Negative Spillovers Across Partnerships for Responsible Innovation: Evidence from the 2014 Ebola Outbreak

Birgul Arslan

Assistant Professor of Innovation Management

Rotterdam School of Management, Erasmus University

P.O. Box 1738 DR

Rotterdam, the Netherlands

b.arslan@rsm.nl

Murat Tarakci

Associate Professor of Innovation Management

Rotterdam School of Management, Erasmus University

P.O. Box 1738 DR

Rotterdam, the Netherlands

tarakci@rsm.nl

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Abstract

Humanity faces ongoing and contemporaneous grand challenges. Occasionally, abrupt shocks escalate a grand challenge's salience over others. Prior research has advocated forming partnerships to address grand challenges via responsible innovation. Yet, it remains unclear how temporal changes in the salience of a grand challenge impact innovation performances of partnerships. We address this research gap by bridging the literature on issue salience, responsible innovation and interorganizational relationships. We argue that shocks either aid or harm the performance of partnerships for responsible innovation depending on whether their domains are directly or indirectly affected. The Ebola outbreak in 2014 sets the empirical context to test our theory. We find that while the innovation performance of Ebola partnerships formed after the outbreak rose eleven-fold, the performance of partnerships treating Influenza fell by 84.9 percent. Our theory and findings have immediate implications for today's COVID-19 outbreak, cautioning against salience shifts among concurrent grand challenges.

Keywords

Grand challenges, Responsible innovation, Interorganizational relationships, Ebola outbreak

INTRODUCTION

"Dark beauty — [a] horror!"

That is how Frederick A. Murphy, the first person to photograph the Ebola virus, reacted to the image he had just captured on October 13, 1976 (DelViscio, 2014). Similar feelings of horror were pronounced globally when the World Health Organization (WHO) officially declared an Ebola outbreak on March 23, 2014. Without effective treatment options beyond supportive care, the disease killed up to 90% of those infected via severe hemorrhage. Until its end in June 2016, the outbreak took 11,325 lives worldwide (Centers for Disease Control and Prevention, 2019). The outbreak's severity sparked a sense of urgency, prompting the WHO to call governments, NGOs and pharmaceutical companies to collaborate toward a cure (WHO, 2014). The recent COVID-19 pandemic, claiming more than 190,000 lives in just four months, reminds us of the urgency and importance of addressing similar challenges. It is now clear that "eradicating and treating diseases that afflict the poorest in the world is one of the most compelling GCs [grand challenges] of our time" (George et al., 2016).

Overcoming grand challenges demands responsible innovation (Voegtlin & Scherer, 2017), defined as "taking care of the future through collective stewardship of science and innovation in the present" (Owen et al., 2013: 1570). Because grand challenges "are typically complex with unknown solutions and intertwined technical and social elements" (Eisenhardt et al., 2016: 1113), collaboration across governments, the private sector, and civil society becomes essential (George et al., 2016; Rangan et al., 2006; Waddock et al., 2015). It is, therefore, no coincidence that the UN's 17th sustainable development goal aims at forming partnerships for addressing grand challenges.

Recent research on grand challenges has unearthed what drives partnership formation (e.g., Williams et al., 2019), which partners to involve (e.g., Olsen et al., 2016), and how to manage the partnerships (e.g., Doh et al., 2019; Powell et al., 2018). This work has contributed markedly to our understanding of partnership response to grand challenges. Yet, the underlying assumption has been that organizational agendas include one grand challenge at a time with a constant level of salience. Organizations, however, face many grand challenges where salience shifts via exogenous shocks. Humanity is often reminded of the significance of a specific grand challenge by sudden shocks such as wildfire, flood, or viral outbreak. Understanding the effects of these shocks on the performance of partnerships is

critical because temporal changes in the salience of grand challenges exert important repercussions on motivation to cooperate, and subsequently, on partnership performance. This paper aims to fill this gap by posing the following research question: how do abrupt shocks impact the innovation performance of partnerships for responsible innovation?

We develop theory explaining how abrupt shocks differentially affect partnerships within and beyond the domain of the grand challenge experiencing the shock. Our proposed theory builds on the premise that organizations face a multitude of issues (Durand et al., 2019; Ocasio, 1997). Issues evoking greater urgency and legitimacy become more salient and attract organizational resources while depriving others. On one hand, partnerships formed in response to a shock benefit due to heightened perceptions of issue salience and the expected benefits of focusing on that grand challenge. The issue gaining salience ensures the resource commitments needed to achieve partnership objectives. The rise in perceived benefits also aligns partnership incentives, mitigating coordination problems and opportunistic behavior. On the other hand, the innovation performance of partnerships addressing *related* grand challenges may falter post-shock since they attract fewer resources and incentive alignment among partners erodes.

We tested and found support for our hypotheses in the context of the 2014 Ebola outbreak affecting intra- and cross-sector partnerships formed to develop drugs to combat both Ebola and Influenza—the two most life-threatening viral infections worldwide (WHO, 2019). While the innovation performance of Ebola partnerships formed after the outbreak increased versus those formed pre-outbreak, the performance of partnerships treating Influenza, a grand challenge in a related domain, dropped. This research finding remains robust accounting for endogeneity in partnership formation and partner selection, as well as in difference-in-differences analyses.

Our study contributes to research on responsible innovation, grand challenges, and interorganizational relationships. The burgeoning literature on responsible innovation has well defined this concept and its dimensions (e.g., Owen et al., 2013), shed light on the antecedents of responsible innovation and types of responsible behavior (e.g., Stahl & De Luque, 2014) and described proper mechanisms for its governance (e.g., Voegtlin & Scherer, 2017). Still, less is known about the performance of responsible innovation activities. We respond to the call for a deeper investigation into the challenges of collaborative innovation and the contingency factors that influence its success (Voegtlin & Scherer, 2017).

Second, while research in grand challenges mentions the existence of multiple challenges facing organizations (George et al., 2016), it treats these challenges in isolation assuming constant salience over time. In contrast, we argue that an abrupt shock increases the salience of a grand challenge, spilling over across related challenges by lowering their priority. Competing for organizational resources, the performance of responsible innovation activities addressing low-priority challenges is adversely affected. We find support for this argument in the setting of Influenza partnerships formed during Ebola's rise in priority after its 2014 outbreak.

Lastly, we deepen our understanding of whether collaborative partnerships can deliver the intended results when sudden shifts in the salience of grand challenges occur. The literature on interorganizational relationships suggests that partnerships foster innovation (Ahuja, 2000; Deeds & Hill, 1996; Hagedoorn et al., 2018; Rothaermel & Deeds, 2004; Shan et al., 1994; Stuart, 2000), and that organizations collaborate in the face of emerging innovation challenges (Schilling, 2015). Yet, collaboration is also fraught with drawbacks such as coordination costs and misappropriation (Gulati & Singh, 1998; Khanna et al., 1998; Sting et al., 2019). Indeed, the field evidence suggests that organizations often fail to share resources and coordinate activities effectively in response to natural disasters (Eftekhar et al., 2017). We posit a contingency view that reconciles these conflicting views. We predict fewer (more) problems in collaboration for partnerships formed in response to sudden shocks that increase (decrease) the salience of a grand challenge.

GRAND CHALLENGES AND RESPONSIBLE INNOVATION

> "The issues we face are so big and the targets are so challenging that we cannot do it alone … When you look at any issue, such as food or water scarcity, it is very clear that no individual institution, government, or company can provide the solution."
>
> Paul Polman, Former CEO of Unilever (Ferraro et al., 2015: 363).

The WHO and United Nations (UN) announced lists of grand challenges to mobilize interest, debate, and collaboration toward solutions (George et al., 2016). Two streams of research echo this call to collaborative action for innovation addressing grand challenges. First, an emerging stream of research has revitalized the idea of responsible innovation (Owen et al., 2012, 2013; Pandza & Ellwood, 2013; Scherer & Voegtlin, 2020; Voegtlin & Scherer, 2017). Broader innovation literature centers on developing new products and services. Conversely,

the literature on responsible innovation emphasizes directing innovation activities: (i) to reducing the harmful consequences of organizational activity (i.e., doing no harm), and (ii) solving the challenges humanity faces (i.e., doing good) (Scherer & Voegtlin, 2020; Stahl & De Luque, 2014; Voegtlin & Scherer, 2017).

Second, management research on grand challenges has unequivocally stressed forging partnerships as a viable, even necessary, action since remedies to grand challenges are long-term and beyond the reach of a single organization (e.g., George et al., 2016; Owen et al., 2013; Rangan et al., 2006; Stahl & De Luque, 2014; Voegtlin & Scherer, 2017; Waddock et al., 2015). As the opening quote illustrates, grand challenges require collaborative partnerships among various actors, including governments, non-governmental organizations (NGOs), and the private sector. Partnerships[i] allow pooling of capabilities and resources (Powell et al., 2005; Rothaermel, 2001) and enable access to complementary capabilities (Asgari et al., 2017; Dyer & Singh, 1998; Stuart, 2000) in ways that foster knowledge flows (Gomes-Casseres et al., 2006; Mowery et al., 1996) and subsequent innovation (Ahuja, 2000; Deeds & Hill, 1996; Hagedoorn et al., 2018; Rothaermel & Deeds, 2004; Shan et al., 1994; Stuart, 2000). This is perhaps why the UN designated the formation of partnerships as the 17th Sustainable Development Goal.

Grand challenges are presented in these two streams of research as issues that are always highly salient (and rightly so), sometimes to the extent that inaction is inconceivable. As former UN Secretary-General H. E. Ban Ki-Moon noted, “there is no Planet B.” While remaining unquestionably important, the priority attached to grand challenges can shift as key events arise. For instance, natural disasters such as hurricanes and wildfires shift public perception of urgency toward climate change concerns. Similarly, the #MeToo movement has sharpened awareness on gender inequality, and the 2014 Ebola outbreak directed civil society’s focus on outbreak preparedness. From a theoretical view, there remains a missing piece in our understanding of the link between such sudden shocks and the performance of organizational efforts aimed at solving an issue. Clearly, grand challenges are many, ongoing and contemporaneous. Abrupt shocks in the context of a grand challenge may inflict additional pressure on the success of responsible innovation activities especially when more than one grand challenge vie for limited managerial attention and organizational resources. Extant theory has yet to explore whether partnerships can effectively balance such

interdependence among responsible innovation activities when facing multiple grand challenges at once.

