# Stimulating Construction Innovation in Singapore through the National System of Innovation

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**Abstract:** This paper examines the national approach to the stimulation of innovation in construction. Based on a qualitative systems thinking approach, a model of the National System of Innovation (NSI) is structured with five main NSI actors: local contractors; suppliers; national research institutions; government; and foreign contractors. This model, established by the assumption that local contractors' key motivation for innovation is based on profit maximization, highlights two main driving forces of construction innovation within the NSI: profit incentives and the social desirability of higher construction productivity and quality. The research findings indicate that high profit levels provide a higher number of growth momentums compared to the social desirability of innovation. Additionally, although social desirability of construction innovation is associated with a number of obstacles, high profit levels do not impose any significant hindrances. Based on the research findings, it is concluded that innovation policies should be focused on sustaining higher profit levels of contractors. The social desirability of innovation can be more efficiently utilized by regular reviews of national policies as the industry develops.

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## Introduction

The past decade has been characterized by an unprecedented rate of economic growth and a race among economic and political entities in search of a competitive edge. Amidst this fast paced environment, innovation has become one of the principal competitive tools which firms can use to achieve greater market penetration and increasing profitability in the construction industry (NRCC 2001). However, despite the importance of innovation tagged on business competitiveness, governments in most countries still face the challenge of stimulating contractors to adopt a higher level of construction innovation.

For instance, in some countries such as Australia, Canada, Japan, and the United States, there is an increasing trend of the replacement of prescriptive building regulations with performance-based versions. It is hoped this will spark higher levels of innovation through greater autonomy in firms. However, these countries still face lower than expected rates of construction innovation (CIB TG 37 2000). In addition, institutionalized research and development (R&D) is identified as a major source of technological innovation (NRCC 1986; Sidwell et al. 1988). This has led to an increase in institutionalized investment for construction R&D in countries such as Singapore, where a construction R&D budget of $20 million adopted in 1999 and 2000 resulted in a low level of innovative activities by local contractors. Such failures in stimulating greater levels of construction innovation may be due to the lack of sensitivity toward firms' fundamental rule of profit creation and the underestimation of the additional efforts and investments required in innovation that compromise the immediate benefits of the normal production process.

Nonetheless, there are consequences for the failure to innovate. The central importance of technological innovation in economic growth has always been recognized. Adam Smith, in the *Wealth of Nations*, discussed "improvements in machinery"; Karl Marx's model of the capitalist economy ascribed a central role to technological innovation in capital goods; and Alfred Marshall described knowledge as the chief engine of progress in the economy. Baumol (2002) observed that innovation is vital for the future economic performance of all nations, noting that (pp. 133 and 34): "Per capita GDP has increased almost nine-fold in the United States since 1870 … nearly ninety percent of current U.S. GDP was contributed by innovation carried out since 1870 … such as the steam engine and the railroad …." Other growth economists observed that innovation itself could change the whole curve of growth as technological innovation leads to productivity gains, a primary basis for growth.

In Singapore, a low level of construction R&D corresponds with negative construction productivity growth every year since 1995 (Construction 21 Committee 1999). As shown in Table 1, the decline of construction productivity has weakened value added in construction. In this study, construction productivity is taken to be one year lagged behind construction GDP to give time for the effects of lower productivity to be perceived by clients, contractors and other relevant actors but the time should not be too extensive to distort the effects of lower productivity on value

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**Table 1.** Descriptive Statistics of Labor Productivity and Construction GDP (Data adapted From Department of Statistics 2004)

| Year | Labor productivity (percentage change) | Annual construction gross domestic product ($ million) | Annual national gross domestic product ($ million) | Contribution of construction gross domestic product to national gross domestic product (percentage change) |
|---|---|---|---|---|
| 1994 | −5.3 | 7,653 | 110,109 | 1.4 |
| 1995 | 4.6 | 8,385 | 118,963 | 12.1 |
| 1996 | −3.8 | 10,323 | 128,679 | 6.9 |
| 1997 | −4.8 | 12,032 | 139,696 | 3.1 |
| 1998 | −5.7 | 12,325 | 138,637 | −17.4 |
| 1999 | −4.7 | 11,217 | 148,108 | −10.5 |
| 2000 | −2.5 | 11,133 | 162,379 | −0.6 |
| 2001 | −0.6 | 10,846 | 159,212 | −17.4 |
| 2002 | −1.0 | 9,530 | 164,255 | −12.0 |
| 2003 | −0.5 | 8,628 | 166,492 | −15.9 |

