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To cite this article: Kaddour Mehiriz (2020): The sources of municipalities' innovation in the management of weather disaster risks, their relationships, and their antecedents, Local Government Studies, DOI: [10.1080/03003930.2020.1816545](https://doi.org/10.1080/03003930.2020.1816545)

To link to this article: <https://doi.org/10.1080/03003930.2020.1816545>



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Published online: 08 Sep 2020.



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# The sources of municipalities' innovation in the management of weather disaster risks, their relationships, and their antecedents

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## ABSTRACT



This article presents the results of a study on the use of internal and external sources of innovation by municipalities to deal with weather hazards. Using data collected by an online survey of municipal emergency management coordinators in Quebec – Canada, this study shows that municipalities rely primarily on their expertise and, to a lesser extent, on peer organisations and upper levels of governments to develop new solutions to weather hazards. In addition, this study finds weak support for the complementarity hypothesis between internal and external sources of innovation and suggests strongly that these sources of innovation are not substitutable. The capacity and vulnerability of municipalities, as well as political support for initiatives to improve the management of weather disasters, seem to be significant drivers of innovation. Finally, efforts aimed at strengthening public organisations' internal capacities and creating incentives to facilitate collaborations between public organisations are important levers to stimulate innovation.

**KEYWORDS** Internal sources of innovation; external sources of innovation; complementarity between innovation sources; climate change adaptation; weather disasters; municipalities; Canada


## Introduction

Climate change is accompanied by an increase in the frequency and severity of extreme weather events that in many cases have profoundly disrupted social and ecological systems (Guidotti 2006; Mehl and Tobaldi 2004). Local governments are at the forefront of efforts to adapt to climate change and, consequently, are under huge pressure to adjust to the new situation by introducing new policies, technologies and practices in a context of resource scarcity and increased population demands for high quality services (Mehiriz

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 Supplementary material for this article can be accessed [here](#).

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and Gosselin 2016). This is not an easy task as climate change consequences are multiple, interconnected and felt at different sectors and scales; a complex situation calling for the collaboration between a myriad of public and private organisations (Bednar, Henstra, and McBean 2019; Ostrom 2010).

There is currently a substantial and growing body of research on innovation in the public sector (see the special issue of the *International Review of Administrative Sciences*: 2018, vol. 84, issue 2). This stream of research has so far focused on understanding the forms, antecedents and diffusion patterns of public sector innovation (De Vries, Tummers, and Bekkers 2018). However, and contrary to research on private sector innovation (Giacomara et al. forthcoming, Laursen and Salter 2004; Hanel and St-Pierre 2006), few studies have analysed the frequency of using innovation sources and their impacts (Bloch and Bugge 2013; Brannan et al. 2008, Demircioglu 2017). Also, I am not aware of any study on the relationships between the sources of public sector innovation. This is an important gap of knowledge as it is difficult to design policies to stimulate innovation in general, and adaptation to climate change in particular, without prior evidence on how organisations use different sources of knowledge in their innovation process.

The objective of this article is to contribute to fill this gap by presenting the results of an empirical study on the sources of innovation used by municipalities in the management of extreme weather events. Innovation studies distinguish between strategies relying mainly on internal sources of knowledge (closed model of innovation) and strategies based not only on internal sources, but also on the expertise found in the environment of organisations such as research organisations, suppliers and customers (open model of innovation) (Chesbrough 2003; Enkel, Gassmann, and Chesbrough 2009). This typology was adapted in this study to the particularities of the management of weather disaster risks and used to provide responses to the following three questions:

What are the sources of innovation used by municipalities in weather disaster risk management?

What is the relationship between these sources of innovation? Are they complementary, substitutable or independent?

What is the association between municipalities' characteristics and the use of innovation sources?

Data were obtained from an online survey of emergency management coordinators of municipalities ( $n = 233$ ) in the province of Quebec – Canada. The results of this study show that municipalities rely primarily on their expertise and, to a lesser extent, on the inputs from peer organisations and upper levels of government. By contrast, they rarely use the expertise of academic institutions in their innovation process. The findings also suggest the presence of weak complementarity between internal and external sources of innovation. In addition, the capacity and vulnerability of

municipalities and the political support for efforts to improve weather disaster risk management seems to have an important effect on the use of innovation sources.