Relatedly, while prior research has provided valuable insights into how partnerships can overcome innovation challenges in general, it is unclear whether partnerships formed to tackle a grand challenge after an external shock can deliver the expected results. Partnerships cannot always assure effective resource deployment when the co-existence of common and private benefits creates problems in incentive alignment, value creation and appropriation (Arslan, 2018; Gulati & Singh, 1998; Khanna et al., 1998; Sting et al., 2019). Since partnerships tackling grand challenges involve social value, i.e., benefits to stakeholders that are not directly part of the transaction (Rangan et al., 2006), incentive alignment becomes more difficult to achieve. Partnerships must often operate under hybrid logics (Quélin et al., 2017) and implement special oversight features to disarm tensions regarding value creation and capture (Kivleniece & Quelin, 2012). Incentive misalignment, in turn, sparks a reflexive grip in the management of partnerships that imperils resource commitments (Johnson et al., 2002; Khanna et al., 1998) and attainment of joint objectives (Katila et al., 2008; Luo, 2007). Shocks may thus animate the 'dark side' of partnerships characterized by potential conflict, opportunism and other unethical behavior (Oliveira & Lumineau, 2019). Such difficulties merit further research on the innovation performance of partnerships responding to grand challenges amid outside shocks.

Consequently, our central goal is to build and test theory explaining the direct effect of an abrupt shock in the domain of a grand challenge, plus its spillover effect in related domains. "Domain" denotes a recognized area of research for responsible innovation. Related domains are those demanding similar resources such as knowledge, technical know-how, and equipment.

THEORETICAL FOUNDATIONS AND HYPOTHESES

We build on the foundation of institutional theory to understand how abrupt shocks impact the innovation performance of partnerships for responsible innovation. Institutional theory notes that organizations face incompatible demands from many stakeholders. A key factor in forging organizational response to these demands is *issue salience*, defined as "the degree to which a stakeholder issue resonates with and is prioritized by management" (Bundy et al., 2013: 353). Issues that stakeholders deem critical and time-sensitive become salient (Mitchell et al., 1997). A grand challenge experiencing a shock, therefore, becomes more salient compared to related grand challenges owing to its urgency and recency.

The level of organizational response to stakeholder demands hinges on the costs and benefits of mobilizing resources (Durand et al., 2019). First, stakeholders impose normative pressures defined as "the evaluative and obligatory dimensions of an institutional order that weigh on an organization to gain, maintain, and defend its legitimacy" (Durand et al., 2019: 301). Failure to respond to these normative pressures may cause reputational and regulatory costs, even risking organizational survival. Relatedly, organizations also respond to salient issues substantively when they perceive significant economic and social benefits in doing so.

This theoretical foundation explains if and when organizations engage grand challenges. We advance this line of inquiry by developing theory regarding the performance implications of organizational response to an issue whose salience changes after an abrupt external shock. We build the argument that a shock increases the salience of the issue, after which normative pressures flare up and expected net benefits rise (Durand et al., 2019). Subsequently, organizations respond to the issue by allocating more resources and aligning incentives with responsible innovation partnerships that, in turn, foster innovation performance. Figure 1 depicts our theoretical framework detailed next along with hypothesis development.

Insert Figure 1 about here

Hypothesis Development

While 'grand challenges' identified by influential global organizations such as the UN and WHO retain a certain level of salience, sudden shocks such as outbreaks, earthquakes and hurricanes prompt public outcry and yield temporal peaks in perceived urgency and salience. These shocks trigger substantial press and analyst coverage calling for appropriate action, thereby establishing legitimacy around the issue and creating an obligation to act.

When the salience of an issue surges, the benefits of responding to the issue increase (Durand et al., 2019). The benefits of organizational response may involve perceived economic benefits stemming from the opportunities that arise when shocks establish new demand (Schilling, 2015). Companies ably responding to a shock obtain a potentially durable, first-mover advantage and market leadership (Argyres et al., 2015). Second, responding to salient issues may become economically beneficial when institutional support emerges, thus reducing the costs of responsible innovation. The increased post-shock demand and

institutional support stir organizations to satisfy emerging market demands (Priem et al., 2012).

In parallel, when issue salience heightens with increased legitimacy and urgency, the associated normative pressures will strengthen. Organizations will perceive growing pressure to engage. Here, organizational response becomes more likely either based on a rationale of social benefit such as improving reputation and legitimacy or on aversion of cost such as reputation loss and regulatory penalty.

Increased normative pressures for and perceived benefits of responding to shocks, in turn, improve in two ways the innovation performance of partnerships formed for tackling the grand challenge. First, partnerships formed after a shock are endowed with more resources to fuel innovation activities in the domain of the respective grand challenge than before the shock. The shift in issue salience, and its resulting normative pressures and expected benefits, attract more organizational attention (Durand et al., 2019; Mitchell et al., 1997). The more mindful organizations are to an issue, the more resources are steered to it. When organizations thus form partnerships in response to a shock in a given grand challenge, these partnerships tend to receive more resources versus those formed pre-shock. Resource allocation to partnership activities is vital for innovation performance since these activities demand time, effort, equipment, funds, and other resources to excel (for a review, see Acar et al., 2019). Clearly, resource commitment is a key factor in collaboration success (Johnson et al., 2002). Partnerships formed to solve a grand challenge experiencing a shock are thus more likely to succeed in their innovation objectives relative to partnerships formed before the shock.

Second, partnerships formed post-shock enjoy better incentive alignment. In general, partner interests only partially overlap where partners tend to pursue their own interests at the expense of joint value creation (Park & Ungson, 2001). The root of this incentive misalignment is the co-existence of and interdependence between potential common versus private benefits stemming from joint activities (Arslan, 2018; Khanna et al., 1998; Sting et al., 2019)—a key factor known to hamper partnership longevity and performance (Das & Teng, 2000; Hamel, 1991; Inkpen & Beamish, 1997; Luo, 2007; Parkhe, 1993). However, when a shift in issue salience raises the perceived benefits of joint response, partnerships focus on greater prospects of common benefits. This, in turn, aligns partner incentives while curbing appetites for private benefit extraction that may otherwise undermine partnership performance. In sum, these arguments form our first hypothesis:

Hypothesis 1: Partnerships formed for addressing a grand challenge after a shock achieve higher innovation performance than those formed before the shock.

Organizations live in an environment where multiple issues clamor for a response. However, organizations cannot respond to all issues substantively since resources are limited. Organizations must prioritize (Mitchell et al., 1997). When an abrupt external shock escalates the salience of one issue, others lose relative priority. At the same time, organizational response to less salient issues will be more symbolic than substantive (Durant et al., 2019). Given their resource limitations, organizations will attach lower priority and allocate less time, effort, and resources to issues experiencing inferior salience after the shock.

Partnerships formed in a related grand challenge after a shock commence with a lack of urgency and priority compared to those formed before the shock. Thus, these partnerships will likely see suppressed levels of organizational resources versus levels assigned pre-shock[ii]. Fewer resources then derail the innovation performance of partnerships formed to address related grand challenges.

Lastly, reduced allocation of resources to achieving the innovation objectives in these partnerships, in turn, exacerbates the likelihood of friction among partners collaborating on lower-priority objectives. Lower resource commitments are likely to increase perceptions of free-riding, opportunistic behavior, and eventual interpartner conflict (Johnson et al., 2002). Misaligned interests naturally hamper progress and agitate disputes (Jones, 2007). Consequently, lack of incentive alignment combined with a drop in resources needed to support innovation activity jeopardizes the overall innovation performance of partnerships formed for addressing lower-priority issues. Accordingly, we propose the following hypothesis.

Hypothesis 2: Partnerships formed in *related* domains achieve lower innovation performance after a shock in a grand challenge than those formed before the shock.

METHODS

Empirical Context

We tested our hypotheses in the context of drug development partnerships for the Ebola and Influenza virus infections, both listed by the WHO among the top 10 threats to global health (WHO, 2019). The WHO officially announced an outbreak of Ebola Virus Disease in West Africa in March 2014. Later that August, the WHO declared the outbreak a 'Public Health

Emergency of International Concern' in the face of deteriorating conditions in West Africa and the further spreading of the infection to seven more nations: Italy, Mali, Nigeria, Senegal, Spain, the United Kingdom, and the United States. The outbreak constituted a shock to the industry because there were no treatment options beyond supportive care at the time while the virus infected 21,206 people and claimed 8,386 lives within one year. The unexpected severity and urgency of the outbreak prompted the WHO, governments and NGOs to urge drug development against Ebola. The outbreak ended in June 2016 when Guinea, the outbreak's origin, was declared Ebola-free. The outbreak's final toll was more than 28,600 cases and 11,325 deaths worldwide (Centers for Disease Control and Prevention, 2019).

To test Hypothesis 2, we identified drug development for Influenza virus as the grand challenge *related* to the Ebola outbreak. The two challenges are related because the WHO, a major stakeholder, identified both among the leading grand challenges in global healthcare. Furthermore, developing drugs for both diseases required similar resources since the Influenza virus most closely mimics Ebola's genome structure. Both Influenza and Ebola viruses have a negative-sense, single-stranded RNA with no DNA step in replication, thus corresponding to Group V in the Baltimore virus classification system. Viruses with similar genome structures replicate and transmit genetic information in like manner. Strategies for treatment development (e.g., targeting, binding, transcription, or replication phases) prove closely related among viruses with similar genomes. For example, the antiviral drug Favipiravir with its record of inhibiting Influenza virus replication, had arisen as a therapy alternative during the Ebola outbreak in West Africa (Chinello et al., 2017; Dhama et al., 2018) where RNA polymerase plays the most important role during replication of both Ebola and Influenza (Choi et al., 2015). Scientists had even created an Ebola virus surrogate from a disabled Influenza virus core coated with Ebola surface protein.

Data

The complexity of drug development, in general, and for Ebola and Influenza virus diseases, in particular, favors partnerships in the pharmaceutical industry. According to the Cortellis database, 71.4 percent of active drugs for Ebola and 48.7 percent for Influenza developed between 2010 and 2017 emerged from ongoing interorganizational drug development partnerships involving firms, universities, government agencies, and NGOs. We compiled data on partnerships for drug development from Clarivate Analytics' Cortellis database (formerly known as ReCap) used extensively in prior research (e.g., Adegbesan & Higgins,

2011; Ryu et al., 2018). Given that the Ebola outbreak started at the beginning of 2014, we assigned a sample period between 2010 and 2017 covering ±4 years framing the outbreak[iii].