All prices are as at 1995, Singapore Dollars

added. Fig. 1 shows that negative productivity has led to the declining contribution of construction GDP to the total national GDP. With construction producing between 6 and 10% of GDP in most advanced economies, this would reduce the overall national GDP by a significant magnitude. With such negative impact on national growth, social pressure on the industry to improve its productivity and quality would rise. Such pressure has already been felt in Singapore by the government's implementation of the construction quality assessment scheme which is used to measure, objectively, the level of quality attained on each public project. The buildable design assessment system (BDAS) is also applied to measure the productivity-enhancing potential of the design of a building. To be granted building plan approval, the design of every building must attain a stated minimum BDAS score. Therefore, innovation is required because there are pressures to improve quality, reduce costs and speed up construction processes (Gann 2000).

Many researchers and practitioners (such as Manseau 1998; Milford 2000; NRCC 2001) observed that for construction innovation to be viable, a broad and systemic perspective should be adopted in order to understand and enhance innovation in the construction industry. Hence, the time is right for a national approach toward stimulating innovation in construction as practitioners have been neglecting the declining efficiency of the industry due to their excessive concern with profit creation. There is thus, a need to observe the consequences of such factors on the wider economy and the related effects that would materialize in businesses. In this paper, it is proposed that the involvement of the construction industry in effective innovation can be best understood and stimulated by taking a systems view of construction within the national economy.

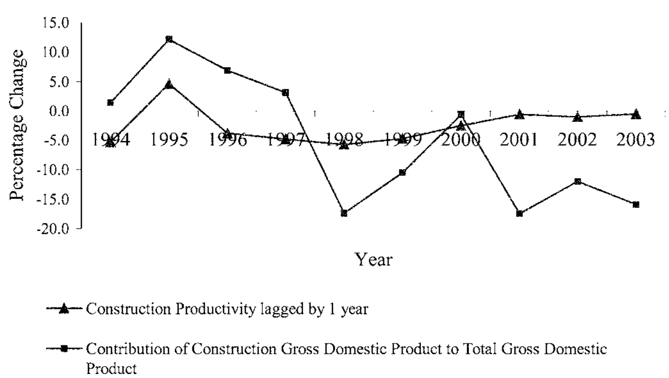


**Fig. 1.** Impact of productivity decline on contribution of construction GDP to total GDP

The objectives of this paper are to: (1) model the role and potential of Singapore's National System of Innovation (NSI) as an effective tool in structuring and supporting the level of innovation of local contractors in Singapore; and (2) recommend policy guidelines that can help attain higher levels of innovation in Singapore's construction industry based on the analysis of the interactions between the key drivers of construction innovation and the actors and variables of the NSI. Qualitative systems thinking is utilized to build and analyze the dynamic model of Singapore's NSI.

After this introduction, the literature is briefly reviewed. This is followed by a description of the research method and an explanation of the technique of systems thinking. The next section presents the statistical analysis. Finally, some conclusions and recommendations are presented.

## Construction Innovation

Various authors have provided a variety of definitions for construction innovation. Pedersen (1996, p. 884) defined construction innovation as "the first use of a technology within a construction firm either in the process or in the product." Although undertaking research on technological improvements in constructed products, Toole (1998, p. 323) termed "process innovation in construction" as the "application of technology that is new to an organization and that significantly improves the design and construction of a living space by decreasing installed cost, increasing installed performance and/or improving the business process." The Construction Research and Innovation Strategy Panel (CRISP) (1997, p. 5) defined construction innovation as "the successful exploitation of new ideas, where ideas are new to a particular enterprise, and are more than technology related—new ideas can relate to process, market or management." These definitions differ in terms of the level of importance they ascribe to technology in innovation.

There appears to exist two distinct forms of innovation. Pedersen and Toole considered construction innovation as inevitably involving the application of technology whereas CRISP deemed it to be "more than technology related" (p. 5). However, Seaden et al. (2001) suggested that an innovative firm is generally innovative in technology and in business at the same time as innovativeness may be a culture that permeates all the activities of the firm. Authors (such as Manseau and Seaden 2001; OECD 1997) hence agree that it is not the degree of technological improvement but the exploitation of an idea, new to a particular enterprise or its processes that must take place for innovation to be deemed to have occurred. Therefore, this study defines innovation from the viewpoint of a construction firm as the purposeful search for new knowledge and the application of this knowledge in production.