The structure of this paper is as follows. The theoretical framework of this study is the subject of the first section. The study methodology and results are reported in the second and third sections, respectively. The article ends with a discussion and policy implications of the findings.

## Theoretical framework

Rogers (2003) defines innovation as an idea, object or practice that is considered new by the adopting organisation. Innovation is either generated internally or imported by organisations from their environment (Damanpour and Schneider 2009). It is usually represented as a 3-phase process: 1) identification and diagnosis of the problem, 2) research of new solutions and 3) experimentation and adoption of the selected option (Berkhout, Hertin, and Gann 2006). In the domain of weather disaster risk management, these phases correspond to the evaluation of extreme weather risks, research of solutions to tackle them and, finally, selection and implementation of the most effective responses (ICLEI Canada 2013). The focus of this study is on the first two steps of this innovation process.

## Innovation sources and their relationships

Research on the private sector distinguishes between innovation strategies relying mainly on internal resources and expertise of organisations (closed innovation model) and strategies combining internal sources with the expertise found in their environment (open innovation model) (Chesbrough 2003; Enkel, Gassmann, and Chesbrough 2009). Organisations are notably presumed to use external sources extensively in the case of complex innovation projects because, for most of them, it is difficult to assemble within their boundaries the required expertise and technologies to design and execute these projects (Rothaermel and Hess 2007). In addition to expanding their knowledge base, organisations seek collaboration for the purpose of sharing innovation risks and internalising innovation spillovers (Veugelers 1997).

There is currently a manifest interest in studying the use of the open innovation model by public sector organisations (Demircioglu and Audretsch 2017; Mergel and Desouza 2013). The context of public sector organisations is assumed to be more favourable to the adoption of this model than the private sector. Compared to public organisations, private firms depend to a large extent for their survival on returns to investment of their innovation projects and, accordingly, are more cautious about protecting their technologies from imitation by their competitors (Bloch and Bugge

2013; Hartley, Sørensen, and Torfing 2013). The imitation risk thus limits their appetite for sharing their expertise with other firms. In addition, subnational governments should comply with the requirements of upper-level governments such as the enactment of new zoning rules prohibiting residential development in areas at risk of flooding (coercive isomorphism). They are also tempted to emulate the innovations of leading organisations in their field (mimetism isomorphism) and adopt the norms shared by the professionals in disasters risk management (normative isomorphism) (DiMaggio and Powell 1983, Berry and Berry 2014). These external pressures push public organisations to import solutions available in their environment.

The first generation of innovation studies maintained that internal and external sources of innovation are substitutable. The availability of external sources of knowledge discourages internal investment in R&D (Veugelers 1997), which raises the classic problem of free riding discussed at length in the economics of innovation (Salter and Martin 2001; Mehiriz and Marceau 2015). Transaction costs theory also sustains that the choice between undertaking innovation projects internally or contracting them out depends on the respective benefits and costs of these options. Inhouse innovation is preferred when transaction costs, including the cost of negotiating and monitoring the execution of innovation contracts, out-passes outsourcing benefits (Giacomarra et al. *Forthcoming*). Some empirical studies however have shown a positive correlation between internal and external sources of innovation in the private sector (Giacomarra et al. *Forthcoming*). This paradox was resolved by introducing the concept of capacity absorption (Cohen and Levinthal 1990). According to this perspective, organisations should develop their innovation capacity that enables them to screen, understand and use effectively the pool of knowledge available in their environment. Also, to be considered as a competent and dependable partner in innovation networks, an organisation should demonstrate its capacity of producing and sharing new ideas and practices of interest for network members (Veugelers 1997). It is thus advantageous for an organisation to build its internal innovation capacity even if, in the short-term, this investment seems to be counterproductive (Denicolai, Ramirez, and Tidd 2016). The capacity absorption model, therefore, predicts the existence of complementarity between internal and external sources of innovation rather than substitutability. Complementarity exists if the increase of the use of one innovation source enhances the marginal return of the use of the other source (Cassiman and Veugelers 2006).

