Conditions for Complex Innovations: Evidence from Public Organizations

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Abstract

Despite the growing interest in understanding innovative activities, an important limitation of the current literature on innovation—both public and private—is an assumption that innovative activity is a homogeneous phenomenon. However, most innovative activities are heterogeneous in nature. One way of characterizing innovation heterogeneity is the complexity of innovations. Using data from public organizations, this paper is one of the first studies to develop a framework for and provide an empirical test of the main influences on innovation complexity within the public sector context. The empirical evidence suggests that employees' innovative behavior and cooperation, along with collaborating with important external sources and the ability to work in a complex environment, are positively associated with complex innovations in the public sector, suggesting that the influences on complex innovations span the individual, work group, and external environment levels. However, an organization's leadership quality and innovation climate do not have any statistical effect on complex innovations.

Key words: innovation; innovation complexity; public sector innovation; public organizations.

1. Introduction

Innovative activity is crucial as it is positively associated with competitive advantage, economic growth and development, employment growth, knowledge generation, entrepreneurship, and have a positive spillover effect to the other sectors (Acs et al., 2017; Audretsch and Link, 2018; Link and Siegel, 2007; Suzuki and Demircioglu, 2018), so it is not surprising that innovation has become an important topic. Despite an increasing number of studies on innovation in public, private, and nonprofit organizations in recent years (e.g. Anzola-Román at al., 2018; Arundel et al., 2015; Bankins et al., 2017; Demircioglu and Audretsch, 2017a; Hartley, 2016; H. Jung and J. Lee, 2016; Keupp and Gassmann, 2013; Lewis et al., 2018; Torfing and Triantafillou, 2016; Torugsa and Arundel, 2017), studies have generally treated innovative activity as a homogeneous phenomenon (e.g. not multi-dimensional).

The purpose of this paper is to provide one of the first studies to explicitly recognize and analyze innovation heterogeneity within the public sector context. In particular, this paper provides a focus on a particular dimension of innovation heterogeneity—the extent to which innovations in the public sector are complex—as well as exploring why some public organizations have a greater propensity for engaging in complex innovative activity. The complexity of an innovation is defined by its multidimensionality, or the number of different dimensions/types embedded in a particular innovation (Anzola-Roman et al., 2018; Torugsa and Arundel, 2016a).

One reason for the paucity of studies analyzing innovation heterogeneity has been measurement constraints. Not only are measures of innovative activity in the public sector scarce, but studies reflecting complex innovations have remained virtually non-existent. In fact, despite increasing research in the public administration literature on innovation, the vast majority

is based on case studies and interviews, or even conceptual pieces (e.g. Albury, 2005, 2011; Bankins et al., 2017; Bartos, 2003; Borins, 2009; Hartley, 2016; Sahni et al., 2013). What is new is the use of innovation surveys in public organizations (Arundel et al., 2015, 2016; Bloch and Bugge, 2013; Demircioglu and Audretsch 2017b; OECD, 2005; Torugsa and Arundel, 2017). In particular, the 2011 Measuring Public Innovation in the Nordic Countries (MEPIN) is probably the first large scale and representative survey aiming to measure innovation activities in the public sector (Arundel et al., 2016; Bloch and Bugge, 2013; Bugge et al., 2011). The MEPIN project is well documented, its approach is close to the Oslo Manual, and it provides extensive analysis for innovation in public organizations. Thus, using large scale quantitative studies to examine public sector innovation is a promising method, as many questions remain unexamined due to the lack of data.

While both scholars and practitioners recognize that some innovations are more complex than others (e.g. Dosi, 1988b; H. Jung and J. Lee, 2016; Sahni et al., 2013; Pavitt, 1984), little is known within the scholarly community about how and why some employees and their work groups are able to generate more complex innovative activity than others. Fortunately, we are able to overcome the severe measurement constraints in this paper by using the 2011 data from the Australian Public Service Commission (APSC), which provides a large and comprehensive measure of not just innovative activities (e.g. innovation, innovation climate, and innovative behavior) but also of complex (multi-dimensional) innovations within the public sector context.

The following section of this paper distinguishes between innovations in general and complex innovations in particular within the context of the public sector. In the third section, a theoretical model is introduced for analyzing why some organizations are more adept at complex innovations than others. The fourth section explains the sources of data and empirical methods

used, and the empirical results are provided in the fifth section. In the final section of the paper, a discussion of the findings, which highlights the main contributions of this paper along with the limitations and qualifications, is provided.

2. Complex Innovations

Innovation is a process through which new ideas, objects, and practices are created, developed, or reinvented, and which are new for the unit introducing that innovation (Walker 2008). Bartos (2003, p. 10) defines innovation as "A change in policy or management practice that leads to a lasting improvement in level of service or quantity or quality of output by an organization." Likewise, Lewis et al. (2018, p. 290) define innovation as "the process from ideas to successful implementation of these, which makes a substantial difference to an organization's understanding of the needs it is addressing and the services it delivers." These most salient definitions of innovations also imply the subjectivity of innovation, such that one person's understanding of "substantial difference" may be different from another's. This study uses a definition of innovation that the APSC survey created by building on the work of Windrum (2008), which follows the OECD Oslo Manual (2005). The Oslo Manual defines innovation as "the implementation of a new or significantly improved product (good or service), or process, a new marketing method, or a new organizational method in business practices, workplace organisation or external relations." This definition also reflects the heterogeneity (e.g. multidimensionality or complexity) of innovations, such as whether a particular innovation is a new process, organizational method, product, or service.

One way of characterizing innovation heterogeneity involves complex innovations. An innovation can be characterized as single, complex, or both. While a single innovation may not incorporate multiple dimensions of innovation, complex innovation refers to innovations that

demonstrate multidimensionality, or a number of different dimensions affected by a single innovation (Anzola-Roman et al, 2018; Demircioglu, 2017; Torugsa and Arundel, 2016a). For instance, if an innovation improves the organizational process, the way employees provide services, and employee policy thinking, the innovation is characterized as complex. Because innovations are typically multi-dimensional (complex), using one binary survey item (innovation or no innovation) does not capture the multidimensionality of the most significant innovations. Therefore, building on the work on complex innovations by Torugsa and Arundel (2016a),[i] this study explores and tests conditions for complex innovations in the public sector.

