3) than for the DWNS (2.0).

475 **4.2.3.Non-market impacts (NMI)**

476 Non-market impacts vary greatly according to the scenarios. For instance, the ENS would lead to
477 delays in the supply chain for half of businesses, against only 21% following the DWNS. Overall,
478 more than two third of businesses would suffer disruptions in their organization (e.g. drudgery of
479 work, waste of time) in both scenarios. On a scale of 0 to 12, NMI reaches on average 5.1 for the ENS
480 and 3.8 for the DWNS.

481 **4.2.4.Recovery time (t)**

482 With 83% of businesses returning to normalcy after the week that would last the DWNS and only 59%
483 after the two days of the ENS, the recovery time is relatively longer for the ENS than for the DWNS.
484 This means that in the long-run, the longer interruption for the DWNS than for the ENS does not
485 outweigh the relative stronger overall immediate economic impacts when faced with electricity
486 outages. Since t depends on the duration of the event, its scale varies according to the scenarios. It
487 ranges from 1 to 4 for the DWNS and from 1 to 8 for the ENS.

488 **4.2.5.Equilibrium state (σ)**

489 A significant share of businesses would not return to their initial level of activity after one year.
490 Respectively 43% and 17% of businesses have a bounce back profile for the DWNS and the ENS,
491 while only one business presents a bounce forward profile for the ENS. Both the recovery time and the
492 equilibrium state indicators suggest a stronger struggle to return to normalcy when faced with
493 electricity outages.

494 **4.2.6.Sensitivity (S)**

495 Scores of sensitivity highlight that businesses resort more to electricity for operating activities than to
496 water. When 79% of businesses use drinking water for current use of their staff, only 49% use
497 electricity for that purpose. Conversely, when 67% of businesses resort to electricity for production
498 and sales, they are only 39% to resort to drinking water to this end. As a consequence, overall
499 sensitivity is higher for the ENS than for the DWNS, with scores of respectively 7.8 and 5 on a scale
500 of 0 to 16. This means that by construction, since sensitivity is the denominator of the economic
501 resilience indicator, if a business suffers a similar aggregated long-term economic impact in both

⁸ The average turnover of businesses that declare they would be impacted by the DWNS is higher than the average turnover of businesses that declare they would be impacted by ENS, which explains the small difference between turnover losses induced by the DWNS and the ENS.

502 scenarios, it will be considered as more resilient to the ENS than to the DWNS, because it would have
503 managed to overcome its relative higher pre-existing sensitivity to electricity outages than to water
504 shortages.

505 **4.2.7. Economic resilience (ER)**

506 Economic resilience is computed on a scale of 0 to 100. It reaches on average 86 for the DWNS and
507 75 for the ENS. The stronger resilience of businesses to the DWNS is mainly due to the contribution
508 of the long-term economic impacts that is about three times less for the DWNS than for the ENS. Over
509 the whole sample, the higher sensitivity to ENS is not sufficient to counterbalance the strength of its
510 economic impacts that result in smaller economic resilience of businesses to electricity outages. When
511 both events are considered, aggregated economic resilience of businesses is 80. With regard to these
512 indicators, business profiles are quite diverse, with profiles such as high sensitivity/low impacts and
513 low sensitivity/ high impacts fairly represented in the sample, and only a small, but significant,
514 correlation between the economic resilience to ENS and DWNS.

515 *Table 2. – Approximately here*

516 **4.3. Insights into the drivers of economic resilience to drinking water interruptions**

517 The limited size of the sample prevents us from examining properly all the potential drivers of
518 economic resilience for which data were gathered through the survey. Explanatory variables were
519 selected based on a literature review on the determinants of the economic resilience of individual
520 businesses to natural disasters (Alesch et al., 2001; Asgary et al., 2012; Boarnet, 1996; Brown et al.,
521 2015; Henriët & Hallegatte, 2008; Kroll et al., 1991; Rose, 2009; Rose et al., 2013; Tierney, 1997 and
522 2007; Webb et al., 2002) and through face-to-face interviews. They can be classified into three
523 categories: socio-economic characteristics, proactive adaptations and reactive adaptations.