## The National System of Innovation in the Construction Industry

According to Edquist (1997), who provided a useful review, the concept of NSI was first proposed by Freeman (1987) and further developed by numerous authors (such as Lundvall 1992; Nelson 1993; Archibugi and Michie 1997; Stern et al. 2000). Freeman (1987) defined the NSI as the network of actors in the public and private sectors whose activities and interactions initiate, modify, and diffuse innovations and implement them in new products, production processes, and organizational forms. There is no agreement on what the key structural elements in a NSI are, and how these elements interact to determine the overall pace and performance of innovative activities in a country, as countries are of diverse sizes, stages of economic development, and historical experiences (Nelson 1993). However, from the various models of the NSI proposed by the OECD (1997), Porter and Stern (2001), and Stern et al. (2000), three critical elements can be highlighted:

1. Firms and the dynamic factors that shape innovation within the firms—such as networks of collaboration with related and supporting industries, rivalry and firms' structures;
2. Common innovation infrastructure—issues of transfer and absorption of technology, knowledge and skills; and
3. Governmental factors—which set the range of opportunities for innovation.

The NSI presents a holistic view of the interrelations among establishments that jointly and individually contribute to the development and diffusion of new technologies. This system of interlinked institutions creates and transfers the knowledge, skills and artefacts that define new technologies. It provides the basic framework within which governments form and implement policies to influence the innovation process.

Laredo and Mustar (2001) observed that analysts have proposed two versions of the NSI. First, the "narrow" NSI focuses on organizations and institutions involved directly in the processes of scientific and technological exploration. Second, the "broad" NSI includes all economic, political, and other social institutions that affect learning, searching and exploring activities. Nelson (1993) stressed the importance of the second approach, bearing in mind that specialists in innovation tend to "play down the existence of active coherent industrial policies" (p. 515) and of a "well-structured and through general policy" (p. 515). Hence, the main actors of the NSI in relation to the construction industry were identified as

1. Firms and the dynamic factors that shape innovations in firms—*construction clients, local contractors, foreign contractors, and suppliers*;
2. Common innovation infrastructure—*national research institutions including higher educational institutions*; and
3. Governmental factors—government.

In this study's NSI model, the actors are placed within the national system of interconnecting relationships, which are further linked by NSI variables. Together under the key drivers of construction innovation within the NSI, the actors and variables structure the level of construction innovation undertaken by local contractors.

To provide empirical support for this study, secondary data are collected from national statistics. These data are based on the statistical methodologies adopted by the OECD in the *Frascati Manual*. Therefore, the actors considered in this study are chosen based on the statistical definitions in the manual. For instance, for the common innovation infrastructure, only research data for non-profit institutions and higher educational institutions are provided. Similarly, only these institutions are considered under this study's common innovation infrastructure.

There are two basic families of science and technology indicators that are directly relevant to the measurement of innovation. First, the resources devoted to R&D and second, patent statistics (OECD 1997). The former relates to innovation input whereas the latter concerns innovation output. However, patents are a measure of only formal innovations whereas a significant amount of informal innovations occur in the construction industry.

R&D expenditure involves the acquisition and generation of relevant knowledge that is new to the firm. It comprises creative work undertaken on a systematic basis in order to increase the stock of new knowledge, and the use of this stock of knowledge to devise new applications (OECD 1997). This proxy however has the limitation that R&D is only an input and although it is related to technical change, it does not measure it. Further, R&D expenditures alone cannot be the appropriate measure for contractors' levels of innovation. Nonetheless, the alternative would be to conduct surveys on contractors but this would also provide only a partial representation of the actual situation. A survey of contractors would be inappropriate in this study as the study considers the macrolevel of a nation. Data obtained from such a survey would be insufficient for comparison and regression against other NSI variables such as construction GDP and annual foreign direct investment in construction. Thus, this study utilizes the total R&D expenditure of construction firms, as a proxy for the level of innovation in construction. Annual R&D expenditure of local contractors is obtained from the *National Survey of R&D in Singapore*, which is based on the guidelines in the OECD's *Frascati Manual* (OECD 1993). This study takes the annual R&D expenditure of local contractors under the area of research of civil and architecture. This area of research is appropriate as the *Frascati Manual* defines civil engineering, under fields of science and technology, to include architectural engineering, building science, and engineering, construction engineering, municipal and structural engineering, and other allied subjects (OECD 1993, p. 60).