Within a framework of innovation heterogeneity, radical innovations and complex innovations are not the same although both are heterogeneous in nature. Radical innovation refers to disruptive (not incremental) innovation that has a significant impact on the organization and the public sector environment, but it may include only one or two dimensions of an innovation. A good example would be the Open University in the United Kingdom, which is a very disruptive innovation; it significantly changed the public sector and higher education environment (Albury, 2005) although it may only affected a few dimensions (e.g. services) of innovation. Thus, not all radical innovations are complex. On the contrary, some innovations may be complex but not radical. For instance, introducing a toll charge for a busy road in a city is not a radical innovation because it is not disruptive; it does not transform the public sector environment, and many cities around the world have been using this system for a long time. However, this innovation may impact more dimensions, such as employees' policy thinking, the way they provide services, the way they interact with stakeholders, and administrative and organizational processes. In this regard, quantitative studies such as surveys are a good way to measure complex innovations because they can measure multidimensionality with survey items,

and they do not require ethnographic research and unstructured in-depth interviews with employees to investigate how radical a particular innovation is. The following section will explore the potential conditions effecting complex innovations in public organizations and introduce the main hypotheses.

3. Conditions for Complex Innovations

As discussed in the above section, the complexity of a public sector innovation refers to the number of aspects or dimensions affected by a single innovation. These aspects or dimensions include administrative or organizational processes, services, human resource policies and approaches, and the manner in which employees provide services and approach problems (APSC, 2011a, 2011b). The more dimensions that are affected, the greater the degree of complexity associated with any particular innovation (Demircioglu, 2017; Torugsa and Arundel, 2016a).

The extant literature suggests a number of factors and influences shaping the ability of a particular organization to generate not just innovative activity but complex innovations. We classify them in different units of analysis corresponding to the individual, group, organizational, and environmental levels, all of which are interrelated and connected. For instance, an organizational culture that encourages experimentation and trying out new ideas may influence complex innovations. Nelson and Winter (1982) distinguish between two disparate organizational contexts. According to them, an organization can be characterized by a routinized regime when it puts a greater priority on producing existing goods and services. By contrast, it can be characterized by an entrepreneurial regime when it puts a greater priority on innovative activity. In an entrepreneurial regime, there is not only a supportive culture for innovation (organizational level) but employees behave innovatively (individual level), group members

cooperate for innovations (group level), there is a high quality of leadership (organizational level), the organization is open to receiving innovative ideas from other sources (external environment), and employees work in a complex working environment (external environment). We argue that in order to implement complex innovations, most of these factors need to be present. Figure 1 illustrates the conditions and the levels for complex innovations in the public sector context.

[Insert Figure 1 is about here]

The first condition for complex innovation in the public sector involves the capabilities, orientation, and behavior of the employees that can contribute to the complexity of innovations. More specifically, an innovative behavior can be defined as "an employee's intentional introduction or application of new ideas, products, processes, and procedures to his or her work role, work unit, or organization" (Yuan and Woodman, 2010, 324). Research shows that the more that employees engage in or exhibit innovative behavior, the greater the innovative output of public organizations (Demircioglu, 2017; Fernandez and Pitts, 2011; Fernandez and Wise, 2010; Van der Wal, 2017). For instance, evidence from public organizations shows that when employees exhibit innovative behavior, innovations flourish, and incentives are created for organizations to implement complex innovations in the public sector (Thompson and Sanders, 1997). Similarly, research suggests that public sector employees' innovative attitudes and behavior such as aspirations and networking capability are positively associated with implementing breakthrough innovations (J. Chan and G. Lee, 2016; Lewis et al., 2018). Furthermore, granting power to employees is positively associated with greater innovative activity in the United States federal government (Fernandez and Moldogaziev, 2013).

Employees are the core of the organization, and its most important asset; without a commitment to innovation and corresponding behavior conducive to exploring new ideas and opportunities, employees will not be able to generate complex innovations. Employee motivation and ability are crucial factors affecting complex innovations (Borins, 2009; Christensen et al., 2004). A paucity of employee innovative behavior may reflect a lack of motivation and incentives for them to be involved in innovations. An organization can have a culture and incentives conducive to innovation, but without the corresponding employees with the capabilities to be creative and think outside the box, it will still fail to innovate, let alone generate complex innovations (Sahni et al., 2013).

H1: Innovative behavior will be positively associated with innovation complexity.

The second condition for complex innovations in the public sector involves cooperation in employee work groups. It is very difficult for a public sector employee to innovative by alone. In fact, innovations are typically a work group outcome (Becker and Whisler, 1967). Cooperation within an employee work group is crucial for implementing complex innovations because the group or team context requires a more collaborative approach among employees. Research has found that better communication and cooperation within an employee work group can increase innovative activity in public organizations (Borins, 2009; Fernandez and Pitts, 2011; Van der Wal, 2017). For example, the Veteran's Benefits Administration in the United States introduced a new intranet; this complex innovation was developed by employee cooperative actions (Fernandez and Pitts, 2011). Likewise, Bankins et al. (2017) have found that effective

communication and collaboration serves to reduce barriers to innovation and increase important innovations in the public sector.

Effective and high quality leaders also promote cooperation among employees, which are conducive to enhancing performance and innovation in their organizations (Engelen et al., 2015; Fernandez and Moldogaziev, 2013; Goldsmith and Eggers, 2004; Linden, 2010). Good communication skills are also associated with significant innovations in the public sector (Lewis et al., 2018). Cooperation in an employees work group can also increase the ability of an employee to contribute her own personal strengths and ideas to a collective initiative. These factors help employees generate more complex innovations. Complex problems require complex solutions, and complex solutions in turn require the involvement and participation of multiple employees:

H2: Cooperation within an employee work group will be positively associated with complex innovations.

The third condition for complex innovation in the public sector is leadership quality. Leadership quality is crucial because "leadership shapes the employees' work environment and helps to construct the culture in which the interests of the organization and its members are aligned" (Engelen et al., 2015, 1072). Research suggests that supportive and high-quality leadership increases employee creativity and innovative behavior, which in turn encourages organizational innovation (Engelen et al., 2015; Fernandez and Moldogaziev, 2013; Thompson and Sanders, 1997; Van der Wal, 2017). For instance, good and effective leaders can motivate employees to be more innovative (Borins, 2009; Fernandez and Pitts, 2011). Likewise, public

sector managers who possess high-quality leadership create a positive organizational environment, enabling employees to develop more complex innovations (Thompson and Sanders, 1997).