524 The econometric models are presented in Table 3. Both models are multiple linear regressions. Model
525 A is an extended model that tests multiple drivers. Model B is a reduced version of Model A. Results
526 show that although annual turnover and number of employees are obviously correlated, they have an
527 opposite effect on economic resilience since it declines with the number of employees and rises with
528 annual turnover. This validates that the less workers there are in the firm, the more flexible the
529 organization is, which eases adaptation and fosters resilience. Turnover is a factor of economic
530 resilience, as previously pointed out by many authors (Chang et al., 2003; Rose et al., 2013, Tierney,
531 1997 and 2007; Webb et al., 2002). Small businesses are more likely to operate with less cash flow
532 which hinders the recruitment of external organizational or logistical support functions to help them
533 anticipate and cope with potential impacts. They are also more likely to be in a precarious financial
534 condition prior to the event, which can be exacerbated by the difficulties emerging from network
535 interruptions. The same point applies to businesses operating in the competitive retail and service
536 sector whose financial stability is more likely to be jeopardized by supply chain disruptions (Tierney,
537 2007). Other characteristics such as the property ownership, the age of the business, whether the
538 manager lives at his workplace, the indebtedness of the company, and the time relying on stocks have
539 been tested but are not statistically significant in our models. However, model A suggests the age and
540 indebtedness of businesses have a negative effect on resilience while the property ownership, its
541 location as the ordinary residence of the owner and the length of time relying on stocks have positive
542 effects. Such findings are in line with expectancies. However, for the age of the business, assumptions
543 can differ: older businesses are more likely to engage in preparedness activities due to their experience
544 with previous disasters, while younger businesses have a longer planning horizon, less organizational
545 inertia and stronger resources that all together enhance their ability to cope with utility outages.

546 Most pro-active adaptations seem to positively influence economic resilience although none of them is
547 statistically significant in our models. Businesses that subscribe to business interruption insurances are
548 already aware of the risks they encounter and voluntarily intend to broaden their insurance cover
549 against those risks. Therefore, non-mandatory business interruption insurance may be considered as a
550 proxy for engaging in preparedness activities and that is why insured businesses tend to be more
551 resilient. Owning substitution solutions to the water network has a mixed effect on resilience.
552 Although having a well contributes positively to resilience, other types of substitution solutions (e.g.
553 water tank, rainwater collector) do not. An explanation stems from the type of water needs for which
554 wells are used. Conversely to other solutions, most of the businesses that have a private well at
555 disposal use water for production or sales, they are therefore by construction more sensitive to water
556 shortages. However, using their well is likely to reduce the economic impacts they would suffer in
557 case of water shortage which makes them all the more resilient, given their high pre-existing
558 sensitivity. As for membership in professional groups, it is an indicator of the ability of a business to
559 resort to professional solidarity. Model A shows that it is positively correlated with resilience, even
560 though this effect is not statistically significant.

561 We investigate the effect of four reactive adaptations. Results show that the ability to modulate either
562 working hours or production processes is a strong driver of resilience. Businesses that are able to make
563 up the initial production loss by rescheduling operations and working extra hours once the service has
564 been restored are less likely to suffer strong economic impacts in the long-run. Results of Model B
565 suggest that flexibility in production processes increase the economic resilience of businesses by 11
566 points, all other things being equal. Using input substitution and implementing conservation actions
567 (i.e. reducing water consumption) have both positive but not statistically significant effects on
568 resilience.

569 *Table 3. – Approximately here*

570 **5. Discussion**

571 Any discussion of our results should start by reminding that the case study is a method validation and
572 illustration case study, with no pretence of it representing the economic context of Martinique. That
573 being said, even with the relatively limited and constrained damages assessed here (i.e. one network
574 interruption with no ripple-effect on interrelated networks), results show that impacts of network
575 disruptions could last over a month and cause significant losses to individual businesses. Measures of
576 economic resilience validate the necessity to account for both the immediate economic impacts and the
577 time span of the recovery process since businesses that suffer the higher economic impacts during
578 shutdowns are not necessarily the ones suffering the higher long-term impacts. Results show that
579 businesses are more resilient to DWNS than to ENS which is in line with the findings of Kajitani and
580 Tatano (2009) and with intuitions. This result supports the validation of our indicator as a relevant
581 measure of resilience. However, since the indicator is a relative measure, its scores are not supposed
582 to be interpreted in absolute terms. They only aim to be compared relatively to the scores of other
583 firms or other events. As a consequence, a score of 86 (mean economic resilience to DWNS) is not
584 high *per se* but should only be considered as higher than a score of 75 (mean economic resilience to
585 ENS).

