Coordination Challenges and Performance Trade-offs Under Uncertainty: Fighting Fires Together[*]

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This paper investigates the effects of inter-organizational collaboration on the effectiveness of U.S. municipal fire departments. Almost all U.S. fire departments engage in the reciprocal exchange of fire services with neighboring departments. However, there is substantial variety in these relationships. First, some departments exchange help with greater frequency than others. Second, some departments manage these exchanges informally with "handshake agreements" while others use formal written contracts. I estimate whether the intensity of resources received from partners and the use of formal contracts affect property damage, injuries, and deaths. I account for the potential endogeneity of collaboration and contract choices using a combination of difference-in-differences and instrumental variables approaches. The results suggest that fire departments with an increase in realized uncertainty experience increased property damage in aggregate each year; however, this negative effect on performance is diminished by an increase in resources received from partners in that year. The results also indicate that fire departments with formal contracts experience decreased property damage in aggregate each year, but this positive effect on performance is diminished by an increase in realized uncertainty. These findings suggest that, in this setting, partner resources received facilitate adaptation to realized demand uncertainty. They also suggest that formal contracts increase coordination and control when demand is stable and regular but restrict adaptation when conditions are volatile and irregular. Trade-offs in the effects of partner resources received and formal contracts across property damage, injuries, and deaths are also explored.

1 Introduction

This paper asks: How does the exchange and coordination of resources with alliance partners affect performance under varying conditions of demand uncertainty? Uncertainty in the organizational environment creates planning and operating challenges for managers. That is because managers must commit to resources before uncertainty is resolved, and because it is costly (and sometimes impossible) to make adjustments as needed. Correspondingly, investments under uncertainty have received considerable attention in the strategic management literature (Porter 1980, Ghemawat 1991, Dixit and Pindyck 1994). This work largely focuses on uncertainty about competitor moves; however, managers must also commit to resources before realizing uncertain demand. As a result, these choices generate trade-offs between hitting resource constraints when realized demand is high and idling resources when realized demand is low.

The costs associated with hitting constraints and idling resources vary across industries. For instance, the cost of idling passenger airplanes when demand is low is enormous compared to the cost of hitting capacity constraints when demand is high. In contrast, the cost of idling emergency room and organ transplant doctors when demand is low can be relatively small compared to the costs of having too few available when demand is high. Similarly, the costs of having insufficient fire department resources available during crises can quickly dwarf the cost of idling them when demand is low.[1] In the absence of spot markets, organizations faced with this trade-off can turn to partners with similar resources; however, it is more difficult to control partner resources than to control resources that are owned by the organization. As a result, alliances often fail (Kale and Singh 2009). Despite the large body of research on alliances and networks relatively little attention has addressed the collaborative aspects of resource investments under demand uncertainty (Galaskiewicz 1985, Burgers, Hill, and

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[1]Resources are broadly defined as anything an organization can use to accomplish its aims.

Kim 1993, Ingram and Roberts 2000).

This paper examines: (1) the extent to which alliances loosen resource trade-offs under demand uncertainty and thereby contribute to organization performance, and (2) the role played by formal governance structures in coordinating the exchange of resources across organization borders. In contrast with research that investigates how vertically-related production partners perform under uncertain environmental conditions (Gulati, Lawrence, and Puranam 2005, Forbes and Lederman 2009, for a recent overview) this paper focuses on the collaborative dynamics among horizontally-related organizations. This paper extends theories about structures for coordinating work (Nadler and Tushman 1997, Baldwin and Clark 2000) to the inter-organizational context, and it argues that organization performance in part reflects how resources are deployed to achieve flexibility and efficiency (Ghemawat and Ricart I Costa 1993, Davis, Eisenhardt, and Bingham 2009).

The key contribution this paper makes is to illuminate two types of trade-offs encompassed in increasing resource sharing with partners and adopting formal contracts. The first type of trade-off is intertemporal. The quantity of available resources resolves the trade-off between the benefits of efficiency and flexibility in dynamic environments. Even though formal contracts resolve an intertemporal coordination problem that limits collaboration *ex ante* they restrict the ability of partners to adapt to conditions unanticipated by the contract *ex post*.[2] The second type of trade-off is among conflicting objectives. The findings suggest a more nuanced set of connections among resources, contracts, and performance than originally theorized. In particular, they imply that organizations trade-off among different facets of performance, and they are interpreted to reflect incompatibilities between objectives, the challenges they entail, and organizational designs. These trade-offs are explored

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[2]Organizations will provide outbound assistance to partners today when resources are fixed and available, but they may not provide outbound support tomorrow because the expectation of inbound resources leads to resource reductions. Anticipating this cycle of behavior partners collaborate less than might be jointly optimal. Contracts resolve the severe time inconsistency problem and facilitate collaboration.

to better understand how multiple aspects of performance may be endogenous in (inter-) organizational designs.

These ideas are tested in the context of collaborations among separate US fire departments. This setting has several advantageous characteristics for this research. First, it is possible to test the performance effects of resources exchanges with partners separate of competitive dynamics such as pricing and market positioning, and separate of endogenous decisions about firm boundaries. That is because fire departments operate as territorial monopolies that almost never alter their markets, exit, or charge users directly for their services. Competition is indirect and organization borders are fixed. Second, it is possible to focus on coordination problems between partners because compared to collaborations among other organizations fire departments have strong intrinsic motivations to cooperate. Third, it is well-suited for studying alliance governance because the observation window covers a period of diffusion of a new contracting technology (i.e. formal written contracts) which was made possible by changes in the industry. Finally, the data set available for analysis is unusually detailed including objective performance measures (i.e. property damage, injuries & deaths) and high-frequency information with which to measure the characteristics of the distribution of fire demands (i.e. realized uncertainty).

The results provide evidence of coordination costs, intertemporal trade-offs, and trade-offs among different aspects of performance. A 10% increase in realized uncertainty—measured with the spikiness of daily fires within a year—increases property damage by 9%. This result is interpreted as evidence of the resource trade-off associated with resource commitments under uncertainty. However, consistent the trade-off between efficiency and flexibility there is strong evidence that an increase in partner resources received diminishes the negative effect of uncertainty on fire performance. A 10% increase in partner resources received above the mean decreases the negative effect of uncertainty on fire performance by 10%. To illustrate, extrapolated to the population this represents a property damage reduction equal to roughly

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$1.2 billion per year. This amount is equivalent to large portion of the estimated $15.5 billion in direct losses in 2008 (Karter and Stein 2009). This result suggests that alliances are an adaptive response to uncertain demand, and that partner resources received can loosen the trade-off between flexibility and efficiency associated with internal capacity decisions.

The estimates also suggest that adding formal contracts to pre-existing relationships decrease property damage up to about 4%, but that this performance gain may be wiped out when demand uncertainty rises less than 10% above the mean. Formal contracts appear to improve coordination among partners when fires arrive in a predictable manner, but they constrain partners from taking actions based on their individual discretion in ways that might improve performance when fires arrive in an unexpected manner.

Finally, there is strong evidence of trade-offs between property damage and injuries & deaths that follow from the way organizations deploy resources and structure collaborations. These results are explored in detail and imply that it is not only important to consider organizational design decisions in an inter-organizational context, but that it is important to consider how different aspects of performance may be incorporated into different organizational designs.

2   Theory

2.1   Reliance on partner resources

Organizations operate in dynamic environments and so face uncertain conditions. While managers would like to act as new information arrives (Trigeorgis 1997, Folta and Miller 2001) they must make decisions based on expectations in which they have varying degrees of confidence. That is, they design the organization *ex ante* to deal with anticipated uncertainty *ex post* while they pursue their main objectives. Organizations are faced with trade-offs between control and flexibility as they design the organization. This tension arises signif-

icantly in choices about the amount of resources available to the organization (Cyert and March 1963, Ghemawat 1991, Borenstein and Farrell 2007) and the amount of structure that determines how resources are deployed (Davis, Eisenhardt, and Bingham 2009). For instance, managers may invest in designs that permits elements of the organization to be easily re-configured (Baldwin and Clark 2000, Argyres and Bigelow 2010). They may relax control processes (Nohria and Gulati 1996). They may invest in production buffers (Cyert and March 1963, Thompson 1967). They may invest in routines that perform well under a variety of circumstances. They may invest in growth and consolidation of markets to reduce environmental variability (Penrose 1959, Davis and Stout 1992). Of course, while these investments may enhance flexibility they come at a price. For instance, slack resources are associated with higher carrying-costs, increased managerial effort, and agency problems (Leibenstein 1966, Borenstein and Farrell 2007) that encourage undisciplined problem-solving (Nohria and Gulati 1996), opportunistic rent-grabbing (Jensen 1986), and the dissipation of created value by non-owners (Ghemawat 1991, Ch.5).