In a study analyzing complex innovations in health and social care delivery, Barlow et al. (2006) found that leadership quality matters for adopting complex innovations. While some leaders delay or hinder the innovation process, high-quality leadership provides more opportunities for staff to develop complex innovations in the healthcare sector (Chuang et al., 2011). Furthermore, Yuan and Woodman (2010, p. 328) argue that "employees with high-quality relationships with their supervisors are likely to be more confident that their innovative behavior will result in performance and efficiency gains." Likewise, Albury (2005, 2011) argues that leadership quality is crucial for complex innovations in public organizations. However, C. Jung and G. Lee (2016) have found evidence that when facilitative and high-quality leaders exist, employees will have lower aspirations for organizational innovation. With lower aspirations, employees are less able to implement complex innovations. In sum, while the vast majority of studies argue that leadership quality is positively associated with innovations and complex innovations, employees may have fewer incentives implement complex innovations when there is a high-quality leadership:

H3: Leadership quality will be either positively or negatively associated with complex innovations.

The fourth condition for complex innovation in the public sector is innovation climate. A public organization with an innovation climate is characterized as encouraging and being more

open to new ideas and innovation, as manifested by a broad spectrum of managerial and organizational practices (Demircioglu, 2017; Popa et al., 2017). If employees are given time and resources to try out new ideas along with autonomy and freedom in their jobs, they tend to be more innovative (APSC, 2011a; Demircioglu and Audretsch, 2017a; Fernandez and Wise, 2010; Torugsa and Arundel, 2016a). Similarly, if they receive support from supervisors who tend to respond positively to new ideas emanating from employees (APSC, 2011a; Fernandez and Pitts, 2011), they tend to implement significant innovations. Thus, an organizational climate encouraging new ideas and innovation is conducive to complex innovations for several reasons. First, these support mechanisms encourage employee involvement in more complex innovations because complex innovations require a greater degree of support, resources, incentives, and established processes than do simple innovations (Popa et al., 2017). The resource-based view of organizations (Barney, 1991) suggests that the performance of an organization is linked to the resources available. If an organization or a leader does not support employee efforts to be innovative by providing resources, then there will be no motivation and incentive for public sector employees to champion complex innovations. Developing a complex innovation is not simple; it requires psychological support.

However, analyzing full-time employees in fourteen agencies in the South Korean government central government, C. Jung and G. Lee (2016) found that an innovation climate is negatively associated with employee aspiration for innovation and thus complex innovation in the public sector. They argue that if the innovation climate of an organization is low, employees will have higher aspirations to implement significant innovations, and if the innovation climate of the organization is high, employees will have fewer ambitions to implement innovations. Likewise, when an organization is very bureaucratic, some employees in the public sector will

desire making significant innovations in the public sector (C. Jung and G. Lee, 2016). In addition, Yuan and Woodman (2010) have found that dissatisfaction with the status quo for an organization is negatively associated with innovativeness. Thus, if employees are dissatisfied, they value invention and innovative ideas that can increase organizational performance. Similarly, when a "unit or organization is less effective, people are more likely to get credit for introducing new technologies and suggesting new ways to achieve objectives" (Yuan and Woodman, 2010, 329), suggesting that in some cases, the innovation climate can be negatively associated with complex innovations.

H4: Innovation climate will be either positively or negatively associated with complex innovations.

A fifth condition for complex innovative activity involves collaborating with important external actors to develop innovations. Research suggests that collaborative approaches both within and across the boundaries of organizations are more likely to be successful and can yield important innovations in both the private (Anzola-Roman et al., 2018; H. Jung and J. Lee, 2016; Lundvall, 2010) and public sector (Thompson and Sanders, 1997; Torfing and Triantafillou, 2016). For instance, analyzing nanotechnology patents in the United States between 1980 and 2006, H. Jung and J. Lee (2016) found that boundary-spanning research increased firms' development of complex innovations. Similarly, analyzing breakthrough innovations in public organizations, Altshuler and Zegans (1997) found that useful innovations are initiated by employees who interact with businesses and service users and learn from these actors. In fact, complex innovations occur when employees in public organizations engage with a more complex

working environment and interact with and learn from multiple groups, ultimately enhancing employees' capability for generating complex innovative activity.

A different study finds that responding to service user needs and demands positively affects complex innovations in the government context (Barlow et al., 2006). Likewise, more actors and sources involved in implementing a complex innovation in health and social care delivery increases the degree of innovation complexity (Barlow et al., 2006). Such collaboration can enable employees to accumulate new knowledge, skills, and experiences, which will help them to implement more complex innovations (Borins, 2009; Goldsmith and Eggers, 2004; Linden, 2010). Analyzing high-performing innovative agencies, Albury (2011, p. 230) has found that "these leaders, these senior managers … are hungry, thirsty, exploring all the time the external environment. They are reaching out to other sectors, other organisations… They're reaching out to the frontline of their organisations," suggesting that high-quality organizational leaders aiming to collaborate with other organizations are conducive to generating more complex innovations in the public sector. Nevertheless, because collaborations involving multiple sources require extensive time and effort, it is suggested that public sector managers and employees should collaborate with important but not extensive sources (Torugsa and Arundel, 2016a). The APSC states that the important sources for collaborative innovation include the Australian government, other government agencies (outside of an employee's agency), industry stakeholders, and members of the public (APSC, 2011a, 2011b):

H5: Collaborating with important actors for developing innovations will be positively associated with complex innovations.

A sixth aspect influencing the propensity for complex innovative activity involves the context external to the organization (Borins, 2009; Goldsmith and Eggers, 2004; Linden, 2010; Popa et al., 2017). Contemporary public organizations typically expect that employees deal with a more multifaceted working environment (Van der Wal, 2017). For instance, public sector employees, and particularly managers in the APS, are working in an increasingly demanding environment (APSC, 2011a). According to the APSC (2011a, 6), "As governments focus on increasingly complex policy problems that demand innovative solutions, it is more important than ever that policy development and implementation be supported by an evidence base, sound arguments and collaboration across government and beyond." One reason for this expectation is that most tasks are now conducted by several actors, which translates into an increased demand for public organization employees to deal with more complex working environments (Goldsmith and Eggers, 2004; Linden, 2010; Van der Wal, 2017).

Examining breakthrough innovations, Keupp and Gassman (2013) found that working in a complex environment increases opportunities for employees to develop more radical innovations. An increased demand to engage with a complex working environment also helps employees stay up-to-date with current knowledge and experiences. Working in complex and competitive environments also requires employees and organizations to be more efficient and effective (Lundvall, 2010; Popa et al., 2017). Nevertheless, if an organization does not require employees to deal with a complex working environment, then employees have only a limited opportunity to communicate and interact with the external environment. These employees may also prefer not to work harder to develop complex innovations, which eventually reduces their capacity, ability, incentive, and motivation to develop more complex innovative activities.

