



PATTERNS AND PREDICTORS OF INNOVATIONS IN THE CONSTRUCTION INDUSTRY

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Abstract: By analyzing innovation management strategies within the Canadian construction industry, are there emergent patterns that identify areas for optimization? Answering this question requires a deep understanding of existing theories and trends. In this preliminary study, an empirical analysis of patterns of innovation adopted by construction firms in response to observed market conditions, are investigated through the use of data from a large sample of firms provided by the BEEPS-EBRD survey. In addition, the hypothesis of an inverse-U shaped correlation between competition and innovation is tested. The results obtained by factor analysis show a high uniqueness of factors driving product, process, organization and marketing innovations among construction firms. Using a logit regression analysis, it can be shown that there is a statistically significant inverse-U shaped correlation between various product innovations and the level of competition observed by firms. Finally, a positive and statistically significant correlation between firms' size, R&D expenditures and the likelihood of adopting various types of innovation is documented.

1 Introduction

Slow technological advancements in the construction industry is a central topic among policy researchers around the world (Sharpe, 2001; Reichstein, Salter and Gann, 2005; Renz and Solas, 2016). Global trends in urbanization suggest that city population is growing by 200,000 people per day which will be driving demand for affordable housing, social, transportation and utility infrastructure in the foreseeable future (Renz and Solas, 2016). An industry agenda prepared for the World Economic Forum by Renz and Solas (2016), in cooperation with The Boston Consulting Group, indicates that the construction industry accounts for around 6% of Global GDP. Meanwhile, the industry is the world's largest consumer of raw materials and producer of 25-40% of the world's total carbon emissions (including those generated by the structures it produces). Nevertheless, the industry remains among the slowest in terms of technological change, which threatens economic growth and sustainability of the global economy. For example, labor productivity in the US construction industry did not change for the last 40 years (Renz and Solas, 2016). According, to Sharpe (2001), in Canada the situation is similar – labor productivity was slowly growing till mid-eighties when the decline began, and by 2000, brought the figures back to the level of 1962 (Sharpe, 2001). Therefore, an understanding of underlying mechanisms that are driving construction firms' decision to implement innovations is crucial for successful government policy of innovation stimulation.

The problem of the lagging pace of technological change in the construction industry has been studied for several decades (see for example Nam and Tatum, 1988). Among the variety of factors affecting innovations in construction industry that are discussed in the construction engineering and management literature, the role of competition is the most debatable. Some authors consider competition as a key driving force of technological changes (Renz and Solas, 2016) and others point at its adverse effect (Waugh,

Froese and Sadeghpour, 2016) on innovations. As well there is no consensus on the matter among the economists. Most of the classical theoretical works (for example, Arrow (1962) and Williamson (1965)) suggest adverse effect of competition on innovations across industries. However, those conclusions are not supported by empirical findings (e.g. Blundell, Griffith and Van Reenen, 1999). As a response to the extensive discussion the model that allows both – negative and positive – effects of competition has emerged (Aghion *et al.*, 2005). The theory suggests that the direction which competition will affect a firm's innovativeness will depend on the initial level of competition at the market.

Being driven by the universal economic mechanism, firms' response to competition predicted by the model of Aghion *et al.* (2005) should hold worldwide. The purpose of this paper is to gain understanding if there is empirical evidence supporting non-linear effect of competition on innovations in the construction industry, so this framework could be applied to the Canadian context when the appropriate data is collected. In this paper we aim to investigate patterns of innovations implementation followed by construction firms in response to observed market conditions and test for non-linear effect of competition predicted in the model of Aghion *et al.* (2005). To do so we are answering the following research questions. What patterns of innovations implementation would Canadian construction firms follow? How the likelihood of a firm following certain pattern is associated with the firm's characteristics and market conditions observed by the firm?

In particular, using survey data gathered from construction firms operating in the emerging markets of Eastern Europe and Central Asia, we perform factor analysis in order to classify innovation practices into groups driven by same underlying factors. Next, we investigate correlation of probabilities that firm will follow any specific pattern of innovations patterns with economic characteristics of the firm (such as size, age on the market, sales) and characteristics of the market environment (such as competition, region of operation, shadow economy) using methods of regression analysis.