The resources available to the organizations for coping with uncertainty need not be owned by the organization itself (Foote and Folta 2002). In fact, partner resources—those owned or controlled by partners—can make up strategic elements of an organization's productive technology. Early applications of network theory to organizations rationalized lasting relations as a way to procure resources under conditions of demand uncertainty (Galaskiewicz 1985, for an early review). More recent research suggests that links between organizations can overcome a variety of internal resource problems. Alliances are widely seen by scholars and practitioners as a strategic source of resources available to managers to improve performance. For instance, friendships can yield preferential resource allocations among production partners (Uzzi 1996, Sorenson and Waguespack 2006) and the exchange of support among potential rivals (Ingram and Roberts 2000). New ventures can profit from ties to prominent investors (Stuart, Hoang, and Hybels 1999) and from better positions in

organizational networks (Baum, Calabrese, and Silverman 2000). The networks and alliances literature emphasizes the instrumental value of linkages to partners and assumes the flow of valuable resources across these conduits. This paper begins by considering the extent to which organizations access these relationships—that is, rely on partner resources.

Why would organizations use partner resources instead of relying solely on internal resources? Partner resources can substitute for internal resources. In this way, organizations can enjoy less binding capacity constraints and the ability to generate the same output given smaller commitments to productive resources. However, even if exchange is not immediately consummated partner resources come at a price. At a minimum, the price that must be paid may be the expectation of future payment in kind. Exchange with partners is more meaningful when partner resources complement internal resources. In particular, partners can organize their resources collectively to enjoy functional consolidation in situations where it is not possible to alter the boundaries of the organization. In this way, partners can co-specialize and share scarce resources; realize economies of scale in purchasing inputs; and, pool variable demand. Therefore, compared to relying on internal resources alone relying on partner resources may be very attractive.

However, by definition partner resources are not owned and so are associated with less control than internal resources. The division of control over the resources available to partners can create problems in coordinating work. These problems arise as partners combine technologies with different technical interfaces, operating procedures, languages, and procedural norms. Differences in technology and the separation of control can result in incompatibilities and signaling problems that reduce the effectiveness with which interdependent elements of work are performed (Williamson 1991, Gulati and Singh 1998, Gulati, Lawrence, and Puranam 2005). However, if the return to dividing work between partners outweighs the coordination costs of dividing control across organization borders then partner resources will improve operational effectiveness. Demand uncertainty increases the probability that

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organizations will experience realizations in which they hit capacity constraints and/or idle resources. Because these outcomes are costly they will diminish performance. Therefore when realized uncertainty is high, the flexibility benefits of partner resources—that is, of <u>not</u> hitting capacity constraints and idling fewer resources—are more likely to outweigh the loss of control. This implies that:

> ***Prediction 1A:*** An increase in demand uncertainty will decrease organization performance (P1A)

> ***Prediction 1B:*** An increase in partner resources received will diminish the negative effect of demand uncertainty on performance (P1B)

2.2 Governance formality and uncertainty

Organizations combine people and resources to perform the tasks necessary to achieve their objectives. These combinations involve stable patterns of activity that constitute part of the organization architecture. The patterns in turn affect how well the organization deploys its resources. As a result, organization architecture can have serious performance consequences. Although organization architectures can result from an emergent process they are nonetheless susceptible to deliberate design by managers. In this way, organization design provides a occasion for managers to influence performance.

Despite the potential benefits of working closely with other organizations these arrangements often fail (Kale and Singh 2009). Working across organization boundaries can involve serious incentive and coordination problems derived from the lack of a central authority to enforce how each party behaves (Milgrom and Roberts 1992, Williamson 1991). The separation of interests across organization boundaries can create motivation problems in which partners free ride and generally behave opportunistically. The separation of production technologies across organization boundaries can create coordination problems that make it

difficult for partners to know what actions to take as they subdivide complex and interdependent activities (Gulati and Singh 1998).

Coordination problems are distinct from incentive problems (Milgrom and Roberts 1992, Williamson 1991). Once organizations agree to collaborate coordination concerns arise because of the lack of a central control structure. Dividing work across organization borders results in additional complexity associated with separate and sometimes incompatible technologies and costly communications to ensure interdependent actions are taken (Gulati and Singh 1998). Coordination problems arise when it is difficult for partners to align actions, and they can occur even when partner interests are aligned (Gulati, Lawrence, and Puranam 2005). Although they are often empirically intertwined coordination and motivation problems can pose distinct challenges.

Collaborations proceed within an architecture of controls (Gulati and Singh 1998). Some controls are explicit and formal such as partial ownership (Oxley 1997), written contracts (Mayer and Nickerson 2005), and information technology (Argyres 1999). Formal contracts are written codes of conduct for planning how organizations work together. They place explicit structure on collaborations with expectations of the actions to be taken by each party that are specified *ex ante* in terms that can be verified *ex post* by third-parties. However, for these reasons they can only include terms that the partners can easily specify and that outsiders can observe.

Some controls are implicit, psychological, and informal such as cooperative norms (Bercovitz, Jap, and Nickerson 2006), trust (McEvily, Perrone, and Zaheer 2003), learning (Mayer and Argyres 2004), and reputations (MacLeod 2007). These mechanisms improve coordination by making the actions of each collaborator more predictable to the other. Informal mechanisms are available when organizations expect a collaboration to continue in the future. They involve unwritten codes of conduct that shape how organizations behave in their dealings with other organizations. In contrast with formal contracts, informal arrangements are

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more information rich because they can incorporate outcomes that are prohibitively costly to specify *ex ante* and outcomes that are observed by only the contracting parties *ex post*. Informal arrangements allow partners to use "detailed knowledge of their specific situation and to adapt to new information as it becomes available" (Baker, Gibbons, and Murphy 2002). For the same reason, these arrangements must be self-enforcing.

Because informal mechanisms are emergent and difficult to effect coordination among recurrent collaborators is more susceptible to formal planning mechanisms such as standards, rules, programs, and information/communication systems. These mechanisms improve coordination by making the actions of each collaborator more predictable to the other. Formal mechanisms align actions by collectively setting explicit expectations of behavior prior to episodes of collaboration. In this way, formal contracts coordinate interdependent actions more tightly than informal arrangements. These arrangements provide organizations with clear signals about the actions partners will take during episodes of collaboration. And, they provide assurances to each partner that the other party will perform as expected. Formal contracts enhance collaboration by employing more hierarchical controls than are available in informal relations not just to address incentives to behave opportunistically but to address difficulties coordinating actions across partners (Oxley 1997, Gulati and Singh 1998, Mayer and Nickerson 2005, Novak and Stern 2008).

Formal contracts have important limitations, however. Because it is costly to specify details formal contracts are incomplete: partners will stop adding detail when the net expected benefits are no longer positive. Formal contracts are also incomplete because the parties writing them are bounded in their ability to imagine future circumstances. As a result, formal contracts are incomplete and so are unable to provide direction to partners that suit all occasions. Uncertainty "evokes the unforeseen, indescribable contingencies" that generate contractual incompleteness (Elfenbein and Lerner 2003). Partners must adapt their decision-making as demand uncertainty is resolved over time (Williamson 1991). How-

ever, the presence of informal mechanisms such as trust, reputation, personal affection that form through repeated interactions can compensate for the limitations of formal contracts (Ryall and Sampson 2009, Argyres, Bercovitz, and Mayer 2007). So, even though formal and informal mechanisms can accomplish the same goals of aligning partner actions, when used together their differences are complementary (Poppo and Zenger 2002, Gulati and Nickerson 2008). These arguments suggests that organizations can benefit from formalizing previously informal relations.

Formal contracts rely on clear and rigid controls to coordinate work and to prevent partners from taking certain actions. But, as a consequences of being incomplete formal contracts also introduce unwanted rigidities—particularly when the environmental demands on each partner falls outside the scope of the contract and even when partners are motivated to cooperate. Specifically, formal contracts oblige partners to behave according to the more limited details of the contract when more detailed knowledge of the situation may call for an alternate set of actions. Informal arrangements are superior to formal contracts at incorporating new and richer information into choices about what actions partners should take. Consequently, informal arrangements permit greater flexibility by providing partners with greater discretion to act new information arrives. This is particularly helpful under increased demand uncertainty which generates more widely variant circumstances than are likely to have been anticipated when contracts were originally drafted.

Gulati, Lawrence, and Puranam (2005) analyze the adaptive benefits of alternate forms of governance among vertically linked organizations, argue, and find evidence suggesting that transaction instability reduces the performance of in-house procurements—where actions may be more tightly coordinated.[3] Similarly, this paper argues that formal contracts, which more tightly coordinate the actions of partnered organizations, may improve outcomes

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[3]Transaction instability is measured as a survey index one component of which asks for agreement with the following statement: "There is significant uncertainty in its annual volume estimates."

within the scope of the arrangement. However, when circumstances change—in particular, when organizations face greater demand uncertainty—formal contracts introduce structure excesses that reduce the individual discretion of partners to make use of new information to better align actions with environmental demands. In contrast, taking formal contracts as more hierarchical than informal relations, the prediction made in this paper contrasts with theory and evidence that integration facilitates adaptation (Williamson 1991, Forbes and Lederman 2010). However, the argument is based on the very same arguments and generates consistent predictions. Contracts are incomplete and cannot include the detail necessary to describe how partners should behave in situations that require adaptation. As a result, formal contracts are more likely to perform worse than informal arrangements under conditions that require adaptation: that is, when demand uncertainty rises.