H6: Working in a complex working environment will be positively associated with complex innovations.

4. Data and Methods

4.1 Data and Sample

The main data used to test the hypotheses developed in the previous section are from the APSC 2011 annual survey of Australian Public Service (APS) employees, or the State of the Employee Survey.[ii] The 2011 annual survey is the ninth survey undertaken by the APSC. The survey asks questions about employee attitudes and behavior such as employee job satisfaction, general impressions about the work, recruitment and retention, APS values and ethics, health and well-being, and innovative activities. In fact, compared to both earlier and later versions of the survey, the 2011 survey contains the most extensive data in terms of measuring innovative activities such as innovation climate, innovative behavior, innovation complexity, and collaboration for innovation.

Because only a single data source is used, common method bias may be a problem in this study. Although there is no perfect way to test or to reduce common method bias, the APSC survey uses several procedural remedies suggested by Favero and Bullock (2015), Keupp and Gassmann (2013), and Podsakof et al. (2003) such as improving scale items, protecting respondent anonymity, confidentiality, and well-developed questionnaire design. In addition, before distributing the survey, the survey was pilot-tested with all levels of job classification and different departments, including the Department of Defense, Department of Immigration and Citizenship, the Australian Electoral Commission, and Department of Finance and Deregulation (APSC, 2011a). Furthermore, Harman's one factor test reveals that a single factor does not account for a majority of the covariance among the measures.

An attractive feature of this survey is that it is highly representative. The sample was also stratified by agency, agency size, and agency location in addition to employees' job classification level. Overall, 10,222 valid responses were received (59% response rate) (see APSC, 2011b). The APSC (2011a) states that the average time required to complete the survey was forty minutes. Based on the 1988 Privacy Act, all individual information collected from surveys is strictly private and confidential, and none of the supervisors or other employees have access to the information concerning their fellow employees (APSC, 2011a, 75). Finally, these data are collected from all employees across a broad spectrum of organizational ranks (e.g. Trainee and Graduate [APS 1-6], executive levels or middle managers [EL], and senior executive service or top managers [SES]). By using the work group as the level of analysis, the database comes with methodological advantages (e.g. all levels of employees are included in the work group and one employee from each group responded to the survey) and is highly representative, both of which enhance the utility of the data (Torugsa and Arundel, 2016b).

Because this study aims to measure innovation complexity, the sample size is reduced to reflect only those in the database whose work group has previously implemented an innovation.[iii] In addition, only employees who have worked in the public service for at least the last five years are included in the analysis because for an employee to be able to understand and compare whether and how she deals with a complex working environment requires her to have worked in public service for a longer period of time. Thus, the final sample used for the analysis consists of 1,415 employee records.

4.2 Dependent Variable

A preliminary question in the survey asks whether the work group in which the employee works has implemented any innovations. Respondents who responded "yes" to this question

were then asked to respond to a follow-up question, which measures the five dimensions of innovation and thus innovation complexity (Torugsa and Arundel, 2016a; Windrum, 2008)[iv]: "Thinking of the most significant innovation that was implemented by your work group in the last 12 months; which parts of your work did it affect?" (1) "Your policy thinking", (2) "Your services", (3) "The way you provide services", (4) "Your administrative or organisational processes", (5) "The way you look at problems or challenge assumptions." It is coded "1" if the particular dimension is stated by employees (and "0" otherwise). Employees are expected to choose at least one of the dimensions of innovation (APSC, 2011b). Thus, the innovation complexity variable, which is used as the dependent variable in this study, is constructed as the sum of the five dimensions (From 1 = no complex innovation to 5 = very complex innovation) (Torugsa and Arundel, 2016a).

4.3 Independent Variables

The independent variables reflect those potential factors affecting the ability of working group to generate a complex innovation. Six different conditions, or independent variables at the individual level (innovative behavior), group level (cooperation in employees' work group), organizational level (leadership quality of senior executives and innovation climate), and environmental level (collaboration with external actors and dealing with complex working environment) are used and tested. All survey questions and response categories are located under the Appendix 1. The first independent variable, innovative behavior, is consist of two survey items with an alpha value of 0.77. A sample survey item is: "I am always looking for better ways to do things." Previous research has used same or very similar item(s) (e.g. Fernandez and Moldogaziev, 2013). The second independent variable, cooperation within the employee work group consists of two survey items with an alpha value of 0.83. A sample survey item is: "The

people in my work group cooperate to get the job done." The third independent variable, leadership quality, consists of five survey items with an alpha value of 0.93. A sample survey item is: "In my agency, the leadership is of a high quality."

The fourth independent variable, innovation climate, which indicates what the organization is doing in terms of innovative activities (C. Jung and G. Lee, 2016) includes ten survey items measuring whether employees receive support when they suggest new ideas, whether there are established processes for evaluating ideas, and whether employees have enough time and resources to try out new ideas. The alpha value is 0.9. A sample survey question is: "My workplace encourages innovation and the development of new ideas." The fifth independent variable, collaboration with external actors, measures the importance of the most important four important external sources in the APS (APSC, 2011a, 2011b) with an alpha value of 0.66. These are the Australian government, other Commonwealth agencies, industry stakeholders, and members of the public. The last independent variable captures employee work over the last five years with respect to "requirement to deal with a complex." The response categories ranges between 1=decreased greatly to 5=increased greatly. Table 1 reports the summary statistics and the Appendix 1 shows the Pearson correlation coefficients. Overall, most of the alpha values suggest that the internal consistency of survey items is very high. In addition, all these items are also validated and pretested by the APSC (APSC, 2011b).

[Insert Table 1 is about here]

Factor scores are used except for the last condition, dealing with complex working environment, as it captures a single survey item. Factor analysis helps to identify a small number of underlying variables (here, six conditions for complex innovations) that efficiently and effectively summarize data. In addition, using a single survey item for variables such as

innovation climate and leadership quality may not perfectly measure these concepts, so using factor analysis bestows several advantages. Rotated factor loadings show that six underlying factors emerge from the analysis (Appendix 3). In addition, results of the confirmatory factor analysis (that assess convergent and discriminant validity) indicates that except the fifth condition, collaboration for innovation, there is no problem with the convergent and discriminant validity (not shown).