2 Literature review

2.1 Definition and operationalization of innovations

Definition of innovation which is the most precise and commonly accepted in the academic literature is provided in the Oslo Manual (OCDE and OECD/Eurostat, 2005). According to the document, *innovation* is defined as an implementation of a new (or significantly improved) to the firm product, production process, marketing method or practice of doing business (OCDE and OECD/Eurostat, 2005). The same document provides detailed guideline for collection and interpretation of innovations data.

The manual defines the following four major types of innovations:

- “A *product innovation* is the introduction of a good or service that is new or significantly improved with respect to its characteristics or intended uses. This includes significant improvements in technical specifications, components and materials, incorporated software, user friendliness or other functional characteristics.
- A *process innovation* is the implementation of a new or significantly improved production or delivery method. This includes significant changes in techniques, equipment and/or software.
- An *organizational innovation* is the implementation of a new organizational method in the firm's business practices, workplace organization or external relations.
- A *marketing innovation* is the implementation of a new marketing method involving significant changes in product design or packaging, product placement, product promotion or pricing” (OCDE and OECD/Eurostat, 2005 p. 49-51)

These definitions are commonly accepted as foundation for the operationalization and justification of innovation as a phenomenon. (Anderson and Schaan, 2001; Reichstein, Salter and Gann, 2005; Lim and Ofori, 2007; Gunday *et al.*, 2011; e.g. Gorodnichenko and Schnitzer, 2013). This study operationalized all four types of innovations and investigated patterns of implementations followed by construction firms.

The Manual (OCDE and OECD/Eurostat, 2005) introduces clear differentiation between *innovations* and *innovative activities*. The specific characteristic of an innovation is that the new product, process, marketing

method or organizational practice must be implemented by a firm. Meanwhile innovative activity implies performing certain activities that facilitate innovations but not necessary lead to the desired result. Those activities include, but are not limited to, engagement into R&D, acquisition of external knowledge through purchasing results of the extramural R&D and new technologies, personnel training. (OCDE and OECD/Eurostat, 2005).

Researchers use both innovations and innovative activities to benchmark innovativeness of an economy or a sector. They regard innovative activities as proxy variables that will likely lead to innovations. For example, Baily (1972) shows that the data reflects the existence of functional dependency between R&D expenditures and the number of new drugs (product innovation) introduced by US pharmaceutical industry. Pavitt (1984) uses R&D expenditures as an alternative measurement of innovations and points out that sectoral distribution of innovations measured by R&D expenditures in the UK is slightly different from the one measured by the number of patents. In turn, this raises the issue of the bias caused by measurement error induced by variation in likelihood that innovative activity will lead to innovation across firms, markets or sectors of the economy.

The use of R&D expenditures as a proxy for innovations was criticized in the work of Koh and Reeb (2015). They showed that on average 10.5% of firms fail to report any R&D expenditures while they are still filing patent applications. Authors attribute such firms' behavior to their reluctance to share proprietary information on their costs with competitors and they exploit subjectivity component in accounting guidelines to R&D disclosure rules.

Another widely used approach to innovations benchmarking is measuring patenting activities. The number of patents is an objective and straightforward measure of a firm innovative activity that very likely to lead to innovations. In particular, this approach was used in the study of Aghion et al. (2005). The authors pointed out possible discrepancy in significance of the inventions protected by patents and used a patent citation weighting procedure in order to account for that heterogeneity.

The patent-based approach to quantifying innovations also faces much criticism in the literature. For example, Gorodnichenko, Svejnar, and Terrell (2010) argue that patents are not the best approximation of innovations for several reasons. First, the patent is the measure of invention but not innovation; patenting activity does not necessary leads to innovations. Second, the practice of invention patenting varies across countries and industries. Gorodnichenko, Svejnar, and Terrell (2010) in their study of the effect of foreign competition on innovations, estimate parameters of the probabilistic model of innovations. As a benchmark for firm innovativeness, they use a binary outcome variable of innovations (i.e. innovation vs. no innovation). Being limited to the same source of statistical data as Gorodnichenko, Svejnar, and Terrell (2010), we also use the set of binary variables indicating whether or not firms' have introduced certain categories of innovations. This approach, however, imposes some limitations such as an inability to justify the scale of innovations.