586 Most results regarding the drivers of economic resilience are coherent with intuitions. In line with
587 previous empirical studies, business size appears as a driver of resilience (Asgary et al., 2012; Chang
588 & Falit-Baiamonte, 2003; Rose et al., 2013; Tierney, 2007). However, when former studies justified
589 the positive effect of business size on resilience with arguments relying interchangeably on turnover or

590 number of employees, our specification allows demonstrating which attribute of business size actually
591 fosters resilience, namely turnover rather than employees. Results also show that flexibility of working
592 hours and production processes contribute largely to economic resilience (see Park et al. (2011) for a
593 theoretical analysis of the influence of recapturing lost production on economic resilience). This is of
594 particular interest considering that these adaptations may bring other co-benefits to businesses, even in
595 the absence of any disasters (e.g. enhanced business continuity due to compressed work schedules,
596 increased staff motivation with telecommuting). Therefore, they can be considered as no regrets
597 adaptations (Hallegatte, 2009). Overall, our indicator seems to better capture the drivers of adaptive
598 resilience than those of inherent resilience since none of the pro-active adaptations that were tested in
599 the regressions emerged as statistically significant. In that respect, it is likely that it still integrates a
600 sensitivity component that is not fully controlled for in the sensitivity indicator. The major challenge
601 for defining an appropriate resilience indicator is indeed removing the sensitivity component from the
602 economic impacts. This would allow focusing on the inherent and adaptive components of recovery.
603 In our research however, some variables were missing to better define sensitivity such as the volumes
604 of water needed per type of use for which the network is currently used by businesses. Essentially,
605 specifying the sensitivity of a firm based on survey data will always remain difficult, because
606 sensitivity relies on complex firm-specific production processes that cannot be accurately captured by
607 closed-ended format surveys. Better characterizing business sensitivity is a challenge for future
608 research.

609 From a methodological perspective, the use of a business survey allows reconstructing the likely
610 impacts and associated behaviours of individual businesses during and after disasters. This enables
611 assessing economic resilience ex-ante, even though some of its components are only manifest in the
612 post-disaster phase. Also, it allows harmonizing the level of hazard and exposition for all businesses
613 by setting identical hazard scenarios. However, resorting to an ex-ante business survey has certain
614 limitations. It carries large uncertainties regarding the actual impacts that would be suffered by
615 businesses in the event of a disaster since potential impacts are hypothetical and depend on how
616 businesses perceive their own vulnerability and adaptive capacity to disaster risks. Such declared
617 impacts are subject to strong cognitive and strategic biases (e.g. accounting for past experiences of
618 natural disasters such as hurricane Dean). Moreover, the robustness of the results highly depends on
619 the response rate and the representativeness of the sample. Here, the low response rate to the
620 questionnaire is mainly due to the poor use of emails for business communications in Martinique. The
621 length of the questionnaire (between 16 and 66 questions, depending on situations) and its filling time
622 (27 min on average) do not appear as major obstacles to participation since out of the 119 respondents
623 that did open the first page of the questionnaire, only 10% did not fill it entirely. Other possible
624 explanations stem from the fact that scenarios depict events that are frequent on the island or that it is
625 challenging to attract the interest of an audience when dealing with hypothetical future disaster
626 situations, not focusing on one particular past event. In the field of natural disasters, most surveys
627 targeting businesses were carried out in the aftermath of well-known past events. For instance,
628 interrogating businesses on the impacts of the Northridge earthquake in California using a mail survey,
629 Tierney (1997) reached a response rate of 23%. However the survey was carried out twenty years ago,
630 long before the mass use of questionnaire-based surveys and the competition it generates on the time
631 availability of respondents. The mailing was followed up by telephone calls, and the survey was
632 carried out sixteen months after the Northridge earthquake, dealing therefore with a real event still
633 very present in the mind of businesses. Using a similar protocol, Brown et al. (2015) recently reached
634 a 25% response rate amongst businesses affected by the 2010/2011 Canterbury earthquakes in New
635 Zealand. All in all, the effort to diffuse Internet questionnaires can outweigh the benefits of saving
636 time to collect the data.