Compared to the rich strand of research on innovation sources and their relationships in the private sector, it is striking to note how rare research on this topic in the public sector is. In fact, most studies on this theme used the innovation diffusion model, notably to understand the spread of new policies and programmes across subnational governments in USA (Berry and Berry

2014). These studies have shown that a subnational government's decision to introduce new policies and programmes is influenced by the orientations and practices of the federal government and the experiences of other subnational governments. However, subnational and local governments are embedded in an environment that includes other public and private organisations whose influence on their innovation activities should be understood as well. In a study on Scandinavian countries, Bloch and Bugge (2013) used survey data on the collaboration of public organisations in general with private firms, research organisations and other public sector organisations and found significant differences between the countries in the use of innovation sources. The percentage of organisations having collaboration with the private sector range between 42% and 76%. This percentage varies between 12% and 39% in the case of collaborations with research and public organisations. On the same topic, Brannan et al. (2008) shows that professional staff is considered as the most important source of innovation in regeneration and safety programs managed by English local authorities. This study also reveals that partnership organisations and other public organisations are important sources of innovation. By contrast, a minority of study participants considered external experts, such as academic researchers and consultants, to have an important impact on innovation activities of their organisations. While related to the general topic of this article, these studies were not focused on the practices of local governments in the matter of weather disaster risk management. The relationship between innovation sources were not among their objectives, either.

In this article, a distinction is made between internal and external sources of innovation. In addition, external sources are subdivided into four categories. The first category is composed of research organisations, the source of innovation most studied by research on the private sector. The second source refers to public sector organisations. Following the innovation model, a distinction is made within the public sector between the horizontal and vertical sources of innovation (Berry and Berry 2014). Horizontal sources designate the use of peer organisations' knowledge as inputs in the innovation process while vertical sources refer to the transfer of knowledge and expertise from upper levels of governments. As discussed in the methodology section, the list of organisations selected as eventual sources of innovation was based on a careful consideration of organisations with a stake in the management of weather disaster risk management in Quebec, Canada.

### **Antecedents of innovation in weather disaster risk management**

Literature on public innovation has identified three categories of factors associated with the likelihood of adopting an innovation; these are organisations' characteristics, their external environment, and the complexity and expected outcomes of innovations (De Vries, Bekkers, and Tummers 2016).

Regarding the external environment, literature has shown that vulnerability and political support are among the principal drivers of preparedness for extreme weather events (McGuire and Silvia 2010; Mehiriz and Gosselin 2016). The reason being is that public organisations act on behalf of the population and thus are expected to respond positively to its demands that, in democratic systems, are expressed directly or indirectly via elected officials. As the frequency of using internal and external sources of innovation reflects an organisation's efforts to respond to external pressures for improving the management of weather disaster risks, vulnerability and political support are presumed in this study to be positively associated with the use of all innovation sources.

As for organisations' characteristics, research on the private sector has found a positive correlation between indicators measuring the absorptive capacity of firms, such as firm size and number of scientific employees, and collaborations with research organisations (Bekker and Freitas 2008; Giuliani and Arza 2009). However, a more nuanced distinction needs to be made in the case of the public sector. As is the case with private firms, large public organisations could reasonably be assumed to rely more on their internal sources and on collaborations with research organisations in their innovation process, thanks to their strong absorptive capacity. For the same reasons, they are likely to be among innovation leaders of their sector and, as indicated by the diffusion model, their practices could be imitated by smaller organisations (Berry and Berry 2014). Accordingly, a negative association between organisations' capacity and the use of knowledge from peer organisations is posited in this study. In the same vein, it is predicted that organisations with insufficient internal capacity are more dependent on help from the upper levels of government in comparison to large organisations.

In sum, it is proposed in this study that most municipalities will adopt a hybrid model of innovation combining internal and external sources of innovation to deal with extreme weather events. Internal and external sources of innovation are supposed to be complementary in the sense that the use of one source increases the effectiveness of the other. In addition, municipalities with strong absorptive capacity are expected to rely more on their internal sources and on collaboration with research organisations compared to those with weak capacity. They are also supposed to be less likely to use the technical support provided by upper levels of government and to emulate the practices of their peer organisations. Finally, the levels of vulnerabilities and political support would be positively associated with the use of all sources of innovation.