2.2 Competition and innovations in the construction industry

The problem of slow technological changes in the construction industry is widely discussed in literature. It is the central theme of a recent report prepared for The World Economic Forum (Renz and Solas, 2016). The authors point out stagnation of technological development in the construction industry worldwide and call on national governments to develop and adopt policy aimed on promotion of innovations in the construction industry. Reichstein, Salter, and Gann (2005) performed comparative statistical analysis of innovation rates in the construction, services and manufacturing. They used a UK innovation survey which is based on Eurostat Community Innovation Survey (CIS). The survey was conducted in the UK in 2001 and covers around 1100 construction firms with more than 10 employees. They revealed substantial differences of construction firms' innovation behavior. First, they documented that innovations in construction occur less frequently compared to other sectors they analyze. Second, on average, UK construction firms less frequently recognize factors hampering innovations. Finally, authors show that *absence of market conditions* requiring innovations were identified as the primary reason for absence of innovations more frequently by construction industry participants than other industries. In this work elements of Reichstein, Salter, and Gann (2005) framework were adopted and extend the analysis to

emerging economies of Eastern Europe and Central Asia. The correlation of innovation and market conditions was estimated among construction firms in the region controlling for other determinants of innovations.

The cornerstone characteristic of market economies is *competition*. It is also the main characteristics of the market observed by a company. The role of competition is defined in classical economic papers (e.g. Mansfield, 1962, 1963; Williamson, 1965 and many others). According to those studies, the primary reason for a firm to innovate is a desire to gain a competitive advantage against its rivals. The mechanisms of competition transmission into innovations is rather complicated and has been extensively studied for the last decades.

There is ongoing debate over the effect of competition on industrial innovations (in the broad sense). According to many theoretical studies¹ (i.e. aforementioned Williamson, 1965) generally competition discourages firms from innovations. However, major empirical studies cited in Aghion et al. (2005) (i.e. Geroski, 1995; Blundell, Griffith and Van Reenen, 1999) and later work of Gorodnichenko, Svejnar, and Terrell (2010) document the positive effect of competition on innovative activities among firms.

There is also a big debate among industrial experts and researchers on the role of competition in the construction industry. Recently, the issue of low innovations intensity and laggard productivity was raised in the report prepared for The World Economic Forum (Renz and Solas, 2016). The authors claim that increase in competition in the construction industry will lead to substantial improvement of innovativeness of construction. They suggest that because of fierce competition and slim profit margins, construction firms will be forced to differentiate their services in order to find a “sweet spot”. In addition, they point out the variety and complexity of today’s customer requirements to the projects, which in turn, will force firms to partnership with, merge with or acquire other firms that have necessary expertise to satisfy complex project requirements. Therefore, the authors recommend that governments facilitate competition in the industry.

A more careful opinion on the role of competition was expressed in the study of Na et al. (2007). The authors point out the importance of the competition moderation by government agencies. They present the example of the Singapore construction industry of the 1980s, where a preferential margin scheme was utilized giving bidding preferences to domestic contractors or joint ventures, where domestic contractors held substantial share. This policy was offered as a response to the unfair competitive pressure claim of domestic contractors which they faced from foreign firms. However, the Singapore government desired to preserve opportunity of technological spillovers and therefore kept the door open for foreign contractors and imposed the policy to moderate the competition.

Waugh, Froese, and Sadeghpour (Waugh, Froese and Sadeghpour, 2016) in their survey of infrastructure owners documented how the excessively competitive environment in the industry created incentives for “individual project participants seeking success through means that detract from the overall project goal”. The authors argue that this environment leaves no possibility for innovations.

Aghion et al. (Aghion *et al.*, 2005) introduced a theoretical framework that implies existing of both positive and negative – effects of competition on innovations. According to their model, two states of the economy exist in equilibrium. In the first state there is low initial level of rivalry among the firms. All firms are at the same technological level and they do not have incentives to introduce innovations to gain profit. Instead, they may collude with their rivals and exaggerate their market power. In this equilibrium, an increase in the competition level will stimulate firms to induce innovations in order to escape competition and gain additional rent² on their technology. In the second state there is high initial level of competition with technological leaders and followers. However, laggard firms do not have incentives to innovate because

¹ Also, Arrow (1962), Gilbert (1982) and Reinganum (1983) cited in Aghion et al. (Aghion *et al.*, 2005) found various negative effects of the competition level on innovations.