We limited the sample to drug development partnerships where the drug under development was either in discovery or a clinical trial phase. We excluded partnerships for the development of diagnostic tests and technology platforms to ensure similar product development challenges and trajectories. Further omitted were pure licensing, patent transfer, manufacturing, and supply deals since they did not involve collaboration for drug development. Finally, to avoid sample heterogeneity, we included partnerships where at least one of the partners was a firm paired with another firm, university, governmental agency, or NGO. Our final sample includes 312 drug development partnerships (115 for Ebola and 197 for Influenza viruses) formed between 2010 and 2017.

Variables

Dependent variable. Drug development entails the following stages: (i) discovery, (ii) phase 1 clinical, (iii) phase 2 clinical, (iv) phase 3 clinical, (v) pre-registration, (vi) registration, and (vii) launch. Organizations advance drugs through these phases sequentially by reporting the results of each phase to the respective regulatory body and obtaining approval for the next stage. At any stage of development, drugs can be suspended, withdrawn or discontinued. Our study specifies the innovation performance of drug development partnerships as measured by the progress of the candidate drug to a consecutive phase in the development process (Girotra et al., 2007). Accordingly, we coded the variable *drug progress* 1 if a drug moved to the next phase in development after the formation of the partnership, 0 when no development was reported, and -1 for drugs that were suspended, withdrawn or discontinued after formation of the partnership. Drug development in all partnerships were observed through the end of June 2018[iv].

Independent variable. To estimate the effect of Ebola outbreak on the innovation performance of partnerships, we constructed the variable *outbreak*—a dichotomous variable coded 1 for partnerships formed after the official WHO announcement of the outbreak on 23 March 2014. The variable is coded 0 for partnerships formed before the outbreak.

Our sample is composed of 33 partnerships formed in the four-year period before the outbreak and 82 in the four years post-outbreak. This confirms that organizations engaged the Ebola outbreak. Ten organizations formed 24 new Ebola partnerships after the outbreak to supplement their 19 preexisting partnerships. The remaining 62 Ebola partnerships (14 pre-

and 48 post-outbreak) were the first Ebola partnerships for their respective organizations. We explored whether there were underlying differences among partnerships formed before and after the outbreak in terms of drug development stage, development technology, drug type (e.g. vaccine vs others), and partnership type. Ebola partnerships formed after the outbreak involve drugs that are at more advanced levels of development (e.g., 7 (8.5%) in Phase 2, 6 (7.3%) in Phase 3 Clinical trials). Development stages for Influenza partnerships are more evenly distributed. This is somewhat expected given that drug development efforts against Ebola have a more recent history. We do not observe significant differences among pre- and post- outbreak partnerships in other aspects.

Control variables. The salience of an outbreak might fade as time passes since its inception. Therefore, we included *years since the outbreak* coded as the number of years elapsed since the outbreak at the time of the partnership formation. The variable was coded 0 for partnerships formed before the outbreak. We include this control variable as a time-varying covariate to account also for the time passed from partnership formation until the observation of the partnership's outcome.

We included several control variables specific to the drug under development. First, we controlled for the development phase of the drugs at the time of partnership formation since the likelihood of progression to the next phase differs across phases[v]. Thus, we constructed the categorical variable *phase* coded 0 for drugs in the discovery phase, 1 for Phase I, 2 for Phase II, and 3 for Phase III. Another important factor is the U.S. Food and Drug Administration's (FDA) priority designation granted to a drug under one of four programs designed to facilitate and expedite development and review of new drugs: fast track, breakthrough therapy, accelerated approval, and priority review designations. We included *expedited program* variable coded 1 for drugs receiving priority designation within three years of partnership formation. We also controlled for the drug type using a dichotomous variable *vaccine* coded 1 for partnerships developing a vaccine and 0 for other treatments (e.g., antiviral agents)[vi]. We also controlled for the type of underlying technology enlisted for drug development. There are two main pathways. The first develops biological therapeutic agents via biotechnological processes that genetically modify cells of microorganisms to form large protein molecules yielding a therapeutic effect. The other approach develops small-molecule drugs synthesized by more conventional chemical processes. To capture this heterogeneity, we controlled for the primary technology deployed in the partnership using the

variable *biological therapeutic* coded 1 for drugs developed using biotechnology, and 0 for others.

Another set of variables controls for partnership-specific factors. First, we controlled for the *number of indications*, i.e., the number of potential diseases targeted by the partnership. Since multiple indications promise greater financial potential, partners may mobilize higher levels of organizational resources that, in turn, may elevate partnership innovation performance. In the sample, 94 (30.1%) of 312 partnerships pursued multiple indications. Next, we controlled for *funding partnerships* denoting partnerships (coded 1 vs. 0) that mainly involved funding arrangements. Here, resource commitments may prove more resilient as funds are released gradually per conditional milestones. Third, public-private partnerships may favor public-benefit creation while also making better use of private actors' resources and capabilities (Rangan et al., 2006). We used the variable *public-private partnership* coded as 1 for partnerships with governmental agencies, NGOs, and universities. Partnerships strictly among firms were coded 0.

We also controlled for factors related to partners' prior experience. The variable *prior ties between partners* denotes the number of partnerships comprising the same organizations for the treatment of infectious diseases within three years preceding the focal partnership. This controls for the possibility that familiarity facilitates collaboration. We also enlisted *general experience in partnerships* defined as the sum of previous partnerships the partners formed in the area of viral infections within three years preceding the focal partnership. Both the number of prior ties and prior experience were log-transformed due to skewness. Third, to control for possible spillover effects among partnership experience in the two domains, we enlisted the dichotomous variable *partnership experience in both Ebola and Influenza* coded 1 where any partner had previous partnership experience in both Ebola and Influenza in the three-year window prior to formation.

Finally, firms with slack resources may not experience a trade-off in allocating resources to innovation activities in domains experiencing the shock. To control for slack, we quantified size of the focal firm in the partnership. Where both partners were firms, we assigned the entity owning the drug as the focal firm. To score the size metric, we used data on size classification in the Orbis database. Orbis defines medium-sized firms as those having operating revenue greater or equal to one million EUR or total assets of at least two million EUR, or those staffed with 15 or more employees. Large firms are either listed or have an operating revenue greater or equal to 100 million EUR or total assets of at least 200 million

EUR, or staffing with 1000 or more employees. Companies outside any of these categories are classified as small firms. There are 80 small, 121 medium, and 111 large firms in our sample. Tables I and II report the descriptive statistics and correlation matrix, respectively.

Insert Table I & Table II about here

Analytical Approach

Our dependent variable, innovation performance, is measured observing the occurrence (or absence) of events: i.e., the progress of a drug candidate to a consecutive phase in the drug development process. With our observations ending June 2018, partnerships with unobserved transition to a different drug development status were censored since they could still progress or discontinue after our observation period. To address this key right-censoring issue, we applied an event-study methodology: competing risks regression.

Competing risks regression is well-suited for our study since drug development can discontinue after partnership formation precluding the likelihood of observing any progress. Competing risks regression accounts for the case where drug progress *cannot* occur when discontinued, rather than treating the case as missing or censored, without making an underlying assumption about the relative desirability of the two potential events. The third advantage of the competing risks regression is that the methodology accounts for time. It can estimate the likelihood of observing an event across time while also tracking temporal covariates. It is thus possible to estimate the time window when an outbreak effect is most salient. For these reasons, our primary analytical approach is competing risks regression.

The competing risks model has also been used in management literature for estimating entrepreneurial entry (e.g., Raffiee & Feng, 2014), entrepreneurial success (e.g., Almandoz, 2012), organizational failure (e.g., Almandoz & Tilcsik, 2016), innovation success (e.g., Katila & Shane, 2005), and alliance formation (e.g., Gimeno, 2004). We also ran alternative models to address potential endogeneity in partnership formation and partner selection, along with the difference-in-differences analysis reported in the Complementary Analyses section.

The competing risks regression estimates the following model per maximum likelihood:

$$h_1(t|x) = h_{1,0}(t)\ \exp\{\beta_1 x_1 + \ldots + \beta_k x_k + g(t)(\gamma_1 z_1 + \ldots + \gamma_m z_m)\}$$

where $h_{1,0}(t)$ represents the baseline subhazard of the occurrence of the event of interest, $(x_1,...,x_k)$ are static, and $(z_1,..., z_m)$ are time-varying covariates. While the competing risks regression assumes nothing about the baseline hazard, the relative subhazards $\exp(\beta_{kj}x_k)$ are deemed time-invariant without violating our model. We used the "stcrreg" command in Stata software.

RESULTS

Table III reports the results of the competing risk regression on innovation performance of partnerships in coefficient form (vs. hazard ratios) to ease interpretation. A positive (negative) coefficient indicates that the covariate increased (decreased) the hazard rate of the focal event (i.e., the progression of a drug to a later phase of development).

Insert Table III about here

Models 1 and 3 include only the control variables. We observe that for partnerships where the drug was enrolled in an expedited program (b=1.609, se=0.706, p=0.023 in Model 1 and b=1.859, se=0.707, p=0.009 in Model 3) and those of large firms (b=1.593, se=0.716, p=0.026 in Model 1 and b=1.899, se=0.671, p=0.005 in Model 3) were more likely to have their Ebola and Influenza drugs progress to the next drug development stage. For Ebola, the drugs in Phase III clinical trials (b= -16.211, se=0.915, p=0.000), the drugs with multiple indications (b= -0.485, se=0.254, p=0.056) and general experience in partnerships (b= -0.546, se=0.263, p=0.038) were negatively associated with drug progress. However, vaccine development (b=2.034, se=0.748, p=0.007), and partnership experience in both Ebola and Influenza (b=2.099, se=0.627, p=0.001) exerted positive effect. For Influenza, drugs in funding partnerships (b=0.834, se=0.397, p=0.036) were more likely to proceed to the next stage.

Model 2 tests the impact of the outbreak on the innovation performance of Ebola partnerships. The coefficient of the variable *outbreak* is positive and statistically significant (b=2.415, se=1.045, p=0.021). Results indicate that drugs developed by Ebola partnerships formed after the outbreak were 11.2 (=exp(2.415)) times more likely to progress to the next stage compared to the partnerships formed pre-outbreak. These findings support Hypothesis 1.

Model 4 tests the impact of the Ebola outbreak on the innovation performance of Influenza partnerships. The variable *outbreak* exerts a negative and statistically significant

coefficient (b= -1.891, se=0.960, p=0.049). Accordingly, Influenza drugs developed by post-outbreak partnerships were 84.9% (=1-exp(-1.891)) less apt to progress in development versus Influenza drugs developed by partnerships formed before the outbreak. This finding provides support for Hypothesis 2.