637 With regards to the ability of the indicator to measure microeconomic resilience, it should be noted
638 that building indicators always requires finding the appropriate balance between *clarity* and
639 *robustness*, i.e. indicators have to be simple but not simplistic, accurate but not convoluted. In this
640 way, our indicator offers a simplified view of a set of complex dynamics. It does not allow measuring
641 the overall economic resilience of communities and its consequences in terms of aggregate output and
642 welfare impacts. It only captures the microeconomic component of businesses' economic resilience,
643 i.e. the ability of individual businesses to cope with a disaster and maintain activities under stress.
644 Doing so, it considers each business as a single economic entity whose ability to cope with a shock
645 depends on a set of non-hazard related factors. This means that macro-economic feedbacks and
646 systemic effects stemming from relationships between producers and consumers within an economy
647 are not accounted for. Moreover, the indicator tells nothing about non-economic dimensions of
648 resilience such as those related to physical, human, cultural or environmental impacts. It can be
649 comprehended as a complement to the resilience indicator developed by Rose (2009) on which we
650 elaborate by adding both non-monetary and dynamic components to the measure of the variation of
651 direct output as well as approximating the theoretical maximum percent change in direct output by a
652 measure of the pre-existing vulnerability of businesses that we call sensitivity. As a result, even if the
653 indicator is not capable of distinguishing different paths, it accounts for the dynamic evolution of
654 recovery and impacts. Moreover, it relies on non-monetary metrics to capture non quantifiable impacts
655 of natural disasters. As advocated by Hallegatte et al. (2011) and Schneider et al. (2000), the use of
656 numeraires to assess indirect impacts avoids going through complex monetary valuations while
657 broadening the scope of potential impacts beyond financial impacts that are rather limited. Because it
658 is made of several subcomponents, our aggregated indicator is also highly dependent on the way
659 variables and indicators are weighted. However, since weights are based on insights from the literature
660 and not on local expert knowledge, our approach lacks an objective field-grounded weighting method.

661 Another limit pertains to the fuzzy distinction between pro-active adaptations and
662 general characteristics. For instance, resorting to inventories can be considered as a characteristic that
663 has nothing to do with anticipating the next hazard because it is a specificity of firms' operations or
664 because it does not result from a conscious risk mitigation strategy. This fuzziness could be a pitfall
665 for anyone willing to compare the influence of these two categories of explanatory variables on
666 economic resilience. Moreover, the size of the sample did not allow undertaking detailed sector and
667 spatial analysis of economic resilience although it would be useful to policy making and decision
668 makers in order to pinpoint hotspots of poor resilience.

669

670 **6. Conclusion**

671 In a context of increasing impacts of natural disasters and high concentration of economic activities in
672 dense urban environments, our research aimed at developing a scientifically sound operational
673 measure of the economic resilience of individual businesses to lifeline service interruptions caused by
674 natural disasters. We stabilized a conceptual framework pinpointing the peculiarities of resilience with
675 respect to pre-existing vulnerability and adaptation. As such, we provided an understandable and
676 useful analytical framework for both "risk" and "resilience" scientific communities whose definitions
677 and overall understanding of these concepts often lack consistency. We then used this conceptual
678 framework to build an operational indicator of the microeconomic resilience of individual businesses
679 that we applied, as an illustration of its interest, to an urban community located in an overseas
680 territory. Indicators of economic resilience are useful because they enable to empirically assess, map
681 and compare resilience within a population of businesses over a given territory while analyzing the
682 drivers of economic resilience, as illustrated in this paper. Moreover, they can also be used to adapt

683 production functions developed in classical macroeconomic models in order to account for resilience
684 of businesses and therefore provide more accurate assessments of the economic impacts of disasters.