4.4. Control Variables

This study also use several control variables. Previous research has suggested that the size of agency, workplace location, respondent's job level classification, job experience, and education may affect complex innovations in public organizations in the context of the Australian Public Sevice (Bankins et al., 2017; Demircioglu, 2017; Torugsa and Arundel, 2016a). For instance, analyzing public sector innovations in the APS, Bankins et al. (2017)'s qualitative research found that organizational size affects innovation complexity. Torugsa and Arundel (2016a) similarly found that location affects complex innovations in the APS. Therefore, we have added these variables as controls.

4.5 Empirical Strategy

The Stata 15.1 software program is used to report findings. Analyzing the dependent variable, innovation complexity, is subject to sample selection bias due to employees who did not report any innovation. In other words, only those employees who already indicated that their work group had generated at least one innovation can respond to the questions measuring innovation complexity. To test whether a selection bias exists, we estimated a two-stage Heckman selection model. The Heckman selection model consists of two stages. The dependent variable of the first stage is whether employees have implemented any innovations (a binary

variable; 1=Yes, 0=otherwise). The dependent variable of the second stage is innovation complexity. We have performed several models, including with full control variables but excluding independent variables and with both independent and control variables. The Mills ratio for all of the results are not statistically significant ($p>0.1$), suggesting that sample selection is not be a concern. For instance, the results show that the Mills ratio is not statistically significant ($p=0.67$), so selection bias is not a concern in this study (Appendix 4).

Since the dependent variable is a count variable (the number of dimensions/parts effected by the single innovation), using OLS may cause biased estimates, so the negative binomial regression model (NBRM) or the Poisson regression model (PRM) is preferable for the second dependent variable (Long, 1997)[v]. No difference exists between the NBRB and Poisson regression models in this study, so that we restrict the results reported in the subsequent section only to those generated by NBRB estimation. Because of the heteroscedasticity, robust standard errors are used for all estimations. In addition, to check for multicollinearity, the variance inflation factor (VIF) scores is calculated. Accordingly, the VIF scores for all the variables in all models are less than 5, suggesting that multicollinearity is not a problem in the estimated models.

5. Results

Descriptive statistics (Table 1) show that on average, most of the innovations are not complex (mean=2.01). Respondents report that they have a stronger innovative behavior (mean = 4.27) and group cooperation (mean = 4.1) compared to leadership quality (mean= 3.1) and innovation climate (mean = 3.35). The mean value of collaboration for innovation is 1.59, and the mean value of complex working environment is 3.99. In addition, while most of the employees are working in large agencies, less than half of the employees' work location is the

ACT. The mean values for job level, experience, and education are 1.57, 3.8, and 1.54, respectively.

Table 2 reports the standardized statistical results based on the negative binomial regression models (NBRM). The first model includes only independent variables, the second model includes both independent and control variables (without agency dummies), and the third model includes agency dummies in addition to independent and other control variables. Results are consistent among the three different models. The results suggest that all of the variables reflecting the main hypotheses have a statistically significant effect on innovation complexity except for the organizational level variables (leadership quality and innovation climate). Thus, H1, H2, H5, and H6 are supported. Holding other variables constant, one standard deviation increase in innovation behavior, cooperation to complete the job, collaboration for innovation, and complex working environment is associated with an increase of 0.099, 0.087, 0.18, and 0.038 standard deviations in innovation complexity, respectively. In particular, the effects of collaboration for innovation are very high, suggesting that collaborating with important external sources is crucial to developing complex innovations in the public sector. However, none of the control variables are statistically significant at the 5% level, suggesting that size of agency, work location, job level, experience, and education are not determinants to develop complex innovations in the public sector. In other words, regardless of these controls, employee innovative behavior, cooperation with teammates, collaboration with external stakeholders, and working within a more complex work environment are conducive to complex innovations in the public sector.

[Insert Table 2 is about here]

A robustness check has been conducted to test how these six conditions for complex innovations affect a single innovation. In other words, instead of treating innovation complexity as the dependent variable, we instead treated innovation adoption as the dependent variable.[vi] Results suggest that in addition to innovative behavior, cooperation to get the job done, and working within a complex environment, innovation climate and leadership quality also have a statistically significant and positive effect on innovation. Thus, the findings suggest that while the underlying conditions conducive to innovation and complex innovations may be similar, they are not same. We will discuss these findings in more detail in the next section.

In addition, as mentioned earlier, employees who have been working in the public service for at least five years are included in the analysis. Excluding employees who have been working fewer than five years may cause bias in the estimations. We therefore removed the last condition (dealing with a complex working environment) from the analysis because in order to answer this question, employees must have at least five years experience in the government. The results are very similar to the original model. Similarly, because there were nonsystematic missing variables, we had already removed observations with missing variables. As a robustness check, we have not removed observations with missing variables (n becomes between 1,986 and 4,716, depending on the variables in a model). These results are also very similar to the original model, verifying the robustness of the findings.

6. Discussion

This study is one of the first to systematically analyze what conditions affect innovation complexity (multi-dimensionality) in the public sector context. More specifically, this paper contributes to the existing literature by identifying those conditions under which public organizations are likely to successfully make complex innovations. The complexity of a public

sector innovation refers to the number of aspects or dimensions (e.g. administrative or organizational processes, services, and the manner in which employees interact with stakeholders and approach problems) affected by a single innovation. As was established in previous studies (e.g. Anzola-Roman, 2018; Demircioglu, 2016; Torugsa and Arundel, 2016a), this study measures innovation complexity as the number of dimensions affected by a single innovation.

The empirical results suggest that those factors conducive to complex innovative activity are multilevel. In particular, complex innovative activity within the public sector tends to respond at the individual level to innovative behavior and creativity. At the group level, complex innovative activity tends to respond to the extent of cooperation to get the job done within a work group. At the external or environmental level, collaborating with external actors and working within a complex work environment are found to be conducive to complex innovative activity. Thus, the results of this paper provide compelling empirical evidence suggesting that there is no single key level serving as a catalyst for complex innovation. Rather, the influences of complex innovations span several key dimensions, ranging from the individual to the work group and even to the external environment.