## **Data and methods**

An online survey was used to collect data from emergency management coordinators of municipalities in the province of Quebec – Canada between April 15 and 31 May 2014. Emergency management coordinators are responsible for preparing and implementing the emergency management plans of their organisations and thus are presumed to have accurate information on innovation strategies adopted to cope with weather disasters. The first draft of the questionnaire was reviewed by regional emergency management coordinators of the Quebec Ministry of Public Security (QMPS), and their comments were included in the final version of the questionnaire. An invitation letter was then sent to all municipal emergency management coordinators. After 3 reminders, 233 municipal emergency management coordinators responded to the survey, corresponding to 23% of Quebec municipalities. In addition to the online survey, data on the number of employees and property value of municipalities were extracted from the annual financial reports of municipalities available on the website of the Quebec Ministry of Municipal Affairs and Habitation.

## **Measurement of innovation sources**

### ***Internal innovation sources***

The objective of this study is to analyse the use of internal and external sources of innovation in the management of weather disaster risks by municipalities. The frequency of using the expertise of municipalities' employees was used as an indicator of the use of internal sources of innovation.

### ***External sources of innovation***

External sources of innovation were subdivided into two categories: public organisations and research organisations. Data were collected on the inputs from public organisations that are involved in the management of weather disaster risks: QMPS, Quebec Ministry of Health and Social Services (QMHS), Environment Canada (EC) and municipalities. As parts of the system of weather disaster risk management in Quebec, these organisations are presumed to exert notable influence on innovation activities of municipalities. Research organisations were for their part grouped together into three categories: public research and expertise centres, universities and community colleges, and private engineering firms.

In the survey of emergency management coordinators, a four-level scale was used to collect data on the frequency of obtaining the help of each type of organisation in 1) assessing the risks of weather disasters and 2) developing new solutions to mitigate them (1 = never to 4 = very often).



## **Covariates of the use of innovation sources**

In this study, three factors that presumably have an impact on the frequency of using innovation sources were taken into consideration: innovation capacity of municipalities, their vulnerability to extreme weather events and political support for initiatives aimed at reducing the risks of weather disasters.

### ***Innovation capacity***

The number of employees and property value were used as proxies for innovation capacity because innovation projects require the mobilisation of the expertise and financial resources of municipalities.

### ***Vulnerability***

Vulnerability to weather disaster was measured by the sum of the perceived risks of 8 extreme weather events (1 = very low to 5 = very high): heat waves, smog episodes, cold spells, heavy rain, snowstorms, ice storms, thunderstorms and floods.

### ***Political support***

Political support was measured by the sum of the responses to 2 items: level of elected officials concerns regarding weather disasters (1 = not at all important to 4 = very important) and level of elected officials' support for efforts to mitigate weather disaster risks (1 = very weak to 5 = very strong).

The Cronbach alpha that was used to measure the internal consistency of the items constituting the variables vulnerability and political support takes the value of 0.79 for the first variable and 0.82 for the second. The internal consistency of these variables is thus very satisfactory.

## **Methods of data analysis**

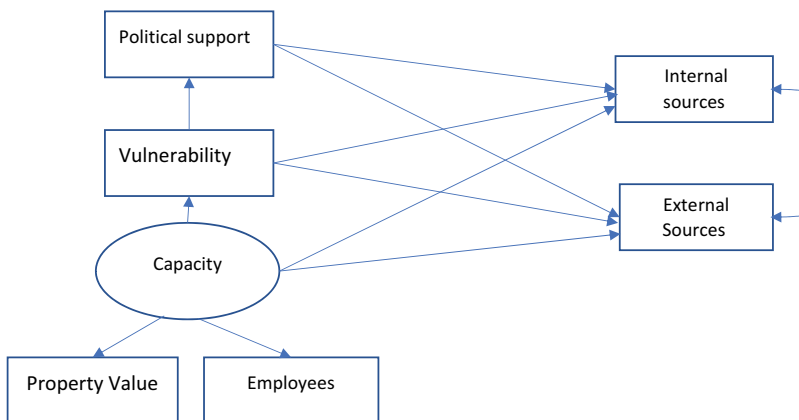
The use of innovation sources was measured by ordinal scales, so frequency distribution was used to analyse the magnitude of using these sources.