**Drivers of construction innovation in the national system of innovation**: In Harper's (1963) judgment, the root problem of poor growth in any industry or nation is the failure to understand the nature of the economic system. This is especially so for the repeated failure to capitalize on the power of profit incentives to induce productive efforts, investments, and innovation. For business investments to increase, there must be an adequate incentive to invest: an expected rate of return that is commensurate with the risks of the business enterprise. However, in the developing countries of Asia, such as India, China, and Thailand, labor is sufficiently cheap to allow profit driven firms to disregard the need for technological advancement. Hence, for private construction firms, undertaking an innovation implies the willingness to act with the hope that this "off-the-regular-business effort" will, despite the associated risks and uncertainties, yield benefits that will meet the expected pay offs (Klein and Sorra 1996). Nonetheless, business rationalism and the risk averse nature of firms involved in one-off construction projects surpass private firms' drives for advancements. In addition, in construction, clients' tendencies to award projects based on the lowest cost results in profit margins in the construction sector that are often so low that they provide inadequate incentives for firms to innovate. Therefore, to induce contractors to innovate, a profit incentive is one of the key motivators. Thus, this trade-off between the implementation hurdles and expected benefits is one of the main challenges of national policies in inducing greater levels of innovation in the construction industry.

This challenge is further intensified by the phenomenon that R&D investments in innovation tend to create improvements in well-being that are much larger than the private returns that are captured by the organization undertaking it (Seaden 1996). A survey by Griliches (1991) indicated that between one-third and two-

| Symbol | Interpretation |
|---|---|
| $X \xrightarrow{+} Y$ | All else equal, if X increases (decreases), then Y increases (decreases) above (below) what it would have been. In the case of accumulations, X adds to Y. |
| $X \xrightarrow{-} Y$ | All else equal, if X increases (decreases), then Y decreases (increases) below (above) what it would have been. In the case of accumulations, X subtracts from Y. |

Source: Business Dynamics: Systems Thinking and Modeling for a Complex World (Sterman, 2000) Reprinted with permission of the McGraw-Hill Companies

**Fig. 2.** Link polarity: Definitions

thirds of the economic benefits of R&D are not captured by the organization that performs it. Mansfield (1977) found that innovation in construction materials presents one of the greatest divides, with social returns of 96% and only 9% of private returns. Hence, the failure to innovate by contractors represents a loss of benefits to society. Over time, society's loss is translated into social pressure on contractors to narrow this gap of inefficient production.

Therefore, in construction, the difference between society's demand for higher construction productivity and quality and the actual productivity and quality provided by contractors, presents the pressure first, on the construction firms to innovate and second on the governments to introduce changes in their policies and regulations toward stimulating innovation in construction. Hence, the profit motivation of private firms and the social pressure to innovate are recognized in this study as the key drivers of innovation in the NSI. They constitute the main force that impels the NSI actors and variables towards a higher level of innovation by contractors within the NSI.

## Methodology

A set of secondary statistical data for Singapore was collected from various national publications such as the *Yearbook of Statistics, Economic Survey*, and *National Survey of R&D in Singapore*. By applying Pearson's correlation and nonlinear regression to the data for 1981–2002, a logical deduction of the relationship and significance of each NSI determinant with regard to construction innovation was obtained. This aided the formulation of the NSI model. Statistical Package for the Social Sciences (SPSS) was used as the analysis software for nonlinear regression whereas Vensim was used in the development of the systems thinking model of the NSI.

### *Principles of Systems Thinking*

System thinking helps individuals to see patterns and helps create the ability to reinforce or change these patterns (Senge and Fulmer 1993). By constructing a formal model, the mental image of the system and its structure are exposed. Hence, systems thinking is a method of dealing with questions about the dynamic tenden-