² In this context, rent is an extra profit generated by firm using its monopolistic position on the market gained through introducing an innovation

the level of competition at the technological frontier will restrain them from enjoying post-innovation rent sufficient to cover their investments in technology to catch up with the leaders. Therefore, according to the model the innovation-competition relationship is non-linear in competition and follows an inverse-U functional form. Using available firm-level data, the hypothesis of existence of inverse-U shape relationship between competition and innovations among construction firms was tested.

Williamson (1965) studying the effects of competition define the level of competition as an extent of rivalry between industry participants in order to maximize their utility. However, the level of rivalry could be measured in many ways. For example, Williamson (1965) uses the concentration ratio, while other researchers use the Learner index (Aghion *et al.*, 2005), self-reported perception of competitive pressure (Gorodnichenko, Svejnar and Terrell, 2010) or simply number of competitors (Russell, Tawiah and Zoysa, 2006). In this work, due to the data available limitation the self-reported number of competitors as a proxy variable capturing the extent of rivalry faced by a firm were used.

2.3 Other determinants of innovations

Among the first factors found to be important for the industrial innovations was *the firm size*, which was attributed to the market power. The biggest firms were considered to be more innovative, because of higher resource possession and the ability to take a risk to invest in innovations with unclear perspective of commercialization of those innovations (Mansfield, 1963). Later, Oliver Williamson challenged that statement and suggested to consider the problem from the prospective of marginal share of innovations supplied by the largest firms (Williamson, 1965). He developed a microeconomic theoretical framework and showed that the largest firms would supply a lower share of innovations with respect to the increase of their market power, whereas smaller firms marginally would supply more innovations. The rationale for this finding was that large firms would rather exploit their market power instead of innovations to gain higher producers surplus. Meanwhile smaller firms would have to innovate in order to compete for customers. Using the data collected by Edwin Mansfield (Mansfield, 1963), he showed some empirical evidence supporting his theory. Since that discussion, controlling for the size of a firm became a common practice in the research of technological changes (Pavitt, 1984; Aghion *et al.*, 2005; Reichstein, Salter and Gann, 2005; Gorodnichenko, Svejnar and Terrell, 2010, 2014)

The stage of a firm development is also considered as a crucial factor of innovations. This indicator is closely tightened to *the age of a firm*. Gorodnichenko, Svejnar, and Terrell (2010) mentioned that two effects are possible in the context of innovations. First, the positive effect associated with a firm's experience in the industry and acquired capabilities which are a function of time. Second, the negative effect associated with complications caused by the need to rebuild business processes associated with delivery of innovative good or service. Therefore, older firms with an established routine are more likely to be reluctant to innovate. The authors report a negative correlation between firms age and likelihood of innovations. Using patenting as a proxy variable for innovations, Balasubramanian and Lee (2008) showed that firms' age affects not only the number (measured as number of patents filed by a firm) but also quality of innovations measured as number of of firms' patents citations.

Another important aspect of industrial innovations is the capability of industry participants to maintain knowledge flow. This related not only to generation of new ideas, but also to a firm's capabilities to acquire them from external sources. This concept is known as a firm's "absorptive capacity" and it was first introduced in the study of Cohen and Levinthal (1989). The absorptive capacity is largely defined by the knowledge stock disposed by the firm and often proxied by qualification (experience) of the personnel (e.g. Gorodnichenko, Svejnar and Terrell, 2014). In this study personnel qualifications were reflected using distributions of formal *education levels* and *experience* of top management in the field of firms' operation.