In this study, complementarity between two sources of innovation is understood as the situation in which the use of one source increases the effectiveness of using the other one. A positive correlation is not a strong evidence of the presence of synergies between innovation sources (Cassiman and Veugelers 2006). Indeed, an organisation experiencing intense pressure to innovate could increase the use of all innovation sources even if the use of one source has no impact on the performance of the other sources. To rule

out this possibility, I tested in this study the correlation between the frequency of using innovation sources while adjusting for the aforementioned antecedents of innovation. Structural equation modelling (SEM) was used for this purpose because this framework is convenient for measuring the covariance between innovation sources after partialling out the variance explained by the antecedents of innovation (Preacher 2006). The SEM also allows for measuring the direct and indirect effects of innovation antecedents as indicated in the SEM model of this study presented in Figure 1.

This study tested the partial correlations between internal sources with three categories of external sources of innovation as well as the correlations between the latter (see Table 3). As it is cumbersome to depict in one figure the links between all these variables, only the relationship between internal and the broad category 'external sources' of innovation is illustrated in Figure 1.

Concerning the covariates of the use of innovation sources, municipal capacity is considered in the model as a latent variable measured by a linear combination of the property value and number of employees of municipalities. Municipal capacity is supposed to have a direct impact on the frequency of using innovation sources. The variables used to measure municipal capacity could also be considered as proxies for municipality size. For instance, data from this study indicate that the correlation between the number of employees and the population is equal to 95%. As large cities are particularly vulnerable to weather disasters (Hanjürgens and Heinrichsl 2014; Mehiriz and Gosselin 2016), municipal capacity is presumed to have an indirect effect on the use of innovation sources through its relationship with municipal vulnerability. Vulnerability is also supposed to have a direct



**Figure 1.** The SEM model used to test the antecedents of and partial correlations between innovation sources.

effect on the use of innovation sources and an indirect effect through garnering political support for initiatives to mitigate the effect of extreme weather events. As illustrated in the model, the control of the effects of these variables allows for testing the correlations between the residuals of the variables measuring the frequency of using innovation sources (partial correlations).

In the SEM, the use of internal sources was measured by the sum of the frequencies of using municipalities' employees in the evaluation of the vulnerability and in developing new solutions to extreme weather events. External sources of innovation were grouped together into 3 variables. The first variable Municipality measures the frequency of using the help of other municipalities. The second variable Upper-level Governments is related to the use of the upper levels of governments' help to innovate, namely the QMPS, QMHSS and EC. Following literature on the innovation diffusion model (Berry and Berry 2014), this distinction between these two categories of external sources of innovation is intended to measure the horizontal and vertical influences of public sector organisations. The third variable, Research Organisation, measures the use of the expertise of public research and expertise centres, universities and community colleges, and engineering firms. Summative indexes were used to measure these variables and Cronbach Alfa to test their internal consistency. For instance, the variable Municipality is the sum of the frequencies of using the help of other municipalities to assess the vulnerability to extreme weather events and in developing new solutions. The Cronbach alphas of the variables Internal Sources, Municipalities, Upper-level Governments and Research Organisations range between 0.76 and 0.90 and thus are higher than the level generally considered as satisfactory (0.69).

Some studies on private firms have tested the complementarity hypothesis by using a regression model in which the dependent variable is a selected indicator of a firm's performance. In addition to external and internal sources, the model includes an interaction term between these sources that is intended to measure the additional effect of using them jointly on the performance of the firms (Cassiman and Valentini 2016; Cassiman and Veugelers 2006). It was not possible in this study to use this method because data on the performance of emergency management services are not available. The method used here is thus an indirect test of the complementarity hypothesis (Cassiman and Veugelers 2006). It rests on the assumption that municipalities use both sources of innovation if the use of one source increases the performance of the other. This is a reasonable assumption as long as municipalities act quite rationally and possess enough information on the additional effects of using multiple sources of innovation. But in an uncertain world, the perception of the reality is probably distorted and thus it is more accurate to interpret a positive correlation as the expression of

perceived rather than real complementarity between innovation sources. Among the other limits of this study, it is difficult to control effectively for endogeneity in the case of cross-sectional studies using non-experimental designs.