Figure 2 depicts the predicted cumulative incidence of drug progress for Ebola (left-hand side) and Influenza (right-hand side) partnerships formed before (dashed line) and after (solid line) the outbreak. Nearly 4% of drugs in post-outbreak Ebola partnerships were likely to progress to the next phase within 1000 days after partnership formation, while only 0.5% of drugs in Ebola partnerships formed before the outbreak progressed within the same time frame. However, 13% of drugs in Influenza partnerships formed *before* the Ebola outbreak proceeded to the next phase within 1000 days after formation while this figure drops to 2.1% post-outbreak. These results support our hypotheses that an exogenous shock increases innovation performance of partnerships in the focal domain experiencing the shock at the expense of lost performance in the domain of the related grand challenge.

Insert Figure 2 about here

Exploring the mechanisms

We have theorized that the 2014 Ebola outbreak generated a shock that escalated the salience of the Ebola virus disease and created strong normative pressures to develop a drug. To explore if Ebola had become a salient issue, we plotted the yearly distribution of the number of news articles headlining Ebola and Influenza in major news sources obtained from Factiva database. Figure 3 shows that media coverage of the outbreak skyrocketed at the onset of the outbreak. Furthermore, firms were heavily criticized for their lack of investment, for instance, by the WHO's director-general[vii], and were repeatedly urged to act. We further investigated whether organizations indeed formed partnerships for drug development under such heightened normative pressures. Figure 4 depicts the number of new partnerships formed per year in the observation period. The 2014 peak in partnership formation supports the idea that the outbreak played a role in boosting the number of Ebola partnerships.

Insert Figure 3 and 4 about here

Figures 3 and 4 also hint at a temporary effect: news coverage plummeted shortly after the outbreak. In parallel, the number of new partnerships decreased gradually after 2014. Mimicking this trend statistically, the results reported in Table III indicate that both the positive impact of the outbreak on the progress of Ebola partnerships and its negative effect on results of Influenza partnerships ebbed over time. More specifically, in Model 2 of Table III, the coefficient for *years since outbreak* is negative and marginally significant (b= -0.581, se=0.339, p=0.087) for Ebola partnerships. That is, the positive performance impact of the Ebola outbreak on Ebola partnerships diminished over time. Furthermore, the coefficient for *years since outbreak* in Model 4 yielded a positive and statistically significant result (b=0.525, se=0.242, p=0.030) for Influenza partnerships. Figure 5 shows the negative performance impact of the Ebola outbreak on Influenza partnerships lessening over time, confirming that Influenza partnerships formed shortly after the Ebola outbreak were most negatively affected.

Insert Figure 5 about here

Our theory predicts the reallocation of resources to Ebola from Influenza following the surge in the salience of Ebola and its associated normative pressures. While we lack data on the actual shift of resources, Model 2 permits important inferences. We observe that innovation performance for Ebola partnerships was positively affected when at least one partner had a partnership in both Ebola and Influenza before engaging the focal partnership (b=2.115, se=0.592, p=0.000). To deepen our inquiry, we collected data on partners' drug-related patents (including therapies, drug combinations, processes, and enabling technologies while excluding diagnostic devices and assays). We created a dichotomous variable *Ebola Patents (Influenza Patents)* coded 1 when at least one of the partners filed for an Ebola (Influenza) patent within two years prior to partnership formation. Filing a recent patent in these domains signaled an active partner in the segment with know-how prior to partnership formation (Arora & Gambardella, 1990). The resource re-allocation mechanism would be validated if the outbreak was associated with a greater decline in the innovation performance for Influenza partnerships where either partner had already pursued Ebola research. Results for Model 8 in Table IV suggest that the likelihood of drug progress for Influenza partnerships

formed after the outbreak was lower (b= -11.930, se=1.144, p=0.000) where one partner had prior activity in Ebola. This finding supports our theorized resource allocation mechanism.

Insert Table IV about here

We also explored if loosened regulatory oversight alternatively explains the acceleration of drug development for Ebola after the outbreak. However, the regulatory framework for accelerating drug development (i.e., expedited assignment in fast track, breakthrough therapy, accelerated approval, and priority review programs) did *not* change after the outbreak, except when US President Obama signed the law to add Ebola to the FDA Priority Review Voucher Program on December 16, 2014. Still, expedited programs do not explain allocation away from Influenza because, with the exception of priority review, they have been available for Ebola and Influenza. In our sample, four drugs appearing in 13 Ebola partnerships were in an expedited program with only one drug obtaining priority review status during the observation period. Influenza drug development did not seem to suffer from withdrawal of regulatory favor. Four drugs appearing in seven Influenza partnerships in our sample enjoyed expedited status, all after the Ebola outbreak. Therefore, changes in the drug approval process do not explain the differential effect of the outbreak on Ebola versus Influenza. Our analyses revealed that expedited programs had similar positive effect on drug progress for both Ebola and Influenza partnerships.

ALTERNATIVE EXPLANATIONS AND COMPLEMENTARY ANALYSES

Endogenous Partnership Formation

An organization may choose to address a grand challenge alone without forming a partnership. We limit our focus to partnerships since the field of responsible innovation research stresses the importance and scarcity of research in collective action to address grand challenges. Still, partnering versus developing a drug independently is an endogenous decision. Results we present may be biased if an unobserved factor that drives partnership formation also impacted the innovation performance of these partnerships.

To address this potential endogeneity, we first compiled the list of firms having a drug in their pipelines for Ebola or Influenza in our sample period and generated a firm-year panel. To estimate the propensity to form partnerships, we tested variables for firm size, the development phase of a firm's drug, and a firm's record in drug development partnerships for

viral infections. Following Kang and Zaheer (2018), we used the logic of mimetic isomorphism for generating the exclusion restriction. Accordingly, we constructed the variable *local partnership intensity* defined as the number of Ebola or Influenza partnerships formed within two preceding years by other firms in the focal firm's city. Next, we ran an ordered probit regression on innovation performance of partnerships using a selection equation capturing partnership formation. Table V reports results. The coefficient of outbreak remains positive and statistically significant (b=0.468, se=0.218, p=0.031) for Ebola partnerships while staying negative and statistically significant (b= -0.641, se=0.331, p=0.052) for Influenza partnerships. Thus, our principal results remain unaffected by any partnership formation bias.

Insert Table V about here

Endogenous Partner Selection

Selecting specific partners is not a random process either. To address sample selection concerns, we conducted an ordered probit regression on innovation performance of partnerships using a selection equation on the choice of a specific partner. We first identified the set of organizations that had formed partnerships on Ebola in two-year moving windows, marking all resulting dyadic combinations of partners 'at risk' of being formed in a given year. The two-year window was chosen since a larger window would have cast the number of realized partnerships as such a tiny fraction of all possible partnerships as to trigger a rare-event bias (King & Zeng, 2001).

Next, we ran a maximum likelihood probit regression on realized partnerships featuring, in the first step, a selection equation for all unrealized but possible partnerships. This selection equation includes all partnership-level variables plus the variable *international partnership* as the exclusion restriction. This variable was coded 1 for partnerships of organizations located in different countries, and 0 otherwise. This variable yielded a statistically significant effect on partner selection (b= -0.367, se=0.209, p=0.079 for Ebola and b= -0.539, se=0.152, p=0.000 for Influenza pairings) without imposing statistically significant effects on innovation performance. The results reported in Table VI indicate a positive impact of the outbreak on the innovation performance of Ebola partnerships (b=1.145, se=0.454, p=0.012) and a negative impact on Influenza partnerships (b= -0.614, se=0.309, p=0.047), thus confirming our main results.

Insert Table VI about here

Difference-in-Differences Analyses

There is a possibility that the effects of the outbreak on the partnerships for Ebola and Influenza may reflect a general, unobserved trend in drug development. To account for this possibility and to strengthen causality in our claims, we enlisted a difference-in-differences analysis. We collected additional data on drug development partnerships for fungal and parasitic infections. These partnerships constitute an appropriate control group to partnerships for Ebola and Influenza viruses since they are very different organisms[viii] not causing significant outbreaks in our sample period[ix].

We ran two probit regressions on innovation performance: first on the Ebola sample of partnerships merged with partnerships for fungal and parasitic infections, and second on the Influenza sample of partnerships merged with partnerships for fungal and parasitic infections. As the difference-in-differences estimator, we included the interaction terms between outbreak and an indicator for Ebola and Influenza partnerships, respectively.

Table VII presents the results. In nonlinear models, the sign, magnitude and statistical significance of the interaction term coefficient can be misleading (Ai & Norton, 2003). Following Mize (2019), we first graph the predicted probabilities of drug progress for different virus groups in the pre- and post-outbreak periods (see Figure 6) and calculate their first and second differences. The left-hand side shows 12.6 percentage points rise in probability for drug progress in Ebola (se=0.063, p=0.045), but only 3.1 percentage points increase in the control group of partnerships for fungal and parasitic infections after the outbreak (se=0.028, p=0.265). That is, the increase for Ebola partnerships is 9.5 percentage points higher than the increase for the control group, i.e. the difference-in-differences. But, this estimate is not statistically significant (se=0.068, p=0.16). The right-hand side plots lessening probability of drug progress for Influenza by 7.3 percentage points (se=0.047, p=0.126) while the opposite is the case for the control group (4.3 percentage points increase, se=0.029, p=0.142). The difference-in-differences is negative (-11.5 percentage points) and statistically significant (se=0.055, p=0.036). These results strengthen support for our second hypothesis but invite caution for the first hypothesis.

Insert Table VII about here

Insert Figure 6 about here

DISCUSSION

This study investigates how abrupt shocks impact the innovation performance of partnerships for responsible innovation. We have hypothesized and provided empirical evidence that shocks (i.e., the 2014 Ebola outbreak) improve the innovation performance of partnerships responding to a global challenge (i.e., Ebola), but at the loss of performance in a *related* grand challenge not directly facing the shock (i.e., Influenza). These results have important theoretical implications for research on responsible innovation, grand challenges, and interorganizational relationships.

First, the burgeoning stream of research on responsible innovation has focused on understanding responsible innovation as a concept and examining its antecedents. Yet, less is known about the factors affecting its success. Our study fills this gap by studying how the sudden increase in the salience of a grand challenge impacts the performance of responsible innovation partnerships both within and beyond the domain of the grand challenge. We find positive impact of a shock on the partnerships in the directly affected challenge. Furthermore, one of the leading perspectives that responsible innovation literature employs is the resource-based view (Voegtlin & Scherer, 2017) that highlights combined complementary resources as the primary benefit of partnerships. We expand this view by highlighting *issue salience* as a precursor for the deployment of complementary resources and alignment of partner incentives for the achievement of intended partnership benefits. Our findings further reveal a negative impact of a shock on partnerships in a *related* grand challenge, indicating that newer shocks supercede previously important issues. This finding lends support to the view that responsible innovation activities should be governed by a broad, farsighted agenda to curb social risks of detrimental spillovers (Owen et al., 2013).