3 Data

For this study the Business Environment and Enterprise Performance Survey conducted by the European Bank of Reconstruction and Development (EBRD-BEEPS) and The World Bank (European Bank of Reconstruction and Development, 2017) was used as the primary source of data. The data set consists of 6,566 surveys of privately owned firms in 32 emerging markets of Eastern Europe and Central Asia. The

firms in the sample represent industry composition across countries and excludes highly regulated sectors such as banking or utility supply. The construction sector is represented by 1,432 companies operating in 32 countries (the full list of countries is available at European Bank of Reconstruction and Development, 2017 website)

EBRD-BEEPS carries questions if a firm has implemented each of four types of innovations outlined in the Oslo Manual (OCDE and OECD/Eurostat, 2005) discussed above. In addition, respondents had to justify statements outlined in Table 1 with yes or no answers to identify the way product, process, organizational practice or marketing method was new to the firm.

Table 1 Summary of innovation related questions

Product innovations	Process innovations	Organizational innovations	Marketing innovations
Added new functions to existing product	New production methods	New knowledge management system	New product appearance
Uses new materials or components enhancing performance	New method of delivery or distribution of inputs or outputs	New general management system	New method of advertising or product promotion
Uses new technology	New ancillary support services (accounting purchasing computing etc.	New method of responsibilities distribution among employees	New method of product placement or sales channels
Looks different		New management structure	New pricing strategies
Completely new product to the establishment		New types of collaboration with other businesses	
New product is more efficient		Outsourcing or subcontracting some business activities	
New product is different in some other way			

A set of binary variables was generated using statements outlined in Table 1. Each variable takes values of 1 if a firm reports it has introduced an innovation matching the description in the statement and zero otherwise, given they have reported non-missing answer to corresponding generic questions on the type of innovations they have introduced. Then the generated binaries were used as outcome variables to estimate parameters of the empirical models.

In addition to the factors already discussed in Section 2.3, the control for the fact that firms compete against informal or unregistered firms was added. Including this variable allows better reflect the quality of institutional environment observed by a firm, as well as severity of competition exposed by the shadow economy in the sector. Self-reported annual sales per worker was used as a proxy variable for firms' overall performance and capabilities to conduct innovations. Finally, expectations of companies' sales in the next year was used to determine the possible variation in innovation decision making due to economic expectations of firms' management. The full list of independent variables that were used in the analysis includes the fact that company competes against informal or unregistered firms; age of a firm – time that firms operate on the market; the number of permanent full-time workers; sales growth expectation; annual sales in constant 2010 USD; percentage of personnel with higher education; top managers' experience in the sector.

4 Statistical analysis

Statistical analysis begins with identifying patterns of innovations by employing a toolkit for factor analysis. Factor analysis is a statistical method commonly used in machine learning and data-mining when there is

a suspicion that several observed factors are driven by some unobserved underlying characteristics (Jae-On and Mueller, 1978). Next, logistic regression analysis was applied to justify how organization and business environment characteristics correlate with probabilities that the firm will follow a certain pattern.

First, a group of five binary variables was analyzed: four general types of innovations plus an additional binary variable indicating if a firm has introduced a product innovation that was completely new to the market of firm's operation. The restriction on the minimum eigenvalue to be equal to one was imposed to identify an underlying factor as significant to the system. It turns out that all these innovations are driven by a single common underlying factor, though each of them preserves a high level of uniqueness (the proportion of variables' variation that is not explained by the factors). Next, the factor analysis was conducted through the set of binary variables generated using statements from Table 1. The results show that all innovations, except product, are driven by one single underlying factor. While product innovations are driven by two underlying factors. For classification purposes it is a widely used practice to accept the threshold of factor loadings of $|0.5|$ in order to group variables driven by a certain underlying factor. The analysis showed that the underlying first factor drives innovations that add new functions to existing products, use new technology, adopt completely new products, and/or improves efficiency. While the second underlying factor drives innovations that use new materials of components or that look and/or behave differently in some other way.

Finally, all innovations were combined into a single system. Next the factor analysis was performed through all of them. Using the same criteria for factor selection and variable grouping, it was documented that all innovations are driven by five underlying factors. In addition, grouping variables based on the varimax rotated factor loadings produces identical groups outlined in Table 1 for all, except product innovations. Product innovations sub-categories are classified in two subgroups driven by the second and fourth factors.