## Study results

### *Sources of innovation*

Table 1 shows that municipalities use a variety of sources at different levels in their innovation process. In the first place, a strong majority of municipalities frequently use their internal sources in the assessment of their vulnerability to extreme weather events (73%) and search for new solutions to tackle them (80%). This is followed by the use of the help of the QMPS in the two stages of their innovation process (41 and 51%). Other municipalities also seem to be significant sources of innovation as 26% of the respondents affirm using them frequently in risk assessment and 33% in finding new solutions. Data also indicate that 21% of municipalities use the expertise of public research centres in assessing the vulnerability and 16% in searching new solutions. Even if this source of innovation is used by a low proportion of municipalities, it remains important when compared to the frequency of using the expertise of universities and CEGEPs (2 and 3%).

Data from this study thus suggest that municipalities rely principally on their internal sources of innovation. They are also exposed to the influence of vertical and horizontal sources of innovation, notably the help provided by the QMPS and other municipalities.

### Relationships between innovation sources

The descriptive statistics of the variables used in the SEM are presented in Table 2.

**Table 1** Sources of municipal innovation in the management of extreme weather events.

Sources	Assessment of weather disaster risks (often to very often)	Development of new solutions (often to very often)
Staff of the municipality	73%	80%
QMPS	41%	51%
Other municipalities	26%	33%
Public centres of research and expertise	21%	16%
QMHSS	16%	13%
Environment Canada	13%	12%
Private engineering firms	6%	12%
Universities and CEGEPS	2%	3%

**Table 2.** Descriptive statistics of the variables used in the SEM.

Variable	Obs.	Mean	Min	max
Upper-level governments	205	12.24	6	24
Municipalities	211	4.19	2	8
Research organisations	209	9.25	6	24
Internal sources	211	6.08	2	8
Political support	213	6.27	2	9
Vulnerability	207	24	11	37
Log employees	212	3.27	0.34	7.99
Log property value	212	19.09	14.9	24.3

The results of the SEM used to test partial correlations between innovation sources are presented in [Table 3](#). Standardised coefficients are reported because the standardisation of covariances allows to obtain Pearson correlations between innovation sources.

The second column of [Table 3](#) presents Pearson correlations between innovation sources before controlling for the covariates. It indicates that all the correlations are positive and statistically significant ( $p$ .value < 0.1). The coefficients of correlations between external sources range from 0.25 to 0.51 and are thus higher than the coefficients of correlations between internal and external sources [0.13–0.32].

A positive correlation provides weak support for the complementarity hypothesis between innovation sources, for it is possible that sources are mutually independent but driven in the same direction by a third factor. To rule out this possibility, 3 covariates of innovations were introduced in the model, namely, innovation capacity of municipalities, vulnerability of municipalities to extreme weather events and the political support for efforts to deal with these events. The analysis shows that the correlations between internal and external sources of innovation are very sensitive to the introduction of the covariates. The partial correlation between using internal sources and using sources from other municipalities is still positive and statistically significant, which lends support to the idea that these sources of innovation are complementary. However, the partial correlations of internal sources with the variables Research Organisations and Upper-level Governments are not statistically significant. Internal sources thus seem to be independent rather than complementary to or substitutable for these external sources of innovation. The partial correlations between external sources of innovation are positive, suggesting the presence of complementarity between them.

Data thus suggest that there is at best a weak complementarity between internal and external sources of innovation. By contrast, a strong correlation between the external sources persist, even after controlling for innovation covariates. This pattern points to the existence of synergies between external sources of innovation.

**Table 3.** Covariance between innovation sources, and their relationships with municipalities' characteristics.

Variables	Standardised coefficients	Standardised coefficients
<b>Internal sources</b>		
Capacity	-	0.17**
Vulnerability	-	0.09
Political support	-	0.24***
<b>Research organisations</b>		
Capacity	-	0.33***
Vulnerability	-	0.10
Political support	-	0.16**
<b>Municipalities</b>		
Capacity	-	-0.21***
Vulnerability	-	0.31***
Political support	-	0.31***
<b>Upper-level Governments</b>		
Capacity	-	0.10
Vulnerability	-	0.15**
Political support	-	0.31***
<b>Vulnerability</b>		
Capacity	-	0.31***
<b>Political support</b>		
Vulnerability	-	0.26***
<b>Measurement of capacity</b>		
Log of property value	-	0.95***
Log employees	-	0.94***
<b>Correlation between sources of innovation</b>		
Corr. Internal – Municipalities	0.32***	0.27***
Corr. Internal – Research Organisations	0.13*	-0.021
Corr. Internal – Upper-level governments	0.22***	0.08
Corr. Research organisation- Municipalities)	0.25***	0.2***
Corr. (research organisations; Upper-level governments)	0.49***	0.47***
Corr. (municipalities; Upper-level governments)	0.51***	0.42***
<b>N</b>	188	187
LR test chid 2	-	6.02
RMSEA	-	0.004
CFI	-	1.00
CD	-	0.94