Second, with rising concerns about the future, management scholars have researched the role that organizations can play in addressing grand challenges such as income inequality (Berrone et al., 2016; Mair et al., 2016; Zhao & Wry, 2016), poverty (Battilana & Dorado, 2010; Cobb et al., 2016), climate change (Ansari et al., 2013; Wittneben et al., 2012), natural

disasters (Ballesteros et al., 2017; Williams & Shepherd, 2016), neglected diseases (Vakili & McGahan, 2016), human rights abuse (Crane, 2013; Khan et al., 2007; Kim & Davis, 2016), and population aging (Kulik et al., 2016). However, this line of research has considered grand challenges only in isolation, assuming the salience of challenges to stay unchanged over time. Since organizations with limited resources face multiple contemporaneous issues, however, they respond to the most salient challenges offering the highest net benefits (Durand et al., 2019). We take this view one step further to theorize and demonstrate the negative spillover effect of a shock on activities addressing related, contemporaneous grand challenges. Here, we underline a theory of interdependence linking organizational responses to grand challenges that must compete for limited organizational resources.

Third, prior research on interorganizational partnerships has provided evidence that forging partnerships enables firms to access and pool resources beyond their organizational boundaries to address innovation challenges. Studies on the innovative consequences of partnerships have focused more on the traits of the firms involved, such as firm position in the collaborative network (Ahuja, 2000), resourcefulness (Stuart, 2000) and diversity of partners (Hagedoorn et al., 2018). This limited focus overlooks the fact that partnerships do not operate in a vacuum, but subject to influence by shocks in the external environment (Schilling, 2015). Few studies investigate how partnerships are affected by external events. Schilling (2015) and Asgari et al. (2017) have examined the link between supply-side technological shocks (instead of the demand-side) and partnership formation (but not partnership performance) and advocate a positive association. Our study contributes to this line of research. In doing so, it also responds to the call for more research on interorganizational relationships using the event-time conceptualization where "a specific event is the reference point to what occurs before and after" (Lumineau & Oliveira, 2018: 451). Prior research has also documented the dark-side of partnerships (for a recent review, see Oliveira & Lumineau, 2019). Given the benefits and drawbacks of partnerships, the question remains whether partnerships formed in response to shocks indeed realize the expected benefits. We provide evidence that a direct-domain shock increases partnership innovation performance in its grand challenge. We further argue, however, that partnerships in *related* grand challenges suffer diminished resources and misaligned incentives. By examining the impact of shocks across grand challenges, our study thus challenges the all-positive stance on the relationship between shocks and innovation performance to feature a more granular view regarding shocks.

Managerial Implications

We found that innovation performance of partnerships formed in response to the 2014 Ebola outbreak was higher than of those earlier formed, while the opposite was true for Influenza. As of this paper's date, the world has been struggling with the COVID-19 pandemic. By April 2020, the death roll has risen to 190,000 with the number of confirmed cases exceeding 2.7 million. In parallel to the Ebola outbreak, we noted a dramatic increase in the number of partnerships formed to develop drugs targeting COVID-19. In the two decades before this pandemic, 116 partnerships were formed to develop drugs against generic coronavirus. Within four months of the onset of the COVID-19 pandemic, 256 partnerships have merged. In light of our findings, we expect that partnerships formed in response to COVID-19 pandemic will be more likely to advance in drug development.

Our findings highlight the importance of careful management of resources and partnerships for responsible innovation activities. Managers can elevate the performance of partnerships for responsible innovation in domains experiencing a shock by capitalizing on increased resource commitment and incentive alignment with their partners. At the same time, managers may safeguard partnerships in related grand challenges against sagging motivation and commitments to better exploit previously allocated resources and productive relationships.

Governance is a vital aspect of responsible innovation (Owen et al., 2013; Voegtlin & Scherer, 2017), and there is considerable debate in the literature on the appropriate form of governance for responsible innovation (Scherer & Voegtlin, 2020; Voegtlin & Scherer, 2017). Coercive, rule-based regulatory frameworks for innovation governance now in vogue fall short of providing adequate flexibility and responsiveness to manage unpredictable or unintended spillover consequences of partnership pursuits (Owen et al., 2013; Voegtlin & Scherer, 2017). Therefore, organizations need to develop "capacity for self-regulation and for proactive action" (Voegtlin & Scherer, 2017: 231). Our findings indicate that there is a downside to temporary shifts in issue salience, potentially spawning resource misallocation.

Clearly, a framework for responsible innovation governance must realize that frequent shifts in the salience of grand challenges (such as the emergence of outbreaks, wildfires, and hurricanes) may imperil the success of responsible innovation activities in related ongoing grand challenges. When planning innovation activities, organizations should embrace the fact that the salience landscape can morph. Rather than follow a reactive innovation agenda that

endangers innovation performance when news cycles swirl, they should pursue a proactive innovation agenda that secures responsible resource allocation.

Limitations and Future Research

We tested the impact of shocks on innovation performance of partnerships in the context of the 2014 Ebola outbreak. More conclusive testing could examine the impact of multiple outbreaks across different periods. For this study, incorporating other outbreaks in the past (such as the coronavirus-related SARS outbreak in November 2002 or the Zika outbreak in February 2016) was infeasible in the virtual absence of drug development partnerships before these outbreaks. Relatedly, the question remains open whether organizational responses to the Ebola outbreak have been influenced by perceived prior failures in properly addressing the HIV/AIDS crisis. By incorporating multiple outbreaks, future research can explore whether organizational responses to outbreaks evolve over time, for instance, by learning from past events.

To improve the generalizability of our results, researchers can investigate the impact of other types of shocks emanating, for instance, from the emergence of novel technologies and the enactment of new regulations. By incorporating both demand- and supply-side shocks, future research can determine the degree to which varying types and characteristics of shocks can drive partnership innovation performance. This would enrich scholarly understanding of the normative pressures exerted by various exogenous events.

In this study, we limited our focus to the innovation performance of partnerships in view of the strong emphasis on collaboration in prior research on grand challenges. While partnership formation is a viable option to tackle grand challenges, an organization may opt to engage in responsible innovation activities independently. While we addressed this issue empirically, future research is still needed to compare the effectiveness of partnerships versus independent effort in addressing grand challenges. Relatedly, we did not focus on factors driving partnership formation in response to exogenous shifts in issue salience. While we address this statistically, understanding the antecedents of partnership formation in response to outside shocks in grand challenges offers a fruitful research avenue.

In our setting, Influenza treatments have enjoyed a large, stable global market while Ebola virus constitutes a niche segment with sporadic and relatively small outbreaks in poorer regions. It has been unclear if enormous investments required for Ebola research could be recuperated. Despite uncertain economics, organizations still engaged the Ebola field. This

questions the assumption that partnerships form when agents prioritize and forecast direct economic benefits. Future research can test this assumption for partnership formation and trace its boundaries.

Another limitation of our study is that the dependent variable, a drug's progression to a consecutive stage, is dichotomous and ignores nuanced levels of development progress. Our output variable of choice was limited by data. Future research can overcome this problem by amassing extended post-outbreak measurements of the multiple stages in drug approval.

Finally, an emerging stream of research has explored how public-private partnerships yield social value while benefiting from private-sector resources and capabilities (Kivleniece & Quelin, 2012; Rangan et al., 2006). While our sample included such public-private partnerships, our results did not detect any difference regarding their effectiveness. More research is needed to reveal contingency factors shaping the effectiveness of public-private partnerships formed in response to grand challenges.

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TABLES AND FIGURES

Figure 1. Theoretical model

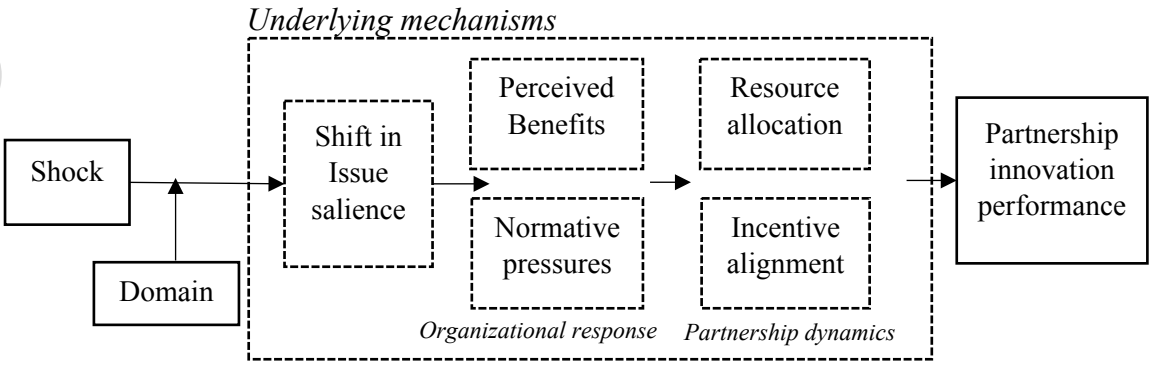

Figure 2. Cumulative incidence of drug progress in partnerships

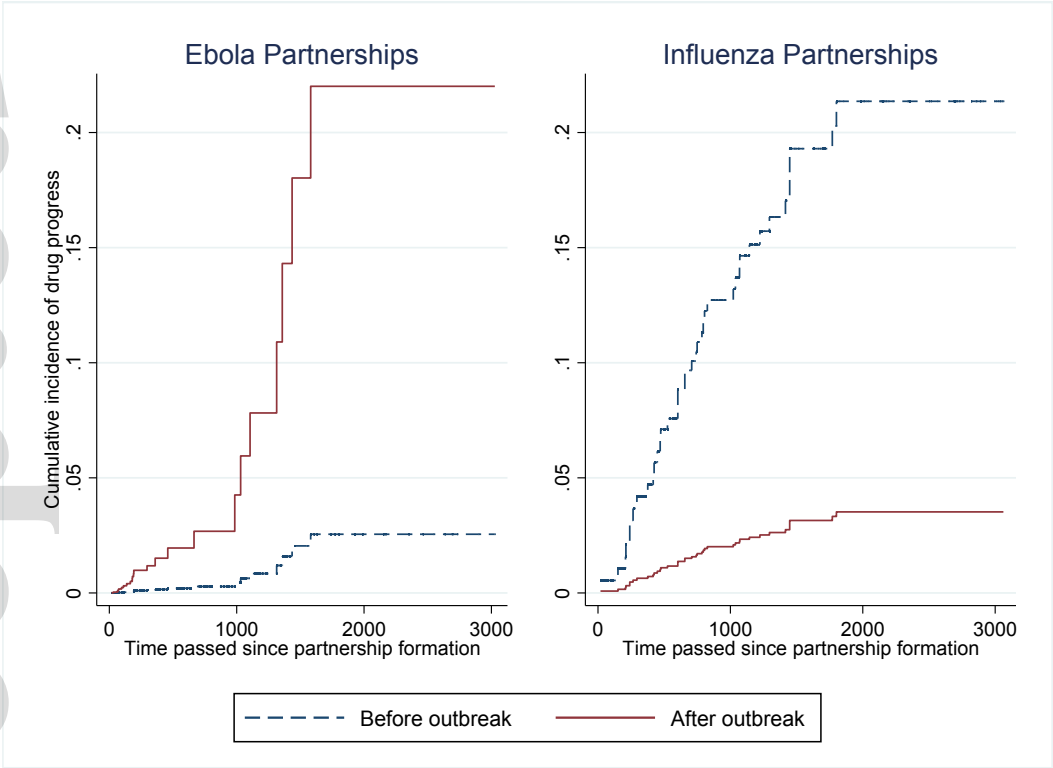

Figure 3. Number of articles headlining Ebola and Influenza in major news sources