> **Prediction 2A:** Adding formal contracts to previously informal relations will improve organization performance (P2A).
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> **Prediction 2B:** The positive effect of formal contracts on organization performance will be diminished by an increase in demand uncertainty (P2B).

3 Model, data and empirics

3.1 Fire departments

In 2008 there were $15.5 billion in direct property damage, 16,705 people were injured, and another 3,320 people died as a result of fires in the US. In that year there were an estimated 30,170 fire departments employing 1,148,850 firefighters (Karter and Stein 2009). Firefighting technology has advanced beyond bucket brigades. Fire services are relatively complex and require active management and planning. Trained professionals and volunteers are the most important input. They use protective equipment, command and control and communications

systems, and specialty apparatus for rescues and fire suppression. Fire departments are locally-funded, budget-constrained organizations. Because the *'stakes are high...[and] serious foul-ups can have serious consequences'* (Weick 1993) department members have incentives to work effectively and to continually improve performance. Fire departments provide services within geographic areas defined by political boundaries. These boundaries are not laid out to accommodate the operational concerns of firefighting, however. For this reason it is not surprising that proximate fire departments regularly collaborate by providing resources and services across political boundaries in a practice known as mutual aid.

Although this has not always been the case, today firefighting is provided with territorial exclusivity under local government authority. US fire departments are not profit-making organizations, and there are few opportunities for members to accumulate wealth. As a result competitive forces at play between proximate fire departments are limited and indirect; however, that is not to say that they are absent. Nonetheless, compared to other horizontally-related organizations fire departments have strong positive incentives to cooperate such as norms of equity, professional oaths of conduct, and opportunities to learn, share best practices, and consolidate support functions and training. They have few incentives to behave opportunistically because of a lack of product market competition, blunted labor market competition, and a lack of capital market competition. And, they have strong interdependencies across geographies, particularly among social and economic factors, that create strong mission alignment. As a result, fire departments have intrinsic interests in cooperating. Nonetheless, fire departments provided relatively little assistance across organization boundaries until recently. Failures to collaborate across political jurisdictions suggest that working together is not a straightforward problem even when cooperation problems are less severe.

Mutual aid involves the exchange of non-money resources across organization boundaries. Although an age-old practice, this form of collaboration gained prominence following

a change in national response guidelines in 1997. At this time, the National Fire Protection Association (NFPA) revised *NFPA 1500: Standard on Fire Department Occupational Safety and Health Program.* This standard sets out the minimum safety guidelines for emergency response personnel, and importantly incorporated the 'two-in/two-out' rule, which stipulates that for every pair of firefighters that are inside the structure there should be another pair outside the structure on stand-by. This rule doubled the recommended number of firefighters available on scene when entering a burning structure. One way to conform to the 1997 guideline for any given department was to call on neighboring departments to provide extra manpower. Thus in 1999, before fully conforming with the recommendation, fire departments engaged in an average of roughly 5 runs per year. By 2006, this figure rose to an average of 22 aid runs (see figure 1).[4]

—— Insert figure 1 here ——

At the same time, a new practice for organizing these interactions spread through the population—an arrangement known as automatic aid. Mutual aid arrangements historically relied on handshakes, but in the last 20 years have been written into formal agreements. Automatic aid arrangements are a newer form of governance in which partners are obligated to respond to partner fires according to the terms laid out in formal written agreements. Automatic aid arrangements are pre-negotiated agreements specifying the actions partnered departments will take under circumstances that call for collaboration. The agreements are detailed in contracts that have legal authority. And, the contracts ascribe legal liability for the actions taken including, for instance, when it is permissible to deny requests for help. Furthermore, the contracts are enacted in dispatching functions and response routines that define default actions to be taken according to the contract terms. In 1999 fewer than 3

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[4]Compliance with the rule is voluntary unless it is written into state law. Different states enacted this into law at different times or not at all.

percent of departments had adopted automatic aid agreements. By 2006, this fraction rose to two-thirds of departments (see figure 2). According to industry informants, in addition to the greater imperative to collaborate the increase in automatic aid may be attributable to a combination of factors. Since the mid-1990's fire departments received credit for automatic aid on municipal fire ratings conducted by the Insurance Service Office.[5] Information technology advanced to support automatic aid: in particular, consolidation of 911 call centers at the county level with alarm dispatch circuits to the fire stations of proximate departments; and, declining cost to implement systems to ensure that collaborating departments have interoperable radio communications on scene. And, following the event on September 11th 2001 there has been an imperative to support greater collaboration between first responders.[6]

—— Insert figure 2 here ——

3.2   Identification strategy & estimation

The empirical goal of this study is to test the link between operational performance and three variables: (a) aid received, (c) formal contracts, and (d) demand uncertainty. The unit of analysis is the department (d) year (t).

3.2.1   Fixed effects and lagged dependent variable models

The simplest approach is to run pooled ordinary least squares (OLS) regression of performance on the treatment variables; however, this requires strong assumptions to deliver consistent estimates.[7] I employ a research design based on two main empirical models: (a) an individual department fixed effects (FE) model, and (b) a distributed lagged dependent

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[5]These ratings affect the cost of fire insurance for the municipal government and property owners

[6]In particular, the 911 Commission Report made strong recommendations for enhanced collaboration which were followed by FEMA grant-making to support interoperable communications, and mandatory mutual aid agreements between proximate agencies across state lines

[7]Importantly, that treatment variables are uncorrelated with the error in each period.

variables (LD) model. Each model has different identifying assumptions and consequently different limitations, but taken together they offer a useful approach for bounding the effects of interest (Angrist and Pischke 2009).[8]

The FE model addresses one form of omitted variables bias—fixed unobservable differences in departments that may affect the relationships under inspection. For instance, departments endowed with special culture, equipment, leadership, or skills may drive a spurious relationship between performance and the treatment variables. Similarly, departments in areas with structural characteristics such as lower population or building density, fire-prone construction materials, or poor roadways may also spuriously drive this link. Additionally, there may also be factors that are correlated with performance and the treatment variables that are invariant across departments in each year. For instance, events with national impact such as the September 11th attacks and the creation of the Department of Homeland Security might systematically affect both department performance and the treatment variables. The main empirical model to be estimated is

$$Y_{dt} = X_{dt}\Theta_1 + U_{dt}\Theta_2 + (X_{dt}U_{dt})\Theta_3 + (control)_{dt}B + \eta_d + \varepsilon_{dt} \tag{1}$$

In equation (1), Y_{dt} is the outcome to be explained: fire loss status. X_{dt} is a vector of variables including partner resources received and formal contracts ($P2A$). U_{dt} is department-specific uncertainty. The hypothesizes are tested on the interaction between the elements of X_{dt} and U_{dt}. $(control)_{dt}$ is a vector of control variables including: year fixed effects, state-year trends, characteristics of demand, aid given, and inputs costs (i.e. labor and capital).[9] η_d

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[8]In principle, it is possible to relax the assumption of strictly exogenous regressors and estimate dynamic panel data models with individual effects via GMM in first differences (Arellano and Bond 1991); however, this requires the assumption that longer lags are uncorrelated with the differenced residuals. Since the residuals are the portion of output not accounted for by the covariates, and because production is likely to be correlated from one year to the next prior outcomes are likely to be correlated with the differenced residual.

[9]Year fixed effects address period specific national shocks that affect all department equally–for example consolidation of US Fire Administration into the DHS. And state-time trends account for state-wide changes

is a department fixed effect. And, ε_{dt} is the residual. Θ_1, Θ_2, Θ_3, and B are the parameter vectors to be estimated.

This specification is based on the identifying assumptions that the causal effects of the treatment variables are constant and additive, that all omitted variables are time-invariant, and that the treatment variables are strictly exogenous conditional on the fixed unobserved effects. That is, when the observed Y_{dt} is either Y_{0dt} or Y_{Tdt} depending on treatment status $E[Y_{0dt}|\eta_d, (control)_{dt}, X_{dt}, U_{dt}] = E[Y_{0dt}|\eta_d, (control)_{dt}]$ where η_d captures all unobserved organizational characteristics that determine performance, partner resources receivedÊand formal contracts for department d.