\* means p.value <0.1, \*\*, p.value < 0.05 and \*\*\* p.value < 0.01

### Antecedents of the use of innovation sources

As expected, [Table 3](#) indicates that the variable Political Support is associated with the use of all sources of innovation, meaning that emergency management services benefiting from strong support from their elected officials are actively involved in mobilising all sources of innovation to improve their interventions. Political leadership is thus an important driver of innovation. Vulnerability has positive associations with the variables Upper-level Governments and Municipalities but not with the variables Internal Sources and Research Organisations. Vulnerable municipalities thus have a higher tendency to seek external sources of expertise to nurture their innovation process compared to less vulnerable ones.

The variable Capacity also behaves as predicted, in general. Municipal capacity is positively associated with the use of internal sources as well as with the use of research organisations' expertise. Furthermore, municipalities with strong capacity are less likely to use the help of other municipalities because they are probably the leaders of their sector and, accordingly, are more likely to be imitated by weak-capacity municipalities. A negative association was predicted between municipal capacity and the use of the help of the upper level of governments. However, this assumption is not supported by the facts as the coefficient of association between the variables Capacity and Upper-level Governments is not statistically significant.

## Discussion and conclusion

The objective of this study is to analyse the sources of innovation used by municipalities in their innovation process, the relationships between these sources, and their antecedents. The results of this study indicate that, while municipalities use a variety of innovation sources, they rely primarily on the expertise of their employees to devise new solutions to weather disasters, a result that is comparable to that obtained by Brannan et al. (2008) in their study on English local authorities. Employees are the core assets of public organisations and providing them with appropriate skills and incentives develops not only the organisations' internal innovation capacity but also their ability to take part in collaborative innovation projects, as suggested by the capacity absorption model (Cohen and Levinthal 1990, Demircioglu and Audretsch 2018). The development of internal innovation capacity should thus not lead to deliberately marginalising external sources, for these sources are needed in the design and implementation of complex innovation projects necessitating the mobilisation of specialised knowledge and expertise (Demircioglu and Audretsch 2018).

As for external sources, the public sector is supposed to constitute a propitious context for vertical and horizontal diffusion of innovations (Bloch and Bugge 2013). The reason being is that public organisations evolve in a less competitive environment than private firms and depend less for their survival on the return on investment of their innovation projects. They are thus less sensitive to the risks of imitation by other organisations (Hartley, Sørensen, and Torfing 2013). The institutional framework is also designed to avoid redundancy and to facilitate coordination and collaboration within the public sector. This cooperative rather than competitive environment therefore facilitates the sharing of knowledge and experiences, in principle. Public organisations are also inclined to imitate leading organisations of their policy sector not only because the new practices would enhance their performance but also because this would help them improve their image and legitimacy (DiMaggio and Powell 1983; Jun and Weare 2011).

In line with these theoretical arguments, this study found that upper levels of government are important actors in the municipalities' ecological system of innovation. The QMPS is notably at the top of the external sources of innovation, and this level of influence is expected since the QMPS is responsible for developing the provincial civil protection plan and coordinating the interventions of the organisations involved in its implementation. The QMPS also has the authority to set the norms of weather disaster risk management and, additionally, provides technical and financial support to the organisations to comply with them (Mehiriz and Gosselin 2016). The study also suggests that the horizontal flux of knowledge and expertise is a significant source of innovation. This situation is expected as municipalities, given their role as coordinators of the emergency management plans of their territory, are supposed to collaborate with other municipalities to find collective solutions to the problems that spill over their territories. As well, municipalities, particularly neighbouring municipalities, are confronted to a large extent by the same problems and thus can mutually benefit from sharing their innovations. As is the case of organisations in general, municipalities are inclined to adopt the practices of their peer organisations, notably of those considered as leaders in their sector (Dimaggio and Powel 1983). Municipalities thus have many incentives to share their experiences, and this horizontal flux of knowledge and expertise is encouraged by the existence of 3 municipal associations in Quebec: the Federation of Canadian Municipalities, the Union of Quebec Municipalities and the Federation of Quebec Municipalities.