**Table 2.** Descriptive Data

| Year | Local contractor's level of innovation ($ million) | Construction labor productivity ($ / person employed) | Construction demand ($ million) | Value of foreign investment in construction ($ million) | Value of exports of construction services ($ million) | National Research Institutions' joint venture with construction companies ($ million) | R & D capability of local contractors (full time equivalent) | Availability of funds for construction innovation ($ million) |
|---|---|---|---|---|---|---|---|---|
| 1981 | 0.05 | 26,712 | 2,163 | 211.6 | 5.0 | 0.0200 | 1 | 2,757 |
| 1982 | 0.05 | 27,883 | 3,146 | 205.1 | 5.0 | 0.0200 | 5 | 3,652 |
| 1983 | 0.05 | 31,016 | 4,202 | 54.2 | 10.0 | 0.0200 | 5 | 5,141 |
| 1984 | 0.05 | 34,083 | 4,943 | 153.2 | 15.0 | 0.0200 | 10 | 6,433 |
| 1985 | 0.60 | 36,143 | 4,167 | 246.2 | 20.0 | 0.0400 | 10 | 6,829 |
| 1986 | 0.60 | 34,653 | 3,149 | 314.9 | 30.0 | 0.0400 | 22 | 6,459 |
| 1987 | 0.60 | 34,933 | 2,885 | 199.6 | 40.0 | 0.0400 | 22 | 5,563 |
| 1988 | 0.60 | 35,501 | 2,811 | 361.2 | 50.0 | 0.0400 | 22 | 5,284 |
| 1989 | 0.60 | 35,536 | 3,106 | 716.6 | 60.0 | 0.0400 | 22 | 6,436 |
| 1990 | 0.70 | 35,968 | 3,614 | 614.7 | 70.0 | 0.1831 | 34 | 7,116 |
| 1991 | 0.55 | 36,928 | 4,697 | 749.8 | 72.0 | 0.0530 | 24 | 12,864 |
| 1992 | 1.30 | 42,107 | 6,048 | 612.2 | 130.2 | 0.0200 | 64 | 9,285 |
| 1993 | 2.60 | 39,988 | 6,771 | 497.0 | 187.0 | 0.0619 | 59 | 11,394 |
| 1994 | 0.50 | 41,916 | 7,975 | 611.5 | 236.0 | 0.1683 | 61 | 13,510 |
| 1995 | 0.60 | 40,323 | 8,365 | 979.3 | 411.0 | 0.3118 | 50 | 16,713 |
| 1996 | 1.20 | 38,388 | 10,629 | 1017.8 | 302.0 | 0.5422 | 97 | 21,401 |
| 1997 | 1.40 | 36,200 | 12,657 | 1190.4 | 499.0 | 0.3552 | 51 | 26,235 |
| 1998 | 1.40 | 34,498 | 12,835 | 1430.6 | 558.0 | 0.2302 | 76 | 25,580 |
| 1999 | 0.50 | 33,636 | 11,125 | 1416.6 | 387.0 | 0.2045 | 38 | 23,444 |
| 2000 | 0.70 | 33,434 | 9,853 | 1963.6 | 572.0 | 0.0268 | 80 | 25,645 |
| 2001 | 0.90 | 33,100 | 9,280 | 1676.5 | 757.9 | 0.1236 | 39 | 26,578 |
| 2002 | 1.30 | 32,934 | 8,375 | 1858.6 | 689.3 | 0.135 | 80 | 23,799 |

Note: All prices are as at 1995.



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**Table 3.** Variables Measurement Framework

| Connotation | Variables/factors | Measurement framework |
|---|---|---|
| LCI | Local contractor's level of innovation | Annual R & D expenditure of local contractors |
| CLP | Construction labor productivity | Construction value add per person employed |
| GDP | Construction demand | Construction industry's contribution to gross domestic product |
| EFC | Value of foreign investment in construction | Stock of foreign direct investment in Singapore in construction |
| ELC | Value of exports of construction services | Stock of Singapore's direct investment abroad for construction |
| NJV | National Research Institutions' joint venture with construction companies | Annual financial statement of building and construction authority's interest in joint venture |
| RDC | R & D capability of local contractors | FTE[a] value of R & D personnel in construction |
| CBL | Availability of funds for construction innovation | Bank loans and advances to local contractors |

[a]FTE=full time equivalent—methodology based on *Frascati Manual* (OECD 1993).



cies of complex systems, which are the behavioral patterns they generate over time. Therefore, systems modeling is able to effectively structure the complex interaction between the various NSI actors and their relationships with NSI variables through the utilization of causal loop diagrams.