This strict exogeneity assumption may be too strong. It is possible that there are omitted variables that vary over time. Of particular concern, there may be feedback from past performance on the treatment variables. For instance, partner resources received and formal contracts may arise in response to unusually severe incidents in the past: that is, transitory shocks such as "Ashenfelter's dip." Similarly, departments may seek out more aid in response to budgetary hardship or poor performance. Consequently, past performance may be a confounding variable not accounted for by η_d. The unique performance histories of each department can then be used to identify the causal parameters by estimating the following model:

$$Y_{dt} = X_{dt}\Lambda_1 + U_{dt}\Lambda_2 + (X_{dt}U_{dt})\Lambda_3 + (control)_{dt}\Gamma + \alpha Y_{dt-h} + \xi_{dt} \tag{2}$$

where Y_{dt}, X_{dt}, U_{dt} and $(control)_{dt}$ are defined as before. ξ_{dt} is the residual. And, α, Λ_1, Λ_2, Λ_3, and Γ are the parameters to be estimated. In this model the strict exogeneity assumption is false by construction. The identifying assumption in this model is $E[Y_{0dt}|Y_{dt-h}, (control)_{dt}, X_{dt}, U_{dt}] = E[Y_{0dt}|Y_{dt-h}, (control)_{dt}]$ where Y_{dt-h} is a h-period lagged dependent variable.[10]

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over time such as the differential adoption of the "two-in/two-out" rule.

[10] These models were estimate with $h = 1, 2$, but because the inclusion of longer lags reduces the regression sample and does not statistically or materially alter the results only estimates with $h = 1$ are presented

I assume that the residuals (ε_{dt} and ξ_{dt}) are identically distributed but not independent. Because residual performance may be serially correlated within departments over time in the FE models—and by construction are correlated in the LD models—estimates of standard errors may be grossly under-stated (Bertrand, Duflo, and Mullainathan 2004). To address this dependence, robust standard errors are estimated clustering on the individual department.

3.2.2 Instrumental variables approach

Fire departments are more likely to collaborate when there are serious fires that are likely to cause major damage. Similarly, fire departments are more likely to enter formal contracts when the gains to doing so are expected to be greatest. As a result, the estimates of the coefficients on department adoption of formal contracts may be biased even after controlling for fixed unobservable differences between departments and their unique performance histories. To address these selection problems I use an instrumental variables (IV) approach estimated with a two-stage least squares (2SLS) procedure.[11] The choice of instruments exploits the fact that the costs and benefits of formal contracts and aid received depend on the characteristics of organizations on both sides of the transaction. And, it relies on the reasonable assumption that many partner characteristics are unrelated to the performance of the other party. As a result, partner characteristics offer instruments that have strong face validity. This approach has been widely employed since Berry, Levinsohn, and Pakes (1995) proposed and implemented a technique that exploits the characteristics of other products in a market as instruments for cost and demand characteristics of a focal product.

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below.

[11]For the IV approach to yield consistent estimates, the instruments must satisfy two conditions: (a) they must influence aid received and the use of formal contracts (i.e. $E(W'_{d,t} Z_{d,t}) \neq 0$, where $Z_{d,t}$ is the vector of instrumental variables, and $W_{d,t}$ is the vector of potentially endogenous treatment variables including aid received and formal contracts), but (b) not affect performance directly (i.e. $E(Z_{d,t}\varepsilon_{dt}) = 0$). Although these estimates are not readily generalized to the population they nonetheless deliver an estimate using plausibly exogenous variation in the treatment effects (Imbens and Angrist 1994).

3.3 Measures

Performance variables. Fire departments have two main objectives: to protect life and property from fires and fire hazards. Therefore property damage and injuries & deaths from fires provide natural measures of fire department performance. Property damage is calculated for each department from incident-level archival data as the annual sum of the replacement value of the structure and contents damaged by fire, smoke, water, and overhaul deflated to 1999 dollars.[12] Injuries & deaths are also calculated for each department from incident-level archival data as the annual count of civilians and firefighters injured or killed either as a result of the incident or during its mitigation.[13] There are $353,249 in property damage and 1.4 injuries & deaths per department per year.

Treatment variables. This article examines the effect of additional resources from outside the organization (aid received) on performance. Aid received—the quantity of additional resources received from partners—is measured with a count of firefighter runs received by the focal organization from mutual aid partners in year t. On average, the sampled departments received 76 firefighter runs per year. Once departments have decided to engage in collaborations they have alternatives for arranging these relations. This article advances a set of arguments about when more structure in the form of formal contracts will have different performance consequences. Mutual aid between proximate departments may or may not be organized with an automatic aid arrangement. Automatic aid represents an unambiguous shift towards more formal and more highly structured arrangements. Mutual aid relations without an automatic aid agreement only sometimes involve written contracts. In contrast,

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[12]'This does not include indirect loss, such as business interruption' (USFA 2006, section 3-40)

[13]'An injury is physical damage to a person that requires either (1) treatment by a practitioner of medicine within 1 year of the incident, or (2) at least 1 day of restricted activity immediately following the incident. Deaths also include people who die within 1 year because of injuries sustained from the incident' (USFA 2006, section 3-42). In models with injuries & deaths as the dependent variable (i.e. Y_{dt}), rather than modelling the errors distributed as a Poisson random variable or a negative binomial random variable I transform injuries & deaths as follows: $\tilde{Y}_{dt} = log(Y_{dt})$ when $Y_{dt} > 0$, and $\tilde{Y}_{dt} = 0$ when $Y_{dt} = 0$. A control for this transformation is included for null values, $1(Y_{dt} = 0)$. This linearization permits use of the three approaches described above.

mutual aid relations with automatic aid agreements always involve written contracts. That is because automatic aid arrangements require investments in written legal contracts, joint training exercises, communications systems, and response protocols. Formality is measured as a regime change with an indicator variable that switches on in the first period that the department has at least one exchange under a formal contract with any of its partners. In the sample, partnerships are governed by formal contracts in 57% of department-years. Finally, this article examines the role of uncertainty in the connection between design choices (i.e. resource allocations and collaboration structures) and performance. Consistent with the strategic management literature, department-specific demand uncertainty is measured with daily fire variability calculated as the cross-sectional standard deviation of daily department per department per year.[14]

Control variables. I control for slack resources within the focal department since this may influence the decisions to use partner resources and the realized performance of the department. The slack resources construct has two components: a) current resources, and b) the expected resource demands of current business. Current resources are measured with archival data on the number of firefighters in a department in a given year. The choice of measure for the expected resource demands of current business is less obvious. This paper suggests that use of department-specific distributions of daily fire demands to understand how expectations correspond with allocations. In particular, fire departments, hospitals, and other organizations that face volatile demands and capacity constraints will aim for some level of reliability by overstaffing relative to the average demand (Lynk 1995). This paper imagines that department managers who want to staff their organizations to adequately cover X percent of fire demands will analyze the empirical distribution of daily firefighter runs and select the number of firefighters that can cover demand on days at the Xth percentile.

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[14]The estimates are robust when using alternate measures including the variance-to-mean ratio of daily department runs—a relative measure of volatility This measure is also consistent with Bloom's (2009) measures of time-varying uncertainty.

Consequently, this paper measures the expected resource demands of current business using the department-specific empirical distribution of daily firefighter runs in the prior year. This paper uses the 95th percentile of daily demands as a proxy for expectations for two reasons. First, it is less sensitive to outliers than the daily maximum or measures based on the standard deviation. Second, it is close to the prescribed method for department managers (Cote 2003, Chapter 6).[15] Slack resources are then calculated as the ratio of current resources (# firefighters$_{d,t}$) and the expected resource demands of current business ($p95$ daily firefighter runs$_{d,t-1}$). This measure captures the extent to which a department is prepared to address fires on the most difficult days. On average, the sampled departments maintain 2.3 times more firefighters than are needed to cover fires in the 95th percentile of daily demands in the prior year.

Fire department performance depends heavily on the underlying demand for services in the period. Since a department's overall fire load is likely to be correlated with personnel decisions and performance it is included as a control; however, not all fire runs place the same demands on the organization. To control for heterogeneity in overall demand that may be correlated with partner resources received and formal contract choices three measures of demands per department per year are included: a count of residential structure fires, a count of non-residential structure fires such as those that occur in offices, hospitals, and commercial buildings, and a count of outside fires such as those that occur in natural vegetation, garbages, vehicles, or mobile homes.

Measures of input costs are also included as controls to facilitate interpretation of performance as net productivity. One for labor and one for capital. Firefighter man hours are calculated for each department from incident-level archival data as the annual sum of firefighter hours spent responding to incidents.[16] This measure of labor-usage intensity is

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[15]The results are robust to variety of alternate measures including: the ratio of personnel to the maximum daily personnel runs, the inverse annual utilization of personnel (in terms of runs, total person-response minutes, and person-runs), and the inverse utilization demeaned by industry averages.

[16]This measure is constructed as the annual sum of the time between the first alarm and the resolution of

selected as a proxy for variable costs for three reasons: first, volunteers are paid on an hourly basis (which captures one aspect of economizing behavior); second, more time spent fighting fires places greater wear on equipment and apparatus; third, whether or not this effort is recognized in budgets it represents a real cost to stakeholders (another aspect of economizing behavior). A similar measure was constructed for the time fire apparatus was deployed to incidents to control for differential use of capital inputs: apparatus hours.[17] Mutual aid operates on the basis of reciprocity. As a result, aid given (i.e. the cost of aid received) is likely to be correlated with both performance and aid received. Correspondingly, this variable is included as a control and is calculated symmetrically as the count of firefighter runs given by the focal organization to its mutual aid partners in year t.