The vertical and horizontal flux of knowledge could be less frequent in countries lacking an institutional framework and platforms designed to facilitate collaboration within the national system of the management of weather disaster risks. The role of this source of innovation may thus vary between political and administrative systems and, consequently, comparative studies are needed to test the impact of these differences on innovation strategies. In terms of the policy implications of this study, the development by the upper levels of government of an accessible pool of knowledge on the disaster risk management and production of guidelines and manuals on best practices would create a favourable context for innovation. Moreover, efforts aimed at creating incentives and platforms to facilitate horizontal and vertical collaborations and interorganisational learning are important levers to stimulate innovation in weather disaster risk management.

Concerning the influence of research organisations, this study finds that public research centres' expertise is by far more frequently used than that of universities. This difference could be explained by the fact that some public research and expertise centres such as the INSPQ, OURANOS and the Centre Hydrique du Quebec were created by the Quebec government to develop the expertise and conduct the applied research needed to solve actual and



emerging policy problems in this province. Their outputs therefore are more likely to be attuned to the needs of public sector organisations than universities. The low direct impact of universities on innovation is not unique to the public sector as studies on the private sector also show that a small proportion of firms have R&D collaborations with universities (Laursen and Salter 2004; Hanel and St-Pierre 2006). Deficiencies in the quality and relevancy of research products, and the incapacity of some users to access, understand and use effectively the available knowledge are frequently cited as among the barriers to knowledge transfer (Mehiriz and Marceau 2012). The two-communities theory of knowledge utilisation also indicates that top university researchers prefer investing their efforts in fundamental research rather than in applied research because fundamental research is more rewarding in terms of peer recognition and academic career development (Caplan 1979). While these arguments could help understand the underuse of academic research in general, studies exploring obstacles to collaboration between universities and municipalities in the domain of the management of weather disaster risks are still needed.

Concerning the relationship between innovation sources, this study found a weak support for the complementarity assumption between internal and external sources of innovation as there is only one out of three possible correlations that is statistically significant after controlling for innovation covariates. The absence of negative and statistically significant correlations between innovation sources also suggests the absence of substitution effect. The substitution effect is a source of concern because the availability of free external knowledge would induce municipalities to invest less in their internal sources of innovation. The internal and external sources of innovation are therefore more likely to be independent than complementary or substitutable. It should be noted that evidence on the complementarity hypothesis in the private sector is also mixed (Cassiman and Valentini 2016; Doloreux, Shearmur, and Rodriguez 2018). The positive outcomes of mixing innovation sources thus seems to be less important than what is presumed by innovation theories. By contrast, this study found moderate to strong correlations between external sources. Why external sources of innovation are strongly correlated while, at the same time, are independent of internal sources is an interesting subject of study. Likewise, and as suggested by one of the reviewers of this article, the importance of innovation sources and their relationships might evolve over time, which require longitudinal cases studies to track these potential changes. The theoretical framework of this study also suggests that the use of innovation sources is sensitive to the complexity of innovations (Rothaermel and Hess 2007), an assumption that is still in need to be tested.

This study also suggests that municipal capacity and vulnerability in addition to political support for improving weather disaster risk management are important drivers of innovation. This finding is consistent with previous studies that have shown that the problem severity, internal capacity and political environment are key factors for understanding public sector organisations' behaviour (McGuire and Silvia 2010; Hui, Smith, and Kimmel 2019).

In conclusion, this study contributes to research on local governments by providing new evidence on the sources of innovations used, their relationships as well as their antecedents. It shows thus most municipalities use a hybrid model of innovation combining internal and external sources of knowledge. The internal and external sources of knowledge are to a large extent independent and their utilisation is sensitive to political support, vulnerability, and municipal capacity. Finally, the study suggests that efforts to enhance internal capacity and horizontal and vertical collaboration are important means to spur innovation in the management of weather disasters.

## Acknowledgements

Open Access funding provided by the Qatar National Library.

## Disclosure statement

No potential conflict of interest was reported by the authors.

## Funding

This research was funded by the Natural Sciences and Engineering Research Council of Canada.

## Notes on contributor

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