Fig. 2 presents the typical denotations used in causal loop diagramming. At the foundation of the systems approach are positive and negative feedbacks. Positive feedback is represented by a reinforcing loop that is structured by none or an even number of negative links while negative feedback is represented by a balancing loop that is structured by an odd number of negative links. Positive feedback creates reinforcing behavior and negative feedback moderates a system toward an equilibrium position. Sterman (2000) suggests that the identification of positive and negative feedback structures in economic and management systems is key to modeling and gaining insights into the developments of innovations.

### Data Analysis

In the model, key NSI variables are highlighted and analyzed in relation to the dependent variable of local contractors' levels of innovation through assigning suitable proxies. Data on the key NSI variables are presented in Table 2. The measurement frameworks of these variables is presented in Table 3. The other NSI variables that link these key NSI factors are not analyzed quantitatively as they are qualitative, intangible factors for which satisfactory proxies could not be found. The descriptive data in Table 2 are first, subjected to Pearson's correlation and second, to nonlinear regression analyses. The results of these analyses are presented in Tables 4 and 5, respectively.

From Table 2, it can be observed that although Singapore's construction industry is highly dependent on FDI, the volume of Singapore contractors' export of construction services is less than one-third of FDI. This shows the importance of foreign contractors as investing entities in contributing to technology transfer in the host country. Conversely, the relatively low level of export of construction services by Singapore contractors suggests that these firms are mostly acting as intelligent imitators to improve their performance rather than following the first innovator strategy which involves high learning costs. However, this strategy of imitation does not place nations at the cutting edge of technology and

**Table 4.** Pearson Correlation Matrix

| | Local contractor's level of innovation | Construction labor productivity | Construction demand | Value of foreign investment in construction | Value of exports of construction services | National Research Institutions' joint venture with construction companies | R & D capability of local contractors | Availability of funds for construction innovation |
|---|---|---|---|---|---|---|---|---|
| Local contractor's level of innovation | 1.000 | −0.538 | 0.526 | 0.718 | 0.788 | 0.578 | 0.851 | 0.662 |
| Construction labor productivity | −0.538 | 1.000 | −0.736 | −0.672 | −0.734 | −0.602 | −0.591 | −0.773 |
| Construction demand | 0.526 | −0.736 | 1.000 | 0.729 | 0.863 | 0.695 | 0.744 | 0.946 |
| Value of foreign investment in construction | 0.718 | −0.672 | 0.729 | 1.000 | 0.902 | 0.658 | 0.771 | 0.861 |
| Value of exports of construction services | 0.788 | −0.734 | 0.863 | 0.902 | 1.000 | 0.730 | 0.898 | 0.949 |
| National Research Institutions' joint venture with construction companies | 0.578 | −0.602 | 0.695 | 0.658 | 0.730 | 1.000 | 0.641 | 0.722 |
| R & D capability of local contractors | 0.851 | −0.591 | 0.744 | 0.771 | 0.898 | 0.641 | 1.000 | 0.822 |
| Availability of funds for construction innovation | 0.662 | −0.773 | 0.946 | 0.861 | 0.949 | 0.722 | 0.822 | 1.000 |



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**Table 5.** Nonlinear Regression Analysis Results

| Variables | Unstandardized coefficients B | Unstandardized coefficients Standard error | Standardized coefficients Beta | $t$ | Significance |
|---|---|---|---|---|---|
| (Constant) | 6.439 | 3.929 | | 1.639 | 0.121 |
| CLP | −0.09 | 0.019 | −0.135 | −1.522 | 0.150 |
| GDP | −1.271 | 0.488 | −0.599 | −2.607 | 0.019 |
| ELC | 0.373 | 0.262 | 0.512 | 1.423 | 0.174 |
| NJV | 0.098 | 0.179 | 0.090 | 0.549 | 0.591 |
| RDC | 0.733 | 0.267 | 0.701 | 2.744 | 0.014 |

Note: Dependent variable: Local contractor's level of innovation. Variable removed due to significant correlation: Value of foreign investment in construction, availability of funds for construction innovation. $R^2$ value = 0.809. Standard error of the estimate: 0.591704.

therefore does not guarantee that the economy will continue to grow at a pace similar to what was first recorded when the imitation of technology took place.