Instrumental variables. The following partner characteristics should be uncorrelated with focal department performance because they occur in other jurisdictions: interactions among network partners ($z_{d,t}^1$), distance travelled to incidents ($z_{d,t}^2$), total fires ($z_{d,t}^3$), and border fires ($z_{d,t}^4$). However, because mutual aid and formal contracting are determined by the returns to both focal departments and their partners characteristics that shift the costs and benefits to one party will affect the realizations for the other.[18]

Establishing an formal contract involves planning and negotiating the rights and obligations of the departments involved. This process requires common knowledge as well as a mutual understanding of the interdependencies that extend beyond their partnership. De-

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each incident multiplied by the number of firefighters assigned to each incident.

[17] Annual fire department budget data is available in the Government Finance Statistics series compiled by the US Census. Fire department operating budgets are measured with operating expenditures on fire protection by local governments. However, this series is not complete and so analysis controlling for these budgets is included in the appendix that is not for publication. The results are qualitatively very similar. Please see supplementary appendix tables 6 through 8.

[18] After interacting these variables with uncertainty there are eight instruments for four endogenous variables: four for the main effects of aid received and formal contracts and an additional four for interactions with uncertainty. In the notation above, the instrument vector $Z_{d,t}^{main} = \{z_{d,t}^1, z_{d,t}^2, z_{d,t}^3, z_{d,t}^4\}$ for the vector of potentially endogenous variables $W_{d,t}^{main} = \{\text{formal contracts, aid received}\} \in (main)_{d,t}$ and the instrument vector $Z_{d,t}^{interaction} = \{z_{d,t}^1 \times uncertainty, z_{d,t}^2 \times uncertainty, z_{d,t}^3 \times uncertainty, z_{d,t}^4 \times uncertainty\}$ for the vector of potentially endogenous variables $W_{d,t}^{interaction} = \{\text{formal contracts} \times \text{uncertainty, aid received} \times \text{uncertainty}\} \in (interaction)_{d,t}$.

partments are embedded in networks of relations in which relevant information arises and is circulated. Interactions among partners are occasions for gathering and transmitting information. Network flow increases the likelihood that information will be circulated to all the nodes. Network flow is measured with the number of recent interactions among a department's ego-centric network partners (i.e. intra-network aid). I expect more intra-network aid to positively influence the use of formal contracts. But, I do not expect these interactions—which occur beyond department borders—to affect performance within the department's jurisdiction.

Formal contracts are intended to enhance the coordination of resources by both reducing the time it takes to decide what responses to deploy and whether to deploy them. When partners have to travel farther to interact the time compression benefits of these contracts are reduced. As a result, I expect the distance partners travel on aid calls to decrease use of formal contracts. However, because I measure partner distance by excluding those runs involving the focal department this variable should not affect the performance of the focal department.

Similarly, inter-department collaboration is more feasible when the services can be delivered over smaller distances. As a result, I expect a partners with a larger distribution of fires close to their political borders to place take more steps to engage in collaborations with their proximate partners. I do not expect a larger number of border fires to influence performance–except through aid received. I measure border fires with the count of fires among a department's partner network that occur at a distance that is greater than the 80th percentile of all runs in the sample window from headquarters.

Incidents generate opportunities to collaborate. Therefore, an increase in incidents will increase the benefits of using aid and investing in costly contracts to organize interactions. Because I measure partner fires by excluding the aid departments give to their partners I do

not expect this variable to influence focal department performance.[19]

Consistent with the literature estimating production functions, all continuous measures are transformed with a logarithmic function. This transformation simplifies interpretation because the coefficients in log-log models can be read as percent changes or elasticities. All variables are described and summarized in table 1.

—— Insert table 1 here ——

3.4   Data & Sample

The dataset from which I draw a sample is an unbalanced panel including 24,211 US fire departments. The dataset covers about 80 percent of the population, and includes observations in the period between 1999 and 2006. The sample was collected by the USFA through individual fire department efforts to record information using the National Fire Incident Reporting System (NFIRS)—a standardized reporting format. NFIRS was first established in 1974 to gather and analyze information on the magnitude of the nation's fire problem, but only gained broad adoption in the last decade. The USFA provides a public-release format of data available since the the most current NFIRS version was introduced in January 1999. This version represents the most comprehensive reporting format since the system began, and it marks the point at which participation took off. The regression sample includes 7,202 departments with a total of 29,714 department-year observations.[20]

Automatic aid arrangements spread throughout sample departments—rising from about 3% to 75%—over the observation window between 1999 and 2006. At the same time these

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[19]However, if the data generating process for fires is based in large part on weather then performance and partner fires will be correlated. I deal with this in two ways. First, I control for broad regional effects that change over time with state-year interactions and higher-order terms in the main specifications. Second, I use county-year interactions and higher order terms as stronger controls for more narrowly defined regional trends as a robustness check in table .

[20]Most of the missing values result from departments not reporting department personnel information: a loss of 12,726 out of 24,211 departments. Another 1,243 of the remainder only appear in the sample for one year. And, the remaining 3,040 departments are excluded from the sample because they are missing data for at least one department-year on regression variables or measures with degenerate values.

departments increased the frequency of interactions with partners. The average number of fire department runs involving aid increased from roughly 5 runs per year to more than 20 (see figure 1). These stylized facts indicate that industry underwent a substantial change in the frequency with which its members interacted and a change in the way they governed these interactions.

—— Insert figure 1 here ——

4   Results

This paper asks: How does the exchange and coordination of resources with alliance partners affect performance under varying conditions of demand uncertainty? I answer this question in three parts. First, I focus on the consequences for property damage of increased aid received from partners when uncertainty about fire demand within the year varies over time. I focus on property damage because the results are large, stable, and statistically robust compared to injuries & deaths. Second, I focus on the consequences for property damage of formal contracts for coordinating the exchange of resources across organization boundaries, and to what extent their effects depend on the stability and regularity of realized demand. Third, I compare the consequences for property damage with those for injuries & deaths and explore unexpected nuances that imply departments experience trade-offs across objectives from differences in partner resources received and contract formality. I conjecture that these trade-offs reflect two mechanisms linking the architecture of collaboration and performance. The first involves sharp preference ordering among objectives. The second involves difficulties coordinating activities to meet multiple conflicting objectives. Whatever the mechanisms, the results suggest that different configurations of resources internally and collaboratively exert interdependent effects on multiple aspects of organization performance that are sometimes incompatible.

From an empirical standpoint, the hypotheses are broadly supported under fairly rigorous controls: in particular, time-invariant differences between departments and feedback from past performance. Furthermore, after purging estimates of endogenous variation in two key explanatory variables the point estimates increase in magnitude; however, so too do the standard errors and not all coefficient estimates are statistically significant.[21] Nonetheless, this paper employs multiple research designs, each with different strengths and limitations, in an attempt more reliably assess the predictions offered above. The estimates are reported in tables 2 and 3. Table 2 presents the OLS regression results for fixed effect and distributed lag models. Table 3 presents the instrumental variables regression results which reproduce the models in table 2 using plausibly exogenous variation in aid received and formal contracts to identify the effects on performance.[22]

4.1 Partner resources increase adaptability

This article tests whether partner resources improve organization performance in response to an increase in realized demand uncertainty. Consistent with the baseline prediction (P1A) the coefficient on demand uncertainty is statistically significant and has the expected sign (see models 1 and 2 in tables 2 and 3). A 10% increase in realized uncertainty—measured with the spikiness of daily fires within a year—increases property damage by 9%. This result is interpreted as evidence of the resource trade-off associated with resource commitments un-

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[21]The application of instrumental variables in this research design is very demanding: first, the instruments must provide time-series as well as cross-sectional variation; second, the variation must be sufficient to be partitioned according to differences in uncertainty (the two-way interactions with the endogenous regressors).

[22]The first stage regressions provide strong evidence that the instruments are relevant (see table A-1 in the Appendix). The estimates have the expected signs and are statistically significant in almost all of the specifications, and the F-statistics for the excluded instruments are significantly larger than 10 in all specifications. Furthermore, the instruments explain a meaningful amount of the total variation in the endogenous variables: the Shea Partial R^2 estimates of about 2.2% and 4.5% for aid received and formal contracts, respectively. Turning to the question of whether the instruments are exogenous, because there are more instruments than endogenous variables it is also possible to test whether the instruments are correlated with error term in the main model. Table 3 reports p-values for the Hansen J tests which in all but one case suggest that the instruments employed are valid. However, given the large sample sizes it is surprising to get non-rejection results—which indicate they are valid—at all.

der demand uncertainty. Organizations access resources beyond their boundaries through close working relations with other organizations in the same field. Collaborations provide an additional source of resources that can be used to enhance adaptability when demand uncertainty increases (P1B). Consistent with the predictions of P1B the estimated coefficients for the interaction between aid received and uncertainty are negative and statistically significant in all models where property damage is the dependent variable (that is, models 1 and 2 of tables 2 and 3). The magnitude of the effects are also material to department performance. The estimates in table 3 imply that a 10% increase in aid received from partners decreases property damage by about 10-11% when uncertainty increases 10% above the mean value. That is equivalent to a savings in property damage of roughly between $34,000 and $40,000 per year per department or $1,000-1,200M nationally. This suggests that alliances provide organizations with an adaptive response to uncertain demand.