However, we have also found that at the organizational level, leadership quality and innovation climate do not have a statistically significant impact on innovation complexity. It may be because to implement more complex innovations, individual employee efforts may be more important than leadership support and an existing positive climate. In addition, because organizational leaders tend to be a task-oriented (Goldsmith and Eggers, 2004; Linden, 2010), they may want employees to focus on a particular dimension of innovation rather than on diversification, suggesting that employees may be discouraged from developing complex innovations. In addition, while most of the research demonstrates that leadership quality and

innovation climate are associated with innovations, as C. Jung and G. Lee (2016) argue, when public sector employees perceive that the leadership is not of a high quality and their current organizational climate is less innovative, those employees may have greater aspirations for developing complex innovations. Therefore, these two different effects may cancel each other out, explaining why leadership quality and innovation climate are not statistically significant. However, robustness tests show that leadership quality and innovation climate are important determinants for single innovations in the public sector. Thus, these findings also show that conditions for single innovations and complex innovations may differ from one another. Future research may explore these differences.

Because of the increased complexity of contemporary problems, developing complex innovations is crucial for organizations, particularly in the public sector. Additionally, complex innovations may generate more value (Dosi, 1988a; Cohen and Klepper, 1992a, 1992b), particularly in improving government services and enhancing government performance (Sahni et al., 2013). As Torugsa and Arundel (2016a, 411) emphasize, "Due to their high value, the ability to develop and implement complex innovations should be an important goal for both policy and for public sector managers." Therefore, public organizations and organizational leaders should find ways to prioritize complex innovations in the public organization context.

Nevertheless, despite the increasing importance of complex innovations, it has not been a focal point for most of the research on innovation undertaken by scholars. This gap is unfortunate because, as mentioned earlier, complex problems require developing complex innovations. This study develops and tests new hypotheses on how certain factors, including individual, group, organizational, and environmental factors, affect complex innovations. By

utilizing a data base from the APS, we were able to test hypotheses positing the most salient influences of complex innovations in the public sector context.

The lack of studies on complex innovation is at least partially attributable to the paucity of measurements for complex innovations. Fortunately, there is a growing interest and investment in measuring innovative activities in the public sector, such as the MEPIN projects in Northern Europe, Community Innovation Surveys in Europe, and APSC data in the APS (Arundel et al., 2016; Demircioglu and Audretsch, 2017b; OECD, 2005). These new sources of data provide scholars with new opportunities for measuring innovative activities in general and complex innovations in particular. Thus, we encourage scholars to analyze innovative activities in public organizations using these novel datasets as well as by collecting their own data.

While the recent literature focusing on the role of innovative activity has been a welcome contribution, compelling opportunities exist for expanding the analysis to incorporate the heterogeneity of innovative activity in general and innovation complexity in particular. Future studies might explore the outcomes of innovation complexity, such as how complex innovations in public organizations can affect organizational performance, cost, the quality of services, service user satisfaction, and inter-agency collaboration. Overall, to develop complex innovations, it is very important to foster innovative employees, cooperation within employee work groups, collaboration with important external actors, and the ability of the organization to rise to the demands posed by a complex working environment.

6.1 Limitations and Future Research Directions

This study has several limitations which need to be acknowledged. First, although it is representative among all public organizations in the APS, this study is based on one national context (Australia) with a cross-sectional data (at one point in time), so the results may be

different for other countries as well as for other time periods. Second and related to the first point, due to the nature of the data, the results are not causal but correlational. Nevertheless, as Lundvall (2010) explains, due to contextual, cultural, institutional, and demographic differences among different countries and organizations, it is very difficult to make generalizable causal arguments for innovation regardless of the quality or type of data, theory, and methodology. Future research may focus on how contextual, historical, demographic, and institutional differences affect innovative activities in public organizations.

Third, due to the lack of objective data measuring innovative activities such as innovation complexity, we have used self-reported and subjective data. An important contribution for subsequent research would be to develop more objective measures of innovative activities in the public organization context. Similarly, future research may consider collecting qualitative data (e.g. in-depth interviews and focus groups) to understand the rationale, personal stories, and evidence about how and why particular variables affect innovation complexity in the public sector. Fourth, this study builds on the work of previous studies in using a measure of innovation complexity based on the number of dimensions effected by the single most significant innovation (Demircioglu, 2017; Goffin and Mitchell, 2010; Torugsa and Arundel, 2016a). There are alternative measurement approaches available for future research to measure innovative complexity, such as in-depth interviews, which would facilitate identifying the specific benefits accruing from complex innovations. Finally, as mentioned earlier, radical innovations and complex innovations are different. By using qualitative data (e.g. case studies and in-depth interviews), future studies could make an important contribution by analyzing which factors are conducive to radical innovations in the public sector context.

7. Conclusion

Innovation was considered to fall within the domain of the private sector until the very end of the last century. However, while recent literature consistently shows that public organizations can be innovative and contribute to innovative activity, this welcome research on public sector innovation has generally ignored the heterogeneity inherent in innovation. Not all innovations are the same. Therefore, an important gap in the literature is the examination of the heterogeneous nature of innovative activity in the public sector. This paper provides a key contribution to the public sector literature by analyzing how and why some public organizations generate complex innovations while others do not.

Drawing a representative sample from the APS, this paper has developed a theoretical framework for analyzing innovation complexity and subjected six hypotheses positing conditions conducive to complex innovations in public organizations to empirical scrutiny. This study has shown that innovative behavior, cooperation in employee work groups, collaborating with important external actors, and an increased demand to deal with a complex working environment are all associated with innovation complexity. However, leadership quality and innovation climate do not have any statistical effect on complex innovations. This study suggests that the influences of complex innovations span all important units of analysis—individual, the work group, and the external environment—but lose their effect at the organizational level. Future research should continue exploring other important factors affecting innovation complexity as well as the outcomes of innovation complexity, such as how complex innovations are associated with organizational performance in the public sector.