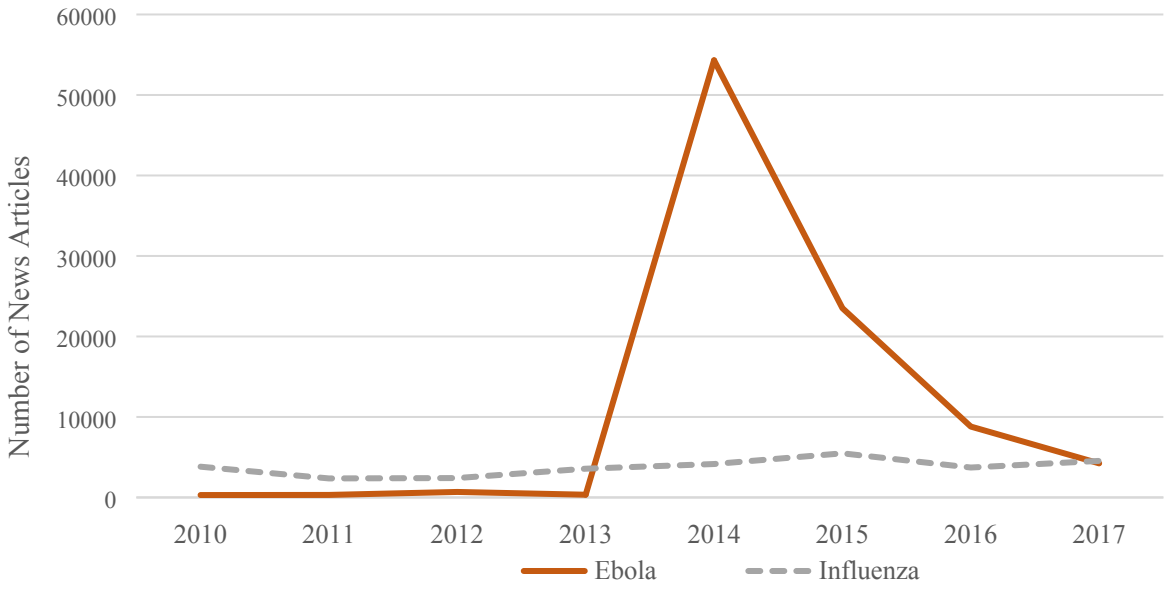

Figure 4. Number of new partnerships formed per year

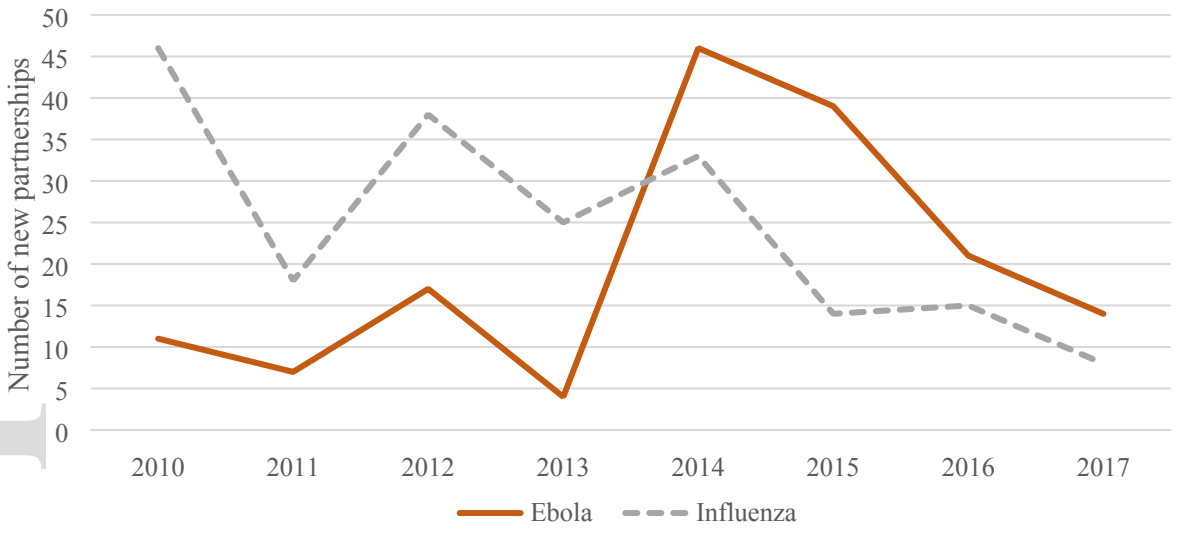

Figure 5. Cumulative incidence of drug progress in partnerships over different years of partnership formation

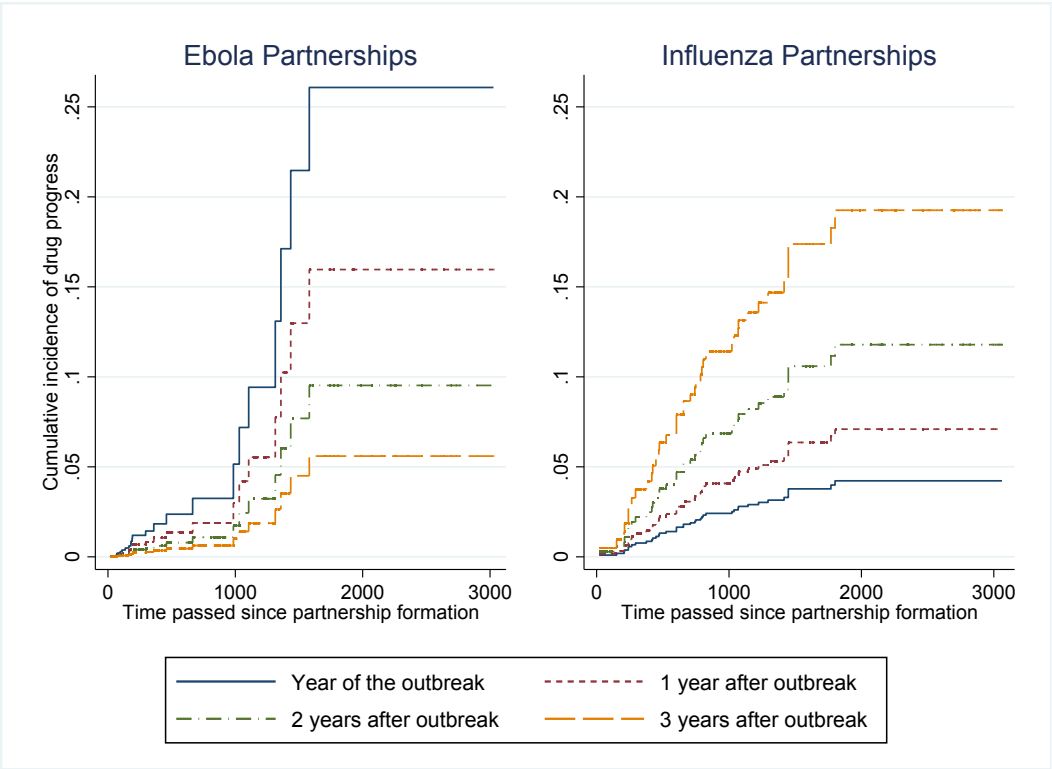

Figure 6. Difference-in-differences estimation of the predicted probability of drug progress in partnerships

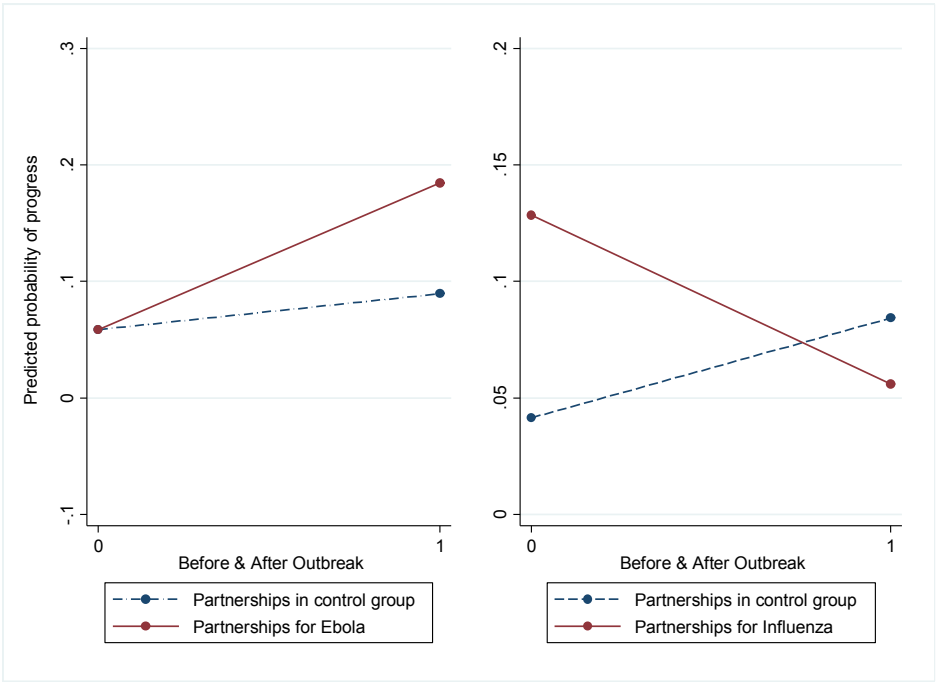

Table I. Summary Statistics

Variable	Mean	Std. Dev.	Min	Max
Outbreak	0.494	0.501	0.00	1.00
Discovery	0.747	0.436	0.00	1.00
Phase I clinical	0.119	0.324	0.00	1.00
Phase II clinical	0.109	0.312	0.00	1.00
Phase III clinical	0.026	0.158	0.00	1.00
Expedited program	0.064	0.245	0.00	1.00
Vaccine	0.462	0.499	0.00	1.00
Biological therapeutic	0.679	0.467	0.00	1.00
Number of indications	1.683	1.389	1.00	9.00
Funding partnership	0.407	0.492	0.00	1.00
Public-private partnership	0.192	0.395	0.00	1.00
Small firm	0.256	0.437	0.00	1.00
Medium firm	0.388	0.488	0.00	1.00
Large firm	0.356	0.480	0.00	1.00
General experience in partnerships	2.277	1.516	0.00	5.09
Prior ties between partners	0.139	0.354	0.00	2.48