Furthermore, the results indicate that increased partner resources are associated with sharper performance trade-offs between efficiency and flexibility than increased internal resources. A comparison of the interaction of slack resources and uncertainty with the interaction of aid received and uncertainty implies that partner resources: (a) introduce much more severe coordination problems when conditions are stable and regular, and (b) introduce greater flexibility benefits when conditions are unstable and irregular. This is consistent with the trade-off between control flexibility associated with resources that are shared rather than owned. Exchanges with partners involve more severe coordination challenges than organizing increased resources internally. Consequently, the costs of collaborating are more likely to swamp the benefits when conditions are more stable and regular. Evidence of these coordination problems suggest why effective alliance governance is so important.

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4.2   Formal contracts improve coordination not adaptation

The estimated effect of formal contracts on property damage has the expected sign in both the OLS and IV models (see models 1 and 2 of tables 2 and 3)—implying reductions in property damage. However, the estimates are only statistically significant in the distributed lag models. A cautious interpretation places the true value somewhere in the range between these two values and the distributed lag estimates thus form an upper boundary. The estimate in model 2 of table 3 implies that the use of a formal contract for organizing how working within a collaboration proceeds decreases property damage by about 4.2% when uncertainty increases 10% above the mean value. That is equivalent to a savings in property damage of up to $14,000 per year per department or up to $440M nationally. These results provide partial support for P2A.

This paper argues that demand uncertainty reduces the performance benefits of formal contracts by restricting the ability of partners to act on greater detail about individual circumstances that lay outside the pre-arranged contract plans even when partners intend to cooperate (see P2B). The estimated coefficient on the interaction between formal contract and uncertainty has the expected sign in all models for which property damage is the dependent variable (see models 1 and 2 in tables 2 and 3); however only two coefficients are statistically different from zero. The fixed effect model delivers a statistically significant result with the use of IVs. The estimate in model 1 of table 3 implies that the use of a formal contract increases property damage by up to 8% when uncertainty increases 10% above the mean value. That suggests a small increase in uncertainty—less than 10%—is sufficient to wipe out the coordination gains from using formal contracts when demand is predictable. These results provide partial support for P2B.[23]

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[23]The preceding analysis does not account for differences in changes that occur at the county level over time. Of particular concern is that each county—in which there are multiple departments—follows a different learning and upgrade path for its 911 call center in which formal contracts are made operational. To control for these differences, the analysis was re-run on a sub-sample of the regression sample to include only departments from the nine states with the largest number of observations. Half the data was effectively

4.3   Trade-offs between property and life

A strong empirical regularity emerged in the results which suggests a more nuanced story. The evidence implies that available resources and formal contracts exert opposing effects on property damage and injuries & deaths. The effects on property damage are consistently larger on a percentage basis than the effects on injuries & deaths. And, many of the effects on injuries & deaths are not statistically distinguishable from zero—in fact, none of the IV estimates with fixed effects are statistically significant. From this I conclude that the effects of configuring resources internally and collaboratively confirm with the predictions on a holistic basis. However, the trade-off between property damages and injuries & deaths require examination.

First the specific trade-offs. While a 10% increase in uncertainty increases property damage by about 10% it decreases injuries and deaths by 2%. This suggests that firefighters "go to the mat" to save lives when conditions are volatile and irregular and departments face high realizations. I interpret this trade-off to imply that when departments are stretched thin they will be increasingly vigilant about saving lives but also more ready to "let a building go" once it has been cleared. On the other hand, a 10% increase in partner resources received when uncertainty increases 10% above the mean value increases in injuries & deaths of up to 2%—nationally equivalent to 440 injuries & deaths per year. Because partner departments have strong incentives to protect lives and are unlikely to shade on performance this result suggests that the reduction in control from dividing work across organization borders may create coordination problems that result in life loss. While formal contracts decrease property damage by up to 4.2% they do not have a statistically significant on injuries & deaths. This

thrown out for this analysis–substantially reducing the statistical power. The results are presented in table A-2 for the OLS and IV estimates with property damage as the dependent variable. The results are qualitatively very similar to the results on the full regression sample that only incorporates state-time trends. In fact, the OLS estimates of the FE and LD models deliver very tight bounds on the effects. The IV estimates produce similar point estimates to the models on the full sample but with larger standard errors and a loss of statistical significance on the coefficient for P2B.

suggests that informal contracts are sufficient to deliver consummate performance on life saving activities when conditions are stable and regular. And, while formal contracts increase property damage by up to 8% when uncertainty increases 10% above the mean value they decrease injuries & deaths by up to 2.2%—nationally equivalent to -490 injuries & deaths per year.

Why might this be? Departments with more firefighters may be able to respond to incidents more quickly and with a better fit between incident requirements and deployed resources. This would improve the quality of overall responses; however, the majority of incidents involve little physical risk to civilians. Departments with more responders relative to expected demands will have have greater exposure to risk of injury and deaths in the regular line of duty, and they will face more acute coordination challenges. Furthermore, both of these factors are likely to be exacerbated when conditions are more irregular. These results are also consistent with the assumption of risk associated with firefighting in general, and the heightened coordination challenges associated with fighting fires when conditions are more uncertain in particular.

When conditions are more certain and regular formal contracts improve property damage outcomes but worsen injuries & deaths. When conditions are more uncertain and irregular formal contracts improve how departments work with their partners to produce better injuries & deaths but worse property damage outcomes. Formal contracts provide structure that constrains the actions of each partner in episodes of collaboration. As predicted, this may generate misfit between designs *ex ante* and requirements *ex post* leading to worse outcomes when conditions are less predictable. But, the trade-off between property damage and injuries & deaths suggest that formal contracts may provide structure with which to enforce activities that contribute differentially to organizational priorities. Under this interpretation, although more structure introduces rigidities that reduce some aspects of performance it may do so as a way of coordinating actions towards the pursuit of clear priorities.

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There is at least one alternative explanation. Formal contracts may resolve *ex post* motivation problems (Hart and Moore 2008). That is, they may induce different trade-offs for different objectives because these objectives may be associated with different incentive problems. On incidents involving risks to life partners are likely to deliver consummate performance, but on incidents involving only risks to property partners may have incentives to free-ride. Specifically, when conditions are more stable formal contacts induce positive cooperation; however, when conditions are less stable formal contracts may act as focal points for partners to comply with the agreement without discharging their duties in a manner consistent with the intention of the agreement. Interpreted this way, the results suggest that formal contracts are needed against a backdrop of incentive problems—that is, when only property is at risk. But, when conditions are more uncertain and partners have stronger incentives to shade on performance these contracts serve as reference points that permit them to limit efforts and assume fewer risks. On the other hand, against a backdrop with fewer motivation problems—when lives are at risk—informal arrangements are sufficient to deliver consummate performance. But, when conditions are more uncertain and partners have greater difficulty coordinating actions formal contracts provide structures that make the actions each partner will take more predictable.

5   Discussion and conclusion

This paper contributes to the literature on the design of organizational architecture in two ways. First, I argue and show that if scholars do not consider how managers configure resources in a collaborative context that they risk overlooking important aspects of what is going on. Second, I argue and show how resource and contract choices are linked with the performance of the organization through demand uncertainty with an emphasis on how coordination problems arise and are resolved. At the same time, this paper contributes to

the literature analyzing investments under uncertainty by focusing on demand uncertainty separate of competitor uncertainty, and by focusing on how investments are made in the presence of alliance partners.

The organization design perspective emerged from the tradition of research emphasizing the importance of congruence between environmental demands and internal programs of action (March and Simon 1958, Lawrence and Lorsch 1967, Miles and Snow 1978). More recently, Nadler and Tushman (1997) elaborate on the crucial role of organization designs for coordinating work under a variety of conditions. This paper extends this analysis by examining how inter-organizational design decisions are linked with performance. And, it emphasizes the interplay between varying coordination requirements and the capacities of different designs to address these requirements. The arguments advanced in this paper regarding design and coordination extend those made by Nadler and Tushman (1997) who draw upon the familiar strategic management tension between efficiency and flexibility in dynamic environments to motivate when different structures will enhance performance (Ghemawat and Ricart I Costa 1993, Davis, Eisenhardt, and Bingham 2009). And, it draws on the strategic alliance literature to predict how this tension manifests across contract forms that encompass trade-offs between incomplete information and authority (Gulati, Lawrence, and Puranam 2005, Baker, Gibbons, and Murphy 2002, Hart and Moore 2008).