In Singapore the level of joint ventures between contractors and national institutions is also low. This shows that although the construction sector still looks to the government to provide directions and leadership in innovation (Ofori and Chan 2001; Dulaimi et al. 2003), there has not been much effort from either side to utilize the collaborative mechanism to reinforce the role of either party in innovation. Similarly, the research capability of contractors as measured by the full-time equivalent of R&D personnel is very low. This is likely due to the absence of formal R&D departments in construction firms.

The data were subjected to Pearson's correlation analysis (Table 4) to first, observe and validate the relationships within the NSI variables themselves and between the key NSI variables and contractors' levels of innovation. Second, Pearson's correlation matrix prepares the data for nonregression analysis through the identification and removal of variables that show multicollinearity. Availability of funds for construction innovation was observed to be highly correlated with construction demand and the value of exports of construction services. They have high correlation values of 0.946 and 0.949, respectively. In addition, value of foreign investment in construction has a high correlation value of 0.902 with value of exports of construction services. Hence, the NSI variable of availability of funds for construction innovation and value of foreign investment in construction were removed to satisfy the multicollinearity assumption, to provide a satisfactory regression. However, this does not imply that these variables do not significantly contribute to Singapore contractors' levels of innovation.

The remaining NSI variables are subjected to nonlinear regression to highlight the key NSI variables that significantly contrib-