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Figure 1: Conditions for Complex Innovations

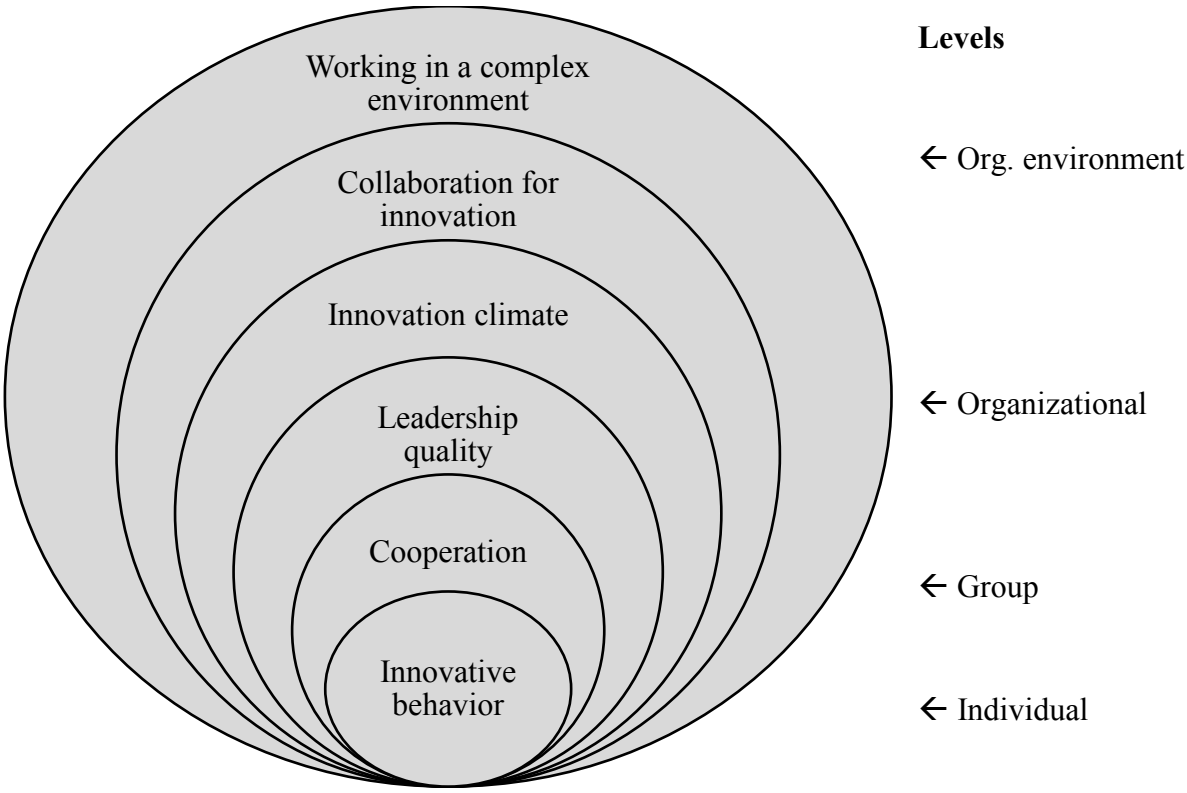

Table 1: Descriptive Statistics

Variable	Mean	Std. Dev.	Min	Max
Innovation complexity	2.01	1.21	1	5
Innovative behavior	4.27	0.55	2	5
Cooperate the complete the job	4.10	0.68	1	5
Leadership quality	3.11	0.95	1	5
Innovation climate	3.38	0.68	1.1	5
Collaboration for innovation	1.59	0.52	1	3
Complex working environment	3.99	0.96	1	5
Size of agency	2.68	0.55	1	3
Work location- capital city	0.43	0.50	0	1
Job level	1.57	0.63	1	3
Experience	3.80	1.20	2	5
Education	1.54	0.50	1	2

n=1,415

Table 2: Results for the Negative Binomial Regression: Standardized Coefficients

	Model 1	Model 2	Model 3
Conditions			
1. Innovative behavior	0.094**	0.092**	0.099***
2. Cooperate the complete the job	0.084***	0.087***	0.087***
3. Leadership quality	-0.031	-0.029	-0.02
4. Innovation climate	0.009	0.007	-0.022
5. Collaboration for innovation	0.165***	0.167***	0.180***
6. Complex working environment	0.043*	0.041*	0.038*
Control Variables			
Size of agency		0.01	0.294
Work location- capital city		-0.023	-0.013
Job level		-0.002	0.012
Experience		-0.018	-0.014
Education		-0.012	0.006
Agency dummies (over 60 agencies)			(Included)
Fit Statistics			
Log-likelihood-model	-2202.3	-2201.2	-2179.7
Chi-square	70.705	75.432	188.145
AIC	4418.6	4426.33	4499.31
BIC	4455.39	4489.39	4867.15
Cox-Shell/ML	0.034	0.037	0.064

n=1,415. * $p<0.05$, ** $p<0.01$, *** $p<0.001$

Appendix 1: Operationalization of Variables

Dependent Variable	
Complex innovations	Number of dimensions affected by the most significant innovation implemented in the last 12 months. (1) "Your policy thinking", (2) "Your services", (3) "The way you provide services", (4) "Your administrative or organisational processes", (5) "The way you look at problems or challenge assumptions" (1 = little complex innovations through 5 = very complex innovations)
Independent Variables	
Innovative Behavior	• I am always looking for better ways to do things. • I am prepared to challenge others' thinking and points of view in order to solve problems in my workplace. *(All items are from 1 = strongly disagree through 5 = strongly agree)*
Work Group Cooperation	• The people in my work group cooperate to get the job done • The people in my work group share job knowledge with each other *(All items are from 1 = strongly disagree through 5 = strongly agree)*
Leadership quality	• In my agency, the leadership is of a high quality • My agency is well managed. • In my agency, communication between senior leaders and other employees is effective. • In my agency, senior leaders engage with staff on how to respond to future challenges. • In my agency, the most senior leaders are sufficiently visible (e.g. can be seen in action). *(All items are from 1 = strongly disagree through 5 = strongly agree)*
Innovation Climate	• I receive support from my manager when I suggest new ideas. • I know exactly who needs to hear about my ideas so that they can be evaluated. • There are established processes for evaluating my ideas. • Employees in my workplace have autonomy and freedom in carrying out their job roles. • Employees in my workplace are provided with enough time and resources to try out new ideas. • My workplace encourages innovation and the development of new ideas.

	• My workplace is prepared to pilot and trial new ideas. • My workplace celebrates its successes in innovation and learns from everything it does. • My workplace shares its ideas and encourages their wider use. *(All from 1 = strongly disagree through 5 = strongly agree)* • My workplace has reward or incentive programs that encourage innovation. *(All items are from 1 = strongly disagree through 5 = strongly agree)*
Collaboration for Innovation	Thinking of the most significant innovation that was implemented by your work group in the last 12 months; how important were the following sources of ideas or information • The Australian Government (e.g. Ministers). • Other Commonwealth agencies. • Industry stakeholders. • Members of the public. *(All items are 1 = not important, 2 = somewhat important, 3 = very important)*
Complex Working Environment	How has the work at your current classification level over the last five years or more changed in relation to your requirement to deal with a complex working environment? *(From 1 = decreased greatly to 5 = increased greatly).*
Control Variables	
Size of agency	Number of people working in the agency. (1=Small (<251), 2=Medium (251-1000), 3=Large (1000+)).
Location	Respondent's workplace (1=Australian Capital Territory, 0=Field Office).
Level of job classification	Respondent's substantive classification level (1=Australian Public Service 1-6, 2=Executive Level (1-2), 3=Senior Executive Service).
Experience	Total length of service in the Australian Public Service (APS) (2=5 to 10 years, 3= 10-15 years, 4=15-20 years, 5=20 years or more).
Education level	Respondent's highest completed qualification (1=Completed year 12 or below, 2=Completed vocational qualification, 3= Completed tertiary qualifications).
Agency Dummies	Over 60 unidentified agencies are coded and included (see the third model of the Table 2).