Towards this, the paper empirically tests two devices for dealing with crises at the interface between organizations: (a) resource deployments within and across organization boundaries, and (b) formal contracts for coordinating resources within collaborations. This study shows how coordination problems manifest in at least two important ways. First, they arise as demand uncertainty creates misalignment between the resources that are available and that are needed. Second, they arise as individual discretion between the subunits that perform interdependent activities increases: that is, when authority over how resources are used is split between alliance partners.

The evidence suggests that fire departments with more internal resources perform relatively better overall than those with more lean resource profiles, but only when demand uncertainty increases. These allocations permit departments to adapt to irregular conditions with fewer adjustments costs and to loosen controls for making improvements. However, these resources entail trade-offs between property damage and injuries & deaths. This trade-off is even more severe as these resources involve exchanges with alliances partners suggesting that these trade-offs may result from increased coordination difficulties. The evidence also suggests that increased demand uncertainty diminishes the property damage decreases fire departments achieve by formally contracting. That is, relative to informal arrangements formal contracts perform worse as conditions become increasingly uncertain. While contracts create predictable expectations of behavior when conditions are more stable they create misalignment when conditions are less predictable and partners are forced to jointly adapt. Furthermore, the trade-offs between property damage and injuries & deaths implied by the results suggest that inter-organizational architectures (i.e. contracts) may be used to channel attention and activities towards objectives with higher priorities: the protection of life ahead of property.

The results also suggest that contracts may serve different purposes for different outcomes. By comparing results across property damage and injuries & deaths it is possible to examine how formal contracts serve different functions—as coordinating devices and as motivating devices. Partners have incentives to free-ride on incidents involving only risks to property, but they have incentives to cooperate on incidents involving risks to human life.

Considered this way, the results imply that formal contracts may also be needed to reduce incentive problems. But, when uncertainty increases and partners have greater opportunity to free-ride contracts may provide reference points to reduce effort to the letter of the agreement rather than the spirit of the agreement. In contrast, in the absence of incentive problems—when lives are also at risk—informal arrangements may be sufficient to induce

consummate performance. But, when uncertainty increases and partners have greater difficulty coordinating actions formal contracts provide structures that make the actions each partner will take more predictable. Although this paper takes a step towards identifying coordination problems separate from incentive problems, further effort is required to understand how and when coordination and motivation problems exert independent and joint effects on behavior. It also suggests that research should consider how multiple objectives with different organizational demands are incorporated into designs.

Organization design for coordination between partnered organizations under conditions of stochastic demand is important to organizations in a variety of settings. In particular, it is important to organization in settings where organizations are enmeshed in obligations and entitlements to other organizations such as in electricity producers involved in pooling arrangements or alliances among transportation suppliers such as airline, rail, and shipping companies. It is important to organizations in markets where demand is changes quickly or is fleeting and where resources investments must be made before these changes are revealed to managers in for instance the better-dress apparel business, in the hotel and resort businesses, and in healthcare and medicine. Organizations in these industries are regularly faced with capacity decisions that entail substantial uncertainty and risk as well as the possibility of engaging in alliances to address resource problems. Under these circumstances coordination problems arise from uncertainty about demand, partner behavior, and the management of larger resources bases. This research provides provides an explanation of when and how these problems arise and are resolved through two different organizational designs. And, it implies that resources configurations operate in an inter-organizational context, that formal and informal arrangements deliver different kinds of performance, and that collaboration architecture simultaneously affects multiple objectives. And, for fire departments, this implies that performance depends on the extent to which managers balance efficiency and flexibility through the choice of resource investment levels and arrangements for coordinating resources

with partners. However, these findings focus on value creation and do not generalize well to understand how aspects of organization design intended to deal with coordination problems interact with those meant to address value capture problems.

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Table 1: Summary Statistics

Dependent Variables	Description	Mean	Std. Dev.	N
Property damage	US$ loss of property (deflated)$_{d,t}$	353,249	1,593,092	29714
Injury & death	# civilian and firefighter injuries and deaths$_{d,t}$	1.39	4.99	29714

Independent Variables	Description	Mean	Std. Dev.	N
Aid received	# firefighter runs received from partners$_{d,t}$	76.31	158.65	29714
Formal contract	Indicator for presence of automatic aid$_{d,t}$	0.57	0.49	29714
Uncertainty	SD(daily firefighter runs)$_{d,t}$	1.62	0.63	29714
Slack resources	Ratio of # firefighters$_{d,t}$ to $p95^{th}$ daily firefighter runs$_{d,t-1}$	2.32	12.69	29714
Aid given	# firefighter runs given to partners$_{d,t}$	52.26	105.79	29714
Firefighter hours	# firefighter hours spent fighting fires$_{d,t}$	92,159	6,195,245	29714
Apparatus hours	# Apparatus hours deployed fighting fires$_{d,t}$	40,421	2,463,159	29714
Residential structure fires	# fires in residential buildings$_{d,t}$	13.32	40.85	29714
Non-residential structure fires	# fires in non-residential buildings$_{d,t}$	8.15	15.48	29714
Outside fires	# non-structure fires	38.66	98.58	29714
Year		2004	1.93	29714

Instrumental Variables	Description ($\mathcal{F}_d \equiv$ partner set for department d)	Mean	Std. Dev.	N
Intra-network aid	$\sum_{p \neq d, p \in \mathcal{F}_d} \sum_{k=0}^{1}$ interactions$_{p,t-k}$	78.59	251.13	29714
Partner distance	$\sum_{p \neq d, p \in \mathcal{F}_d}$ # miles travelled$_{p,t}$ excluding aid to d	1256	3581	29714
Border fires	$\sum_{p \neq d, p \in \mathcal{F}_d}$ # fires $> p80^{th}$ distance from headquarters$_{p,t}$	147.05	280.91	29714
Partner fires	$\sum_{p \neq d, p \in \mathcal{F}_d}$ # own fires$_{p,t}$	445.85	695.61	29714

Table 2: OLS regression: aggregate annual performance

Dep Var	(1) Property damage	(2) Property damage	(3) Injury & death	(4) Injury & death
Model	FE	LD	FE	LD
Estimator	OLS	OLS	OLS	OLS
Unit of analysis	d,t	d,t	d,t	d,t
Aid received	0.725***	0.563***	-0.011***	-0.042***
	(0.046)	(0.038)	(0.004)	(0.006)
(P1A) Uncertainty	0.648***	0.510***	-0.023***	-0.028**
	(0.104)	(0.086)	(0.008)	(0.013)
(P1B) Aid received × uncertainty	-0.150***	-0.125***	0.010***	0.021***
	(0.023)	(0.019)	(0.002)	(0.004)
(P2A) Formal contract	-0.295	-0.555***	0.021	0.004
	(0.189)	(0.145)	(0.013)	(0.017)
(P2B) Formal contract × uncertainty	0.117	0.176**	-0.007	-0.007
	(0.096)	(0.079)	(0.008)	(0.012)
Department FE	Yes	No	Yes	No
Lagged DV	No	Yes	No	Yes
Year FE	Yes	Yes	Yes	Yes
State-time trends	Yes	Yes	Yes	Yes
Controls	F(7)=54.5	F(7)=131.6	F(7)=12.3	F(7)=94.4
R^2	0.110	0.461	0.661	0.830

All specifications include additional controls: *slack resources*, *man hours*, *apparatus hours*, *aid given*, *residential structure fires*, *commercial structure fires*, and *outside fires* tested with composite linear hypotheses. The coefficients on these variables are not reported but are available upon request. Unit of analysis is the department (d) year (t). State-time trends include first and second order terms. Robust standard errors in parentheses clustered on 7,202 departments. $^+ p < 0.10$, $^{**} p < 0.05$, $^{***} p < 0.01$, n=29,714.

Table 3: IV regression: aggregate annual performance

Dep Var	(1) Property damage	(2) Property damage	(3) Injury & death	(4) Injury & death
Model	FE	LD	FE	LD
Estimator	2SLS	2SLS	2SLS	2SLS
Unit of analysis	d,t	d,t	d,t	d,t
Aid received	2.789***	1.534***	-0.016	-0.128**
	(0.421)	(0.349)	(0.029)	(0.051)
(P1A) Uncertainty	0.779**	1.141***	-0.055	-0.178***
	(0.390)	(0.292)	(0.045)	(0.042)
(P1B) Aid received × uncertainty	-0.623***	-0.538***	0.022	0.101***
	(0.152)	(0.160)	(0.018)	(0.024)
(P2A) Formal contract	-1.021	-4.171***	0.037	0.050
	(1.571)	(1.279)	(0.117)	(0.165)
(P2B) Formal contract × uncertainty	0.793**	0.891	-0.027	-0.231**
	(0.384)	(0.656)	(0.043)	(0.090)
Department FE	Yes	No	Yes	No
Lagged DV	No	Yes	No	Yes
Year FE	Yes	Yes	Yes	Yes
State-time trends	Yes	Yes	Yes	Yes
Controls	$\chi^2(7)=112.1$	$\chi^2(7)=371.3$	$\chi^2(7)=17.0$	$\chi^2(7)=217.5$
Hansen J-test (p-value)	0.355	0.003	0.785	0.647

All specifications estimated by two-stage least squares treating *aid received*, *formal contract*, and their interactions as endogenous. Excluded instruments include *network flow*, *partner distance*, *partner fires*, *border fires*. All specifications also include additional controls: *slack resources*, *man hours*, *apparatus hours*, *aid given*, *residential structure fires*, *commercial structure fires*, and *outside fires* tested with composite linear hypotheses. The coefficients on these variables are not reported but are available upon request. State-time trends include first and second order terms. Unit of analysis is the department (d) year (t) level. Robust standard errors in parentheses clustered on 7,202 departments. $^{+}$ $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$, n=29,714.