Next, two sets of binary variables were generated. The first set includes five binary variables taking a value of one if any innovation from the group being driven by a corresponding underlying factor was introduced by a firm. The second set contains five binary variables taking a value of one if all innovations driven by a corresponding factor were introduced by firms.

The regression analysis starts with estimating coefficients for the linear in competition specification of the logistic regression. Empirical models were estimated over the set of dependent variables that includes general product, process, organizational and marketing innovations, detailed innovations within each category outlined in Table 1, and the set of factor-based dummy variables described above. The estimates, where convergence of log-likelihood function was achieved show mostly negative correlations of competition and probabilities of innovations. However, in most cases, except two, those correlations were statistically insignificant. Two cases with statistically significant coefficients suggest that under competitive pressure, firms are less likely to collaborate with other businesses and are less likely to simultaneously introduce innovations driven by the second factor -products that added new functions to an existing product, introduction of new technology, introduction of a completely new product, and/or the introduction of product that is more efficient).

Next, coefficients for the quadratic in competition specification of the logistic regression was estimated over the same set of dependent variables. The estimates, where convergence of the log likelihood function was achieved, provide consistent evidence of the inverse-U shaped correlation between competition and the likelihood of an innovation being adopted by construction companies.

The much higher number of statistically significant coefficients at competition was observed among quadratic in competition specifications compared to the linear ones. Among statistically significant specifications are those where depended variable was represented by product innovations (in general); radical product innovations (those products that were new to the market); product innovations that use new technology; innovations that delivered more efficient product; at least one innovation was from the group driven by the second underlying factor (which are the product that added new functions to the existing product, it uses new technology, completely a new product, and the product that is more efficient).

In addition to competition, consistently positive and statistically significant coefficients were obtained for the size of a firm (measured as the log of the number of full time permanent workers) and the fact that a firm

had spending on internal research and development within last three years in most of the investigated specifications. This supports the idea that larger firms are more capable of producing innovations. Another interesting result was that competition against firms operating in the shadow economy positively correlated with the probability to introduce innovations.

5 Discussion and conclusion

The global economy faces two major tasks: long term sustainability and growth. Therefore, innovations are crucial for accomplishing both tasks. Given its size, specific features, and current state of technological change the construction industry requires urgent changes in order to promote innovations. The model of an innovative construction industry implies high level of innovative activity among economic agents operating in the sector; development and implementation of innovative products and technologies and substantial use of inputs that are originating from highly innovative sectors (such as Information and Communication Technology, advanced machinery etc.). However, the worldwide trends in the construction industry show negative dynamics in terms of technological change. Therefore, the construction industry requires policy changes in order to stimulate investments into innovations, technological re-equipment, and implementation of innovative solutions at all stages of the business process.

The analysis shows that underlying factors standing behind different types of innovations (i.e. product, process, organizational and marketing) are quite unique to those categories of innovations. Moreover, in most cases, innovations within those categories are driven by a single underlying factor.

A regression analysis revealed that the quadratic in competition specification model provided much better performance compared to the linear specification. In particular, more specifications provide statistically significant correlations between competition and the probability of innovation adoption. The functional form of those relationships is consistently inverse-U shaped. This in turn provides empirical support to the theoretical model of Aghion et al. (2005). In addition, a positive correlation between firms' size and R&D expenditures with the likelihood of introducing innovations by construction firms was observed. This is in line with predictions of theories inspired by works of Edwin Mansfield that argues larger firms are more capable of implementing innovations in the presence of an unclear market perspective. A surprising positive correlation of competition with firms operating in the shadow economy and innovations was documented. The proper interpretation of this finding requires additional investigation that will be attempted by the authors in future research.

Obtained evidence supports the hypothesis of the existence of the inverse-U shaped relationship between competition and certain types of innovations among construction firms. The knowledge gained from this study will be applied to the ongoing research of competition and innovation among Canadian construction firms conducted by the authors of this work. Specifically, this work has allowed to understand the data need and demonstrates the effectiveness of the applied methodology. In the forthcoming work, authors will attempt to collect similar data for the Canadian construction sector, investigate the relationship between competition and innovations, empirically show the causal link between them, and develop a model of competition optimization employing alternative modes of public procurement.

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