685 The added-value of this research is threefold. First, it builds on previous work on resilience to
686 elaborate a conceptual framework that highlights the multidimensional nature of economic resilience
687 at the microeconomic level. This is of interest to identify the factors that determine the rebound
688 capacity of businesses which is at the core of resilience, as opposed to vulnerability and adaptation.
689 Second, it develops a methodology to measure the economic resilience of individual businesses using
690 empirical data. The indicator that is developed addresses two important shortcomings regarding the
691 measurement of individual economic resilience. It accounts for both market and non-market impacts
692 of disasters and therefore enlarges the scope of impacts considered in resilience assessments. It also
693 isolates pre-existing sensitivity to shocks from overall economic impacts and thereby allows
694 comparing pattern of resilience across businesses according to their ability to absorb and respond to a
695 shock, disregarding their pre-existing sensitivity to the shock. This avoids mistaking the root cause of
696 the economic impacts. In doing so, it differentiates businesses that are little impacted because they are
697 by essence little sensitive to the disaster from businesses that are little impacted because they are
698 resilient. Third, it enables to compare economic resilience among firms or events and thereby identify
699 the types of firms, sectors or geographical areas that are the most prone to suffer long-term damages
700 from disasters. This is of prime interest to elaborate targeted policy recommendations for building
701 resilient economies.

702 Understanding the drivers of resilience without mingling them with the drivers of sensitivity which is
703 *per se* embodied in current business practices and has nothing to do with its ability to cope with
704 upcoming events, will help develop efficient risk reduction policies targeted at businesses that
705 effectively lack resilience rather than businesses that are solely sensitive to the disaster but potentially
706 very well prepared to its effects. Our results illustrate the challenge of removing all sensitivity
707 components from resilience in an empirical exercise.

708 Although results should be used with caution, the application of our methodology to a case study in
709 the French West Indies shows that it is suited to test assumptions empirically. It confirms the essential
710 role of business size on resilience differentiating a positive effect of turnover on resilience and a
711 negative effect of the number of employees. Flexibility in working hours and production processes
712 also showed to be significant drivers of resilience.

713 Further research could investigate more thoroughly the inherent component of resilience. This is an
714 important issue since ex-ante risk reduction strategies would be more effective focusing on fostering
715 the resilience already built in business functioning than on anticipating the best ways of assisting
716 businesses during disasters when resources are scarce and the capacity to act is limited. Observing the
717 paths and dynamics that businesses follow when recovering would be also very instructive and should
718 be a perspective for future research in the field of economic resilience. Detailed examination of the
719 double counting issues when compiling resilience indicators such as the one suggested in this paper is
720 also an important challenge for the operationalization of the resilience concept. In addition, getting a
721 larger dataset would allow investigating the effect of more variables (e.g. economic sector, geographic
722 location, supplier diversification, production of perishable goods, previous disaster experience) and
723 explore the substitution effect between insurance and adaptation in order to better understand firm
724 strategies with regard to risk reduction. Ultimately, results aim at feeding broader resilience
725 assessments that account not only for individual resilience but also for both hazard characteristics and
726 systemic effects on overall economies.

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736

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897

898 **Appendix. Data collection**

899 The two-step data collection process consisted in (i) preliminary interviews and (ii) the dissemination
900 of a business internet survey.

901 **Preliminary interviews**

902 The first stage started with a first series of interviews (10) with local decision makers and natural
903 hazard experts selected for their concrete knowledge and global vision of the stakes related to the
904 vulnerability and resilience of businesses to natural risks in the case study among which local policy-
905 makers, state representatives, network managers and natural hazard scientists. These interviews
906 allowed better understanding the peculiarities of the Martiniquese context and the exposure of its
907 economic agents to natural risks. It also helped fine-tuning the design of the next steps of the research
908 in light of empirical information gathered from local stakeholders. A second series of face-to-face
909 interviews was carried out with a sample of twenty business managers located within the perimeter of
910 the Urban Community of Central Martinique. These semi-directive interviews aimed to characterize
911 how network interruptions impact firm activities (e.g. which technical, economic and organizational
912 processes are likely to be affected at firm level), identify the set of adaptation measures implemented
913 by businesses to cope with these impacts/recover from the shock, and identify the factors likely to
914 have an influence on the economic resilience of businesses to natural risks. The selection of
915 interviewed businesses from the business contact database of the UCCM was realized with a stratified
916 and quota sampling approach. Businesses were differentiated according to three stratifying variables:
917 economic sector, city location and number of employees. The sample was then built so as to match the
918 current share of each of these variables in the Martiniquese economy. Results of this qualitative
919 analysis were then used in the second stage of our study for the design of a web questionnaire that was
920 addressed to a large sample of businesses.