Partnership experience in both Ebola and Influenza	0.327	0.470	0.00	1.00
Innovation experience in Ebola	0.167	0.373	0.00	1.00
Innovation experience in Influenza	0.404	0.491	0.00	1.00
Local partnership intensity in Ebola	1.219	2.252	0.000	23.00
Local partnership intensity in Influenza	0.905	2.032	0.000	30.00
International partnership	0.321	0.467	0.00	1.00

Table II. Correlations

		1	2	3	4	5	6	7	8	9	10	11
1	Outbreak	1.00										
2	Discovery	-0.04	1.00									
3	Phase I clinical	-0.04	-0.63	1.00								
4	Phase II clinical	0.05	-0.60	-0.13	1.00							
5	Phase III clinical	0.12	-0.28	-0.06	-0.06	1.00						
6	Expedited program	0.21	-0.27	0.15	0.20	0.04	1.00					
7	Vaccine	0.01	-0.14	0.20	0.01	-0.03	-0.06	1.00				
8	Biological therapeutic	0.00	-0.13	0.12	0.06	-0.02	0.07	0.39	1.00			
9	No of indications	-0.01	0.19	-0.12	-0.10	-0.08	-0.01	0.00	-0.20	1.00		
10	Funding partnership	-0.04	-0.04	0.08	-0.02	-0.01	0.00	0.02	0.04	-0.01	1.00	
11	Public-private partnership	0.01	0.15	0.00	-0.22	0.03	-0.07	-0.04	0.01	-0.06	0.24	1.00
12	Small firm	-0.01	0.16	-0.08	-0.11	-0.05	-0.06	-0.01	-0.15	-0.01	0.19	0.12
13	Medium firm	0.00	0.12	-0.13	0.00	-0.05	0.03	-0.05	0.10	0.03	-0.06	-0.01
14	Large firm	0.00	-0.26	0.20	0.11	0.09	0.02	0.06	0.04	-0.02	-0.11	-0.10
15	General experience in partnerships	0.05	-0.04	0.02	-0.01	0.08	0.01	-0.01	-0.02	0.02	0.45	0.29
16	Prior ties between partners	0.00	0.04	-0.04	0.00	-0.02	-0.05	0.01	0.01	0.01	0.25	0.09
17	Partnership experience in both Ebola and Influenza	0.15	-0.05	0.02	0.02	0.06	0.10	-0.03	-0.05	0.04	0.37	0.20
18	Innovation experience in Ebola	0.02	-0.02	-0.03	0.01	0.09	0.09	-0.05	-0.02	0.03	0.01	0.09
19	Innovation experience in Influenza	-0.05	-0.21	0.08	0.13	0.16	0.13	0.09	0.08	0.09	0.00	-0.06
20	International partnership	-0.09	-0.15	0.07	0.13	0.02	-0.04	0.05	0.06	-0.11	-0.22	-0.29
21	Local partnership intensity in Ebola	0.30	0.06	-0.13	0.06	0.00	-0.01	0.11	0.07	0.10	0.00	-0.06
22	Local partnership intensity in Influenza	-0.18	-0.11	0.07	0.12	-0.09	-0.08	0.10	0.04	0.20	0.08	-0.02

		12	13	14	15	16	17	18	19	20	21
13	Medium firm	-0.47	1.00								
14	Large firm	-0.44	-0.59	1.00							
15	General experience in partnerships	0.05	0.00	-0.05	1.00						
16	Prior ties between partners	-0.01	0.06	-0.05	0.42	1.00					
17	Partnership experience in both Ebola and Influenza	0.12	-0.08	-0.03	0.69	0.33	1.00				

18	Innovation experience in Ebola	-0.12	0.14	-0.03	0.14	0.05	0.09	1.00			
19	Innovation experience in Influenza	-0.20	0.11	0.07	0.08	0.02	0.07	0.28	1.00		
20	International partnership	-0.17	-0.12	0.28	-0.24	-0.10	-0.23	-0.12	0.06	1.00	
21	Local partnership intensity in Ebola	-0.03	0.22	-0.20	0.08	0.12	0.14	0.10	0.00	-0.07	1.00
22	Local partnership intensity in Influenza	0.02	0.08	-0.10	0.17	0.12	0.09	0.02	0.20	0.00	0.15

Table III. Competing risks regression on the innovation performance of partnerships

	Ebola Partnerships						Influenza Partnerships					
	(1)			(2)			(3)			(4)		
	b	se	p	b	se	p	b	se	p	b	se	p
Outbreak				2.415	1.045	0.021				-1.891	0.960	0.049
Phase I clinical	-0.176	0.817	0.829	-0.131	0.771	0.865	-1.068	0.856	0.212	-1.114	0.834	0.182
Phase II clinical	2.088	1.493	0.162	1.907	1.436	0.184	-0.220	0.594	0.712	-0.115	0.576	0.842
Phase III clinical	-16.211	0.915	0.000	-20.078	0.804	0.000	2.208	1.517	0.146	2.195	1.804	0.224
Expedited program	1.609	0.706	0.023	1.428	0.667	0.032	1.859	0.707	0.009	2.049	0.709	0.004
Vaccine	2.034	0.748	0.007	1.693	0.710	0.017	0.244	0.431	0.572	0.236	0.417	0.572
Biological therapeutic	0.472	0.813	0.561	0.668	0.836	0.424	0.924	0.573	0.107	0.881	0.575	0.126
Number of indications	-0.485	0.254	0.056	-0.397	0.252	0.115	-0.408	0.293	0.163	-0.417	0.311	0.180
Funding partnership	0.188	0.433	0.665	0.181	0.485	0.710	0.834	0.397	0.036	0.756	0.384	0.049
Public-private partnership	-0.763	0.743	0.305	-0.694	0.783	0.375	-0.089	0.339	0.793	-0.016	0.332	0.961
Medium firm	-0.439	0.890	0.622	-0.405	0.892	0.650	0.583	0.600	0.331	0.596	0.644	0.355
Large firm	1.593	0.716	0.026	1.672	0.702	0.017	1.899	0.671	0.005	1.825	0.693	0.008
General experience in partnerships	-0.546	0.263	0.038	-0.538	0.252	0.033	0.106	0.208	0.611	0.100	0.199	0.616
Prior ties between partners	0.531	0.794	0.504	0.640	0.776	0.409	-0.550	0.499	0.270	-0.546	0.473	0.249
Partnership experience in both Ebola and Influenza	2.099	0.627	0.001	2.115	0.592	0.000	-0.465	0.656	0.478	-0.315	0.658	0.633
Years since outbreak	-0.106	0.217	0.626	-0.581	0.339	0.087	0.109	0.146	0.454	0.525	0.242	0.030

No. of observations	115	115	197	197
No. of clusters	68	68	144	144
No. of progress	26	26	40	40
Chi-squared	844.97	1581.19	63.04	52.66
p value	0.000	0.000	0.000	0.000
Loglikelihood	-79.50	-77.53	-181.61	-178.77

Table IV. Competing risks regression on the innovation performance of partnerships

	Ebola Partnerships						Influenza Partnerships					
	(5)			(6)			(7)			(8)		
	b	se	p	b	se	p	b	se	p	b	se	p
Outbreak	2.907	0.830	0.000	2.759	1.632	0.091	-1.841	0.913	0.044	-1.855	0.923	0.044
Ebola patents	1.223	1.199	0.307							-0.060	0.815	0.941
Outbreak x Ebola patents	-0.840	1.439	0.559							-11.930	1.144	0.000
Influenza patents				2.666	1.651	0.106	0.084	0.461	0.855			
Outbreak x Influenza patents				-0.961	1.930	0.619	-0.143	0.772	0.853			
Phase I clinical	-0.339	0.926	0.714	-0.419	0.876	0.632	-1.121	0.840	0.182	-1.111	0.839	0.185
Phase II clinical	1.991	1.537	0.195	2.535	1.502	0.091	-0.132	0.595	0.825	-0.082	0.584	0.888
Phase III clinical	-19.502	0.848	0.000	-17.535	1.000	0.000	2.136	1.924	0.267	2.284	2.145	0.287
Expedited program	1.279	0.767	0.095	1.208	0.789	0.126	2.079	0.739	0.005	1.995	0.709	0.005
Vaccine	1.712	0.649	0.008	1.567	0.560	0.005	0.219	0.428	0.608	0.258	0.418	0.536
Biological therapeutic	0.693	0.914	0.448	0.487	0.921	0.597	0.882	0.573	0.124	0.881	0.578	0.128
Number of indications	-0.346	0.288	0.229	-0.545	0.269	0.043	-0.424	0.301	0.159	-0.396	0.293	0.177
Funding partnership	0.335	0.474	0.480	0.395	0.573	0.490	0.762	0.396	0.055	0.732	0.386	0.058
Public-private partnership	0.721	0.841	0.391	0.367	0.872	0.674	0.001	0.361	0.998	0.005	0.341	0.989
Medium firm	-0.539	1.099	0.624	-0.453	0.928	0.626	0.583	0.676	0.388	0.600	0.648	0.355
Large firm	1.694	0.834	0.042	1.463	0.674	0.030	1.827	0.701	0.009	1.828	0.707	0.010
General experience in partnerships	-0.589	0.262	0.024	-0.818	0.295	0.006	0.092	0.198	0.642	0.095	0.196	0.629