Appendix 2: Correlation Coefficients

	Variables	1	2	3	4	5	6	7	8	9	10	11	12
1	Innovation complexity	1											
2	Innovative behavior	0.11	1										
3	Cooperation	0.09	0.10	1									
4	Leadership quality	0.00	0.09	0.19	1								
5	Innovation climate	0.05	0.20	0.26	0.56	1							
6	Collaboration	0.15	0.09	-0.03	0.13	0.13	1						
7	Working environment	0.09	0.07	0.05	0.00	0.05	0.06	1					
8	Size of agency	0.00	-0.04	-0.07	-0.05	0.01	-0.03	-0.01	1				
9	Work location	-0.01	0.07	0.06	0.10	0.01	0.07	-0.04	-0.19	1			
10	Job level	0.00	0.19	0.07	0.20	0.07	0.05	0.02	-0.21	0.35	1		
11	Experience	-0.05	-0.15	0.06	-0.01	0.02	0.00	-0.07	-0.02	0.05	0.20	1	
12	Education	0.00	0.11	0.00	0.03	-0.11	0.02	0.04	-0.15	0.20	0.46	0.00	1

Appendix 3: Factor Analysis

Variable	Factor 1	Factor 2	Factor 3	Factor 4	Factor 5
Innovative behavior 1				0.7381	
Innovative behavior 2				0.8226	
Cooperation 1			0.8624		
Cooperation 2			0.7852		
Leadership quality 1		0.8064			
Leadership quality 2		0.8139			
Leadership quality 3		0.826			
Leadership quality 4		0.7994			
Leadership quality 5		0.7319			
Innovation climate 1	0.5571				
Innovation climate 2	0.4359				
Innovation climate 3	0.6119				
Innovation climate 4	0.5505				
Innovation climate 5	0.6577				
Innovation climate 6	0.8078				
Innovation climate 7	0.7533				
Innovation climate 8	0.7746				
Innovation climate 9	0.7627				
Innovation climate 10	0.5693				
Collaboration 1					0.6571
Collaboration 2					0.5806
Collaboration 3					0.4993
Collaboration 4					0.5471

Note: Orthogonal rotation (varimax) are used. Only the highest factor loadings are reported.

Appendix 4: Heckman Selection Model

	First-stage	Second-stage
Variables	Innovation	Innovation Complexity
Innovative behavior		0.101***
Cooperate the complete the job		0.079**
Leadership quality		0.009
Innovation climate		-0.027
Collaboration for innovation		0.139***
Complex working environment		0.055*
Control Variables	(included)	(included)
Agency Dummies	(included)	(included)
Inverse Mills Ratio (lambda)		0.63 (p=0.67)
Wald chi2(df=69)		136
Observations		1572
Total observations	2848	

* p<0.05, ** p<0.01, *** p<0.001

[i] Both this study and Torugsa and Arundel (2016a)'s paper use the concept of innovation complexity, which is "the number of dimensions of the 'most significant innovation' implemented by each public employees' workgroup as a proxy for innovation complexity" (Torugsa and Arundel, 2016a, 392). However, several differences exist between our study and Torugsa and Arundel (2016)'s study. First, this paper's main focus is to determine which factors are affecting complex innovation, suggesting that the outcome variable is complex innovations. In contrast, Torugsa and Arundel (2016a)'s focus is outcome variety (a summated scale of how the most significant innovations affect cost, procedures, quality, user satisfaction, job satisfaction, workplace, and cross-agency collaboration) in addition to innovation complexity. They also did not focus on the "conditions" for complex innovations. Thus, these two papers have two different research aims. Moreover, this study explores conditions for complex innovations in the public sector using individual, group, organizational, and contextual levels of analysis, including variables for work group cooperation, leadership quality, collaboration for innovation, and a complex working environment, and not including variables for search breadth and barriers. This paper also uses a negative binomial regression models as the number of dimensions are treated as count data while Torugsa and Arundel (2016a) use an ordered probit as they did not assume that the dependent variable is not count data. Thus, the aim, expected contributions, theoretical development, and methodology for this study differ from Torugsa and Arundel (2016a) in many ways.

[ii] Although more recent data is available from the Commission, the APSC 2011 data is the most extensive data on innovation activities. More recent data do not include questions about innovative activities such as innovation complexity, innovative behavior, innovation climate, and collaborative innovation in the same survey. Thus, we have used the APSC 2011 data rather than more recent data. However, due to path-dependence and the institutional nature of public organizations, innovation activities in public organizations are typically consistent across different years. For instance, we have analyzed the percentage of employee work groups that implemented any innovations in the last 12 months using the APSC datasets between 2011 and 2017. The findings show that around 50% of employee work groups have implemented at least one innovation in all of the years, suggesting that employees' innovativeness is consistent during this time period.

[iii] However, to test whether a selection bias exists, we did not remove the observations of employee work groups who have not implemented any innovations in the last 12 months (otherwise, the model never converges because there will be no variation). See the results of the Heckman selection models (Appendix 4).

[iv] As suggested by Torugsa and Arundel (2016), the following dimension of the innovation, "The way you interact with stakeholders," is excluded because it overlaps (and confounds) with the collaborative innovation variable. However, as a robustness check, we also measured innovation complexity including this dimension (with six dimensions total). The results are very similar to the original results.

[v] We have also used ordinal logit and ordinal probit models for robustness checks and to test the statistical significance. Almost no differences exist for t-values among these models, suggesting the robustness of the findings across different models.

[vi] Since collaboration for innovation variable is nested under an innovation adoption question, we could not add the former variable in the analysis. Thus, we have tested five conditions (H1-H-4 and H6, excluding H5). Findings are available upon request.