921 **Business internet survey**

922 The questionnaire is divided into four parts: (1) the general characteristics of the business, including
923 its economic sector, annual turnover, current number of employees, geographic location, use of
924 insurance and ownership of business property; (2) the dependence of its activities to lifeline services
925 provided by critical networks and infrastructures, including questions on the operational and economic
926 impacts that businesses sustain as a result of lifeline service interruptions and on preparedness
927 measures undertaken both before and following an interruption; (3) the exposure of business activities
928 to natural hazards, including events that may have impacted the business in the past and their impacts
929 on its operation and revenue; and (4) the individual socio-economic characteristics of the respondent.
930 The overall questionnaire consists of 83 questions, of which 34 are mandatory and 39 are conditional

931 on answers provided to previous questions (some questions are both conditional and mandatory). All
932 in all, the backbone of the questionnaire includes 44 questions, of which 16 are mandatory. Since
933 some sets of conditional questions depend on a unique previous question, there is no case in which a
934 respondent would be asked to answer to each of the 83 questions. It is mostly made of closed-ended
935 questions and multiple choices questions, although a few open-ended questions are also included in
936 order to gather detailed answers on specific aspects and offer respondents the opportunity to freely
937 express their views on the topic.

938 The questionnaire is introduced by a few pedagogic lines on the research topic and a description of the
939 aim and scope of the questionnaire. A particular attention was paid to highlighting the contribution of
940 potential respondents to a singular research effort so as to enhance their motivation to participate in the
941 survey. To maximize the response rate, a lottery incentive was also added to the survey. Respondents
942 that would entirely fill the questionnaire were offered to participate in a lottery selecting randomly 30
943 winners of a Guide to the Geological Curiosities of Martinique whose retail price is 19 €₂₀₁₅.

944 The survey was broadcasted exclusively on the internet. It was distributed to individual businesses
945 located within the perimeter of the UCCM during the summer of 2015. The distribution process was
946 three-fold and consisted in e-mailing a short paragraph introducing the objective, the content and the
947 link to the survey to individual businesses. First, the questionnaire was sent to businesses whose e-
948 mail addresses were registered in the business contact databases of three local public institutions: the
949 UCCM, the Regional Chamber of Commerce and Industry and the Regional Chamber of Trade and
950 Craft. In order to benefit from the long-term trustful relationship linking these institutions to their
951 members, the three entities were asked to send themselves the questionnaire to their members. Second,
952 the main business associations exercising in Martinique were asked to transfer the link to the survey to
953 their members. The use of sectorial and local business associations to relay the questionnaire aimed at
954 fostering the response rate by increasing the credibility of the approach among business managers. It
955 also allowed targeting a wider list of businesses so as to broaden the scope of the sample. Based on
956 public data, a particular attention was paid to targeting similarly each economic sector to ensure that
957 targeted businesses be representative of the general structure of the Martiniquese economy. The third
958 approach consisted in broadcasting and publicizing the survey on social media. Specific pages
959 promoting both the survey and the RESILCITY project were created on Facebook, Viadeo and
960 LinkedIn. Each page encouraged business managers to click on a link to open the questionnaire.
961 Moreover, on Facebook, an advertising campaign was carried out in order to promote the survey to a
962 specific audience consisting in individual profiles matching two criteria: the geographic location of the
963 individual (Martinique) and its general interests (business, trade, business, sales and entrepreneurship).
964 The campaign made visible a small box promoting the questionnaire on the Facebook pages of about
965 12 500 profiles matching these criteria. Two series of emails were sent to businesses by public
966 institutions and business associations in July and September 2015. Similarly, the advertising campaign
967 took place both in July and in September 2015.