Figure 1: Aid interactions per department
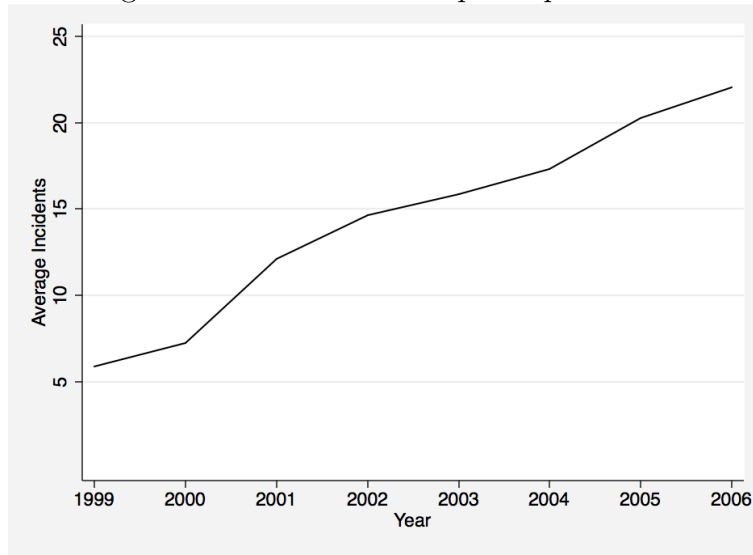
This graph depicts the rise in aid interactions per department from roughly 5 runs per department in 1999 to more than 20 runs in 2006 for 7,202 sampled departments.

Figure 2: Spread of formal contracts
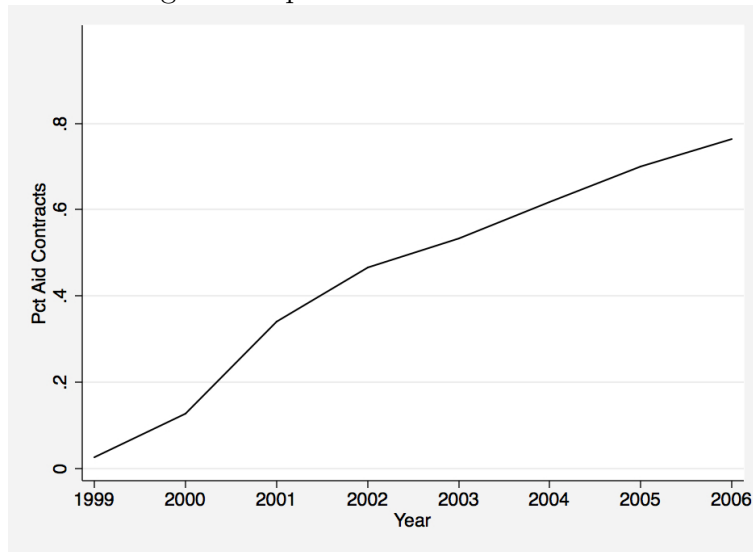
This graph depicts the spread of automatic aid for sampled departments for 7,202 sampled departments.

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Appendix

Table A-1: First-stage results: aggregate annual performance

Dep Var Model Estimator	(1) Aid received Fixed effect OLS	(2) Aid received Distributed lag OLS	(3) Contract Fixed effect OLS	(4) Contract Distributed lag OLS
Uncertainty	0.648***	0.493***	-0.020***	-0.029***
	(0.026)	(0.0277)	(0.005)	(0.007)
Intra-network aid	0.019$^+$	0.169***	0.023***	0.025***
	(0.011)	(0.010)	(0.003)	(0.003)
Aid distance	-0.057***	-0.107***	-0.021***	-0.001
	(0.021)	(0.026)	(0.005)	(0.007)
Border fires	0.247***	0.057***	0.012$^+$	0.002
	(0.027)	(0.022)	(0.007)	(0.006)
Partner fires	0.049***	0.119***	0.001	0.019***
	(0.015)	(0.013)	(0.003)	(0.003)
Year FE	Yes	Yes	Yes	Yes
State-time trends	Yes	Yes	Yes	Yes
Controls	Yes	Yes	Yes	Yes
R^2	0.28	0.34	0.42	0.35
F-stat (excluded instruments)	24	184	18	62

Note: controls not displayed include slack resources, man hours, apparatus hours, residential structure fires, commercial structure fires, and outside fires tested with composite linear hypotheses. State-time trends include first and second order terms. Robust standard errors in parentheses clustered on 7,202 departments. $^+$ $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$, n=29,714. $^+$ $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$

Table A-2: County-time trends: aggregate annual performance

Dep Var	(1) Property damage	(2) Property damage	(3) Property damage	(4) Property damage
Model	FE	LD	FE	LD
Estimator	OLS	OLS	2SLS	2SLS
Unit of analysis	d,t	d,t	d,t	d,t
Aid received	0.740***	0.616***	1.574	1.616***
	(0.062)	(0.056)	(1.028)	(0.490)
(P1A) Uncertainty	0.620***	0.448***	0.977	0.459
	(0.134)	(0.120)	(0.756)	(0.348)
(P1B) Aid received $\times$ uncertainty	-0.157***	-0.138***	-0.447**	-0.314+
	(0.031)	(0.027)	(0.212)	(0.172)
(P2A) Formal contract	-0.450+	-0.619***	-0.194	-4.061**
	(0.256)	(0.213)	(1.517)	(1.591)
(P2B) Formal contract $\times$ uncertainty	0.259**	0.254**	0.796	0.338
	(0.130)	(0.115)	(0.661)	(0.468)
Department FE	Yes	No	Yes	No
Lagged DV	No	Yes	No	Yes
Year FE	Yes	Yes	Yes	Yes
County-time trends	Yes	Yes	Yes	Yes
Controls	F(7) = 34.8	F(7) = 79.4	$\chi^2(7)$=60.9	$\chi^2(7)$=121.2
Observations	15217	15217	15217	15217
Obs - Parameters	14512	14503	14512	14503
# Departments	3430	3430	3430	3430
R^2	0.199	0.514	n/a	n/a

Note: Sample restricted to departments from 9 states with most number of observations from the sample above. Controls not displayed include slack resources, man hours, apparatus hours, residential structure fires, commercial structure fires, and outside fires tested with composite linear hypotheses. Instruments include intra-network aid, partner distance, partner fires, border fires. State-time trends include first and second order terms. Unit of analysis: d = focal department, t = year. Robust standard errors in parentheses clustered on departments. + $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$

Table A-3: Incident-level performance comparisons

Dep Var	(1) Property damage	(2) Property damage	(3) Property damage	(4) Property damage	(5) Property damage	(6) Property damage
Model	FE	FE	FE	FE	FE	FE
Estimator	OLS	OLS	OLS	OLS	OLS	OLS
Unit of analysis	j,k,i	j,k,i	j,k,i	j,k,i	j,k,i	j,k,i
(P2A) Contract	-0.308***	-0.303***	-0.314***	-0.126***	-0.163***	
	(0.051)	(0.052)	(0.052)	(0.044)	(0.046)	
(P2A) Contract (Zip)						-0.159***
						(0.042)
Fire personnel		0.059***	0.057***	0.054***	0.053***	0.053***
		(0.005)	(0.005)	(0.004)	(0.003)	(0.003)
Fire apparatus		0.057***	0.058***	0.077***	0.080***	0.080***
		(0.015)	(0.015)	(0.010)	(0.008)	(0.008)
Constant	1.062***	0.619***	1.116***	0.760***	0.765***	0.753***
	(0.041)	(0.066)	(0.099)	(0.059)	(0.061)	(0.059)
Time of day FE	No	No	Yes	Yes	Yes	Yes
Month of year FE	No	No	Yes	Yes	Yes	Yes
Partner-pair FE	No	No	No	Yes	No	No
Partner-pair-Zip FE	No	No	No	No	Yes	Yes
# clusters	27243	27243	27243	27243	42075	42075
R^2	0.003	0.018	0.026	0.026	0.026	0.026

Sample includes all individual instances of collaboration for the sampled departments where there are at least two incidents for each pair of partners in a particular Zip code. All specifications are with the unit of analysis at the partner-pair (j,k), Zip code (z), date (t), incident (i) level. Robust standard errors in parentheses clustered on department pair and department ZIP code pair. Unit of analysis: j = focal department, k = partner, i = incident. [+] $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$, n=136,656.