Prior ties between partners	0.841	0.865	0.331	0.979	0.986	0.321	-0.552	0.466	0.236	-0.532	0.472	0.260
Partnership experience in both Ebola and Influenza	2.038	0.622	0.001	2.009	0.712	0.005	-0.288	0.661	0.663	-0.308	0.656	0.639
Years since outbreak	-0.608	0.344	0.077	-0.450	0.328	0.170	0.527	0.256	0.039	0.529	0.236	0.025
No. of observations	115			115			197			197		
No. of clusters	68			68			144			144		
No. of progress	26			26			40			40		
Chi-squared	1679.86			951.97			52.83			363.62		
p value	0.000			0.000			0.000			0.000		
Loglikelihood	-76.60			-70.14			-178.74			-178.37		

Table V. Ordered probit regression on innovation performance with endogeneity in partnership formation

	Ebola Partnerships (9)			Influenza Partnerships (10)		
	b	se	p	b	se	p
Outbreak	0.468	0.218	0.031	-0.641	0.331	0.052
Phase I clinical	-0.425	0.409	0.299	-0.031	0.413	0.941
Phase II clinical	0.156	0.462	0.736	-0.112	0.468	0.811
Phase III clinical	-2.799	0.826	0.001	1.142	1.258	0.364
Expedited program	1.327	0.395	0.001	-3.707	1.082	0.001
Vaccine	0.731	0.248	0.003	0.101	0.268	0.708
Biological therapeutic	-0.568	0.219	0.009	0.185	0.335	0.581

Number of indications	-0.049	0.030	0.100	-0.152	0.192	0.429
Funding partnership	0.561	0.157	0.000	0.269	0.344	0.434
Public-private partnerships	-0.446	0.240	0.063	0.051	0.245	0.836
Medium firm	-0.941	0.363	0.009	0.461	0.388	0.235
Large firm	-0.298	0.368	0.419	0.754	0.659	0.252
General experience in partnerships	-0.304	0.069	0.000	-0.040	0.109	0.713
Prior ties between partners	0.265	0.293	0.366	-0.745	0.757	0.325
Partnership experience in both Ebola and Influenza	0.956	0.263	0.000	0.031	0.394	0.937
Selection equation						
Outbreak	0.112	0.194	0.563	-0.215	0.088	0.015
Medium firm	0.796	0.259	0.002	0.178	0.113	0.116
Large firm	0.618	0.242	0.011	0.091	0.116	0.433
Drug development phase	0.203	0.139	0.143	-0.050	0.025	0.042
General experience in partnerships	0.025	0.124	0.838	0.201	0.119	0.091
Local partnership intensity in Ebola	-0.150	0.056	0.007			
Local partnership intensity in Influenza				0.036	0.019	0.065
No. of observations	353			2553		
No. of selected observations	100			162		
No. of nonselected observations	253			2391		
No. of clusters	128.00			595.00		
Chi-squared / p value	63.283	0.000		36.952	0.000	
Loglikelihood	-220.39			-637.99		

Table VI. Ordered probit regression on innovation performance with endogeneity in partner selection

	Ebola Partnerships (11)			Influenza Partnerships (12)		
	b	se	p	b	se	p
Outbreak	1.145	0.454	0.012	-0.614	0.309	0.047
Phase I clinical	0.092	0.655	0.889	0.028	0.449	0.951
Phase II clinical	0.492	0.675	0.466	0.018	0.449	0.969
Phase III clinical	-4.922	1.148	0.000	1.479	0.947	0.118
Expedited program	2.457	0.588	0.000	-4.185	0.334	0.000
Vaccine	1.575	0.401	0.000	0.075	0.291	0.797
Biological therapeutic	-1.169	0.389	0.003	0.253	0.330	0.443
Number of indications	-0.154	0.126	0.221	-0.249	0.146	0.089
Funding partnership	0.474	0.461	0.304	0.359	0.288	0.214
Public-private partnerships	-1.031	0.560	0.066	0.044	0.346	0.898
Medium firm	-0.503	0.561	0.370	0.529	0.363	0.144
Large firm	0.437	0.801	0.585	0.858	0.397	0.031
Prior ties between partners	0.378	0.524	0.471	-1.054	0.575	0.067
General experience in partnerships	-0.483	0.286	0.092	-0.065	0.151	0.666
Partnership experience in both Ebola and Influenza	2.159	1.782	0.226	0.327	0.846	0.699
Selection equation						
Public-private partnerships	1.653	0.459	0.000	1.402	0.402	0.000
Prior ties between partners	1.057	0.250	0.000	1.086	0.252	0.000
General experience in partnerships	0.588	0.113	0.000	0.740	0.114	0.000
Partnership experience in both Ebola and Influenza	-10.595	0.810	0.000	-11.124	0.746	0.000
International partnership	-0.367	0.209	0.079	-0.539	0.152	0.000
No. of observations	2643			14018		
No. of selected	100			176		

Chi-squared	74.044	738.270
p value	0.00	0.00
Loglikelihood	-141.34	-222.55

Table VII. Difference-in-difference analysis with probit regression on partnership progress

	Ebola & Other Partnerships (13)			Influenza & Other Partnerships (14)		
	b	se	p	b	se	p
Outbreak	0.378	0.319	0.235	0.435	0.260	0.094
Ebola partnerships	-0.003	0.753	0.997			
Outbreak x Ebola Partnerships	0.678	0.789	0.390			
Influenza Partnerships				0.725	0.280	0.010
Outbreak x Influenza Partnerships				-0.981	0.457	0.032
Phase I clinical	0.607	0.445	0.172	0.557	0.305	0.068
Phase II clinical	0.417	0.546	0.446	-0.049	0.494	0.921
Phase III clinical	-0.678	0.569	0.234	0.647	0.549	0.239
Expedited program	2.022	0.334	0.000	1.305	0.338	0.000
Vaccine	0.593	0.237	0.013	0.008	0.241	0.975
Biological therapeutic	-0.448	0.278	0.108	0.279	0.255	0.274
Number of indications	-0.037	0.110	0.734	-0.144	0.112	0.197
Funding partnership	0.204	0.285	0.474	0.278	0.226	0.218
Public-private partnership	-0.583	0.312	0.061	-0.159	0.245	0.517
Medium firm	-0.484	0.264	0.067	0.216	0.260	0.405
Large firm	0.605	0.322	0.061	0.562	0.281	0.045
General experience in partnerships	-0.096	0.102	0.345	0.066	0.103	0.518
Prior ties between partners	0.329	0.321	0.305	-0.074	0.353	0.835
Partnership experience in both Ebola and Influenza	0.443	0.404	0.273	-0.542	0.354	0.126
No. of observations	337			414		
No. of clusters	254			333		
Chi-squared	84.58			61.93		

p value	0.000	0.000
Loglikelihood	-59.48	-93.35

NOTES

[i] Interorganizational relationships can take many forms including "strategic alliances, joint ventures, buyer-supplier agreements, licensing, co-branding, franchising, cross-sector partnerships, networks, trade associations, and consortia" (Parmigiani & Rivera-Santos, 2011: 1109). In this paper, we use the term partnerships to encompass both strategic alliances (i.e. private-private partnerships) and cross-sector (public-private) partnerships. Both types of relationships involve exchanging, sharing and co-developing resources (Gulati & Singh, 1998; Quélin et al., 2017) to the extent necessary for overcoming innovation challenges.

[ii] Research on organizational inertia suggests that resource reallocation may not happen despite a shock. While one source of inertia is existing internal arrangements and politics, a counterforce is the "public legitimization of organizational activity" (Hannan & Freeman, 1977: 957). Public legitimization during the periods of events like hurricanes, outbreaks and wildfires favors change over status-quo, thus urging organizations to comply with or even lead those changes. The repercussions of inaction are more serious in terms of negative stakeholder reactions (e.g., customer churn, adverse analyst reviews, regulatory penalties, drops in stock price, or negative publicity) (Birkinshaw & Lingblad, 2005; Mishina et al., 2010). Also, inertial forces may be less relevant for partnerships because they are relatively young (younger than an organization itself), making it easier to alter their configurations and resource endowments. Therefore, we expect inertial forces to be less powerful in the context of partnerships formed for addressing grand challenges.

[iii] It is difficult to assume the time needed for firms to jump-start partnerships in response to the Ebola outbreak. For our sample, the earliest partnership formed after the outbreak on July 31st, 2014 allied Profectus Biosciences with the Department of Defense. Announcement of the partnership for the clinical development and manufacture of Profectus' VesiculoVax™ acknowledged the urgency of taking action against the outbreak: "We are gratified that the Department of the Defense has recognized the potential of Profectus' VesiculoVax™ Zaire-Ebola virus vaccine to combat the current outbreak in West Africa." We are therefore comfortable assuming that partnerships formed since were in response to the Ebola outbreak.

[iv] There are two alternative strategies for measuring the dependent variable. The first is to focus on drug approval rather than progress. However, by the end of our observation period, no drug was approved for Ebola, making this measurement infeasible for our study. The second is to define progression as a continuous variable, for instance, by counting the number of phases that the drug completed after the partnership formation. This creates problems in comparing instances of progress and discontinuation of the drug where there can be multiple levels of progress, but a single discontinuation. This also invokes the right-censoring problem where more recent partnerships lack time to attain multiple levels of progress.

[v] According to the Biotechnology Innovation Organization report on drug development (Thomas et al., 2016), 70% of drugs treating infectious diseases progressed from Phase I to Phase II while only 43% progressed from Phase II to Phase III over the period between 2006 and 2015.

[vi] Vaccines are designed to provoke an immune response (e.g., production of an antibody) in the human body to a specific antigen, per our sample, the Ebola or Influenza virus. They can be administered before or after exposure to the virus. An alternative strategy is to develop treatments such as: antiviral agents targeting viral expression

and replication, humanized monoclonal antibodies neutralizing viruses, small interfering RNAs, or antisense drugs. For our sample, 52 (45.2%) of 115 Ebola partnerships and 92 (46.7%) of 197 Influenza partnerships involved the development of a vaccine.

[vii] https://time.com/3555706/who-ebola-vaccine-pharmaceutical-industry-margaret-chan/

[viii] Fungi and parasites are part of a large group of organisms called eukaryotes which, in contrast to viruses, have a nucleus and complex internal structures.

[ix] For instance, the number of cases of fungal meningitis in 2015 was 753 (https://www.cdc.gov/fungal/outbreaks/index.html), and the number of cases of infection with the parasite Cyclosporiasis was 162 in 2013 (https://www.cdc.gov/parasites/cyclosporiasis/outbreaks/foodborneoutbreaks.html).