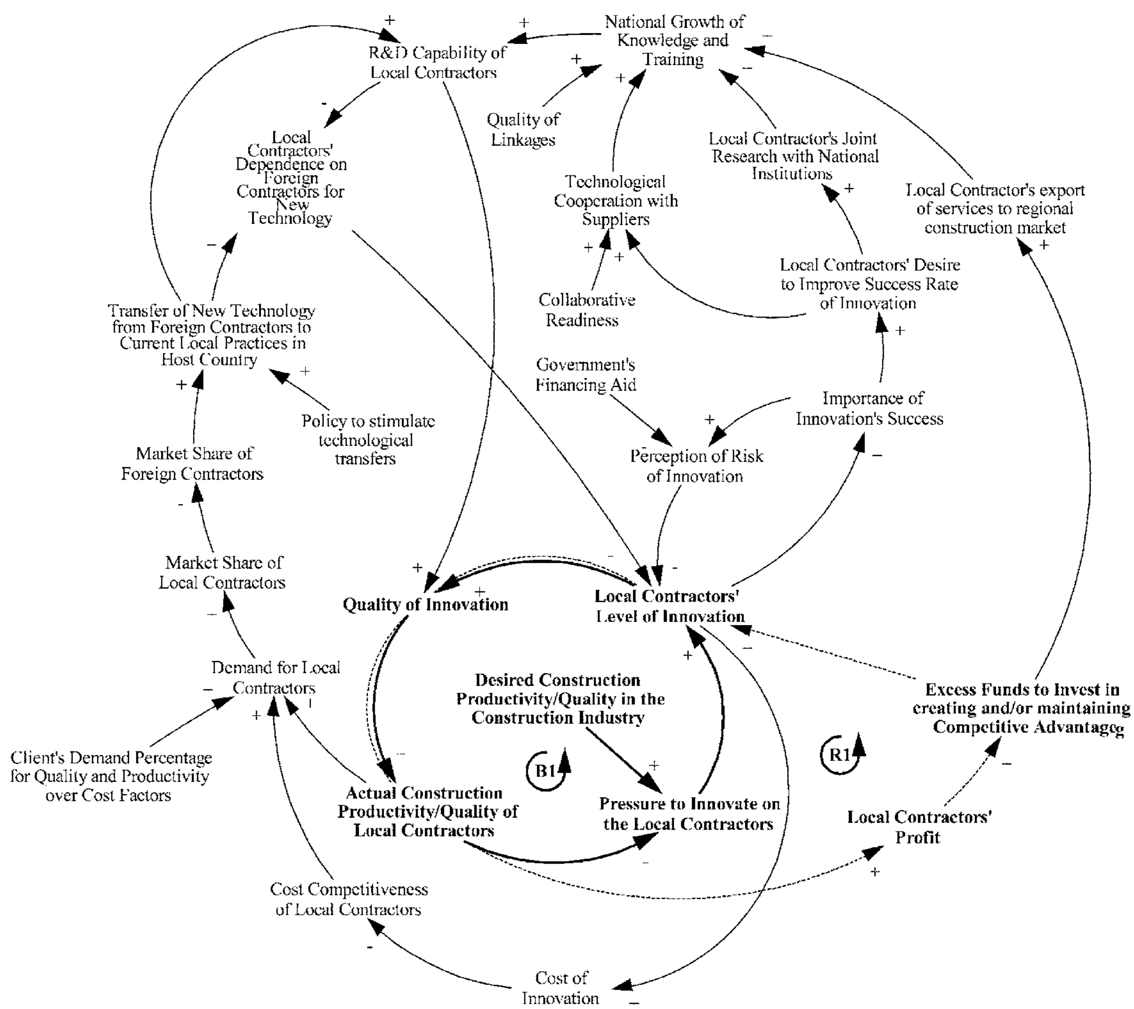


**Fig. 3.** Forces of the NSI in initiating construction innovation by local contractors



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ute to contractors' levels of innovation. This would identify the crucial feedbacks within the NSI model. The findings from the regression analysis show that all key NSI variables subjected to nonlinear regression are significant except for National Research Institutions' joint venture with construction companies. This may be due to the exceptionally low value of joint ventures between national research institutions and construction firms. The final regression result provides a high $R$-squared value of 0.809. The regression's coefficient table (Table 5) provides the model equation for this study's NSI model as

$$\mathrm{LCI} = 625.78(\mathrm{CLP})^{-0.09}(\mathrm{GDP})^{-1.271}(\mathrm{ELC})^{0.373}(\mathrm{RDC})^{0.733}1.807.$$

### Model Validation

Pearson's correlation analysis partially validates the systems model through verifying the positive and negative relationships of each independent variable to the dependent variable and within the independent variables themselves. Together, the variables provide the basic structure of the model, characterizing each of the feedbacks into either reinforcing or balancing loops. However, to provide a logical flow of notions that is easy to comprehend, further qualitative variables that are not tested are introduced. Nonetheless, the introduction of these variables does not distort the statistical relationship of each key independent variable with the dependent variable within the model. Thus, the model is, to a degree, conceptual in nature, and has not been fully validated.

## Logic of the National System of Innovation and Construction Innovation

As the model in Fig. 3 shows, the two drivers of innovation, profit motivation and social pressure, shape the centrifugal force that propels innovation in the NSI. In Fig. 3, the profit level of local contractors depends on the state of construction productivity and quality. This, in turn, is driven by the pressure on local contractors to innovate, established by the disparity between the social and private desire for higher construction quality and productivity. These interlocking loops between R1 and B1 portray the independent forces of profit incentives and the social desirability of developing a sustainable NSI that, nevertheless, bear an interdependent relationship. From this, the impacts of this centrifugal force on each of the NSI actors are analyzed. A summary of their impacts is presented in Table 6.

### Firms

The OECD (1997) observed that it is the firm that is at the center of an enabling network of suppliers, competitors, clients, as well as educational, communication, financial, and legislative infrastructures. Hence, the firm is the dynamo that fuels innovations in construction. However, in most countries, the rate of construction innovation has been found to be slow (Veshosky 1998). The NSI model notes two reasons that impede innovation in Singapore construction firms. First, local contractors do not place high importance on the success of innovation. This may be because, owing to the typically low profit margins in construction, the firms fear that a loss on an innovation may have a critical impact on their survival. The focus on the need to succeed in innovation hence leads to the perception of high risks that will lower the local contractors' level of innovation (Fig. 4, B2).

**Table 6.** Dynamic Feedbacks of the NSI on Construction Innovation by Local Contractors

| | Drivers of innovation | |
|---|---|---|
| | Profit driven | Social desire |
| Momentum for growth in construction innovation by local contractors | | |
| Local contractors | R3 | — |
| Suppliers | R4 | — |
| Institutions | R5 | — |
| Foreign direct investment | R7 | — |
| Anticipated barriers to growth in construction innovation on local contractors | | |
| Local contractors | B2, B6 | — |
| Suppliers | — | B4 |
| Institutions | — | B5 |
| Foreign direct investment | B3 | — |

Second, the conventional practice in Singapore of awarding construction projects based on the lowest cost places price-based competition at the top of contractors' lists of business strategies. Hence, investments in R&D and innovation have been regarded as cost burdens with high risks of failure and inadequate returns (Fig. 4, B3). Thus, contractors in Singapore still adopt conventional cost-based competitive strategies that they are accustomed to, and the nation relies on foreign contractors for technological advancements. However, the model demonstrates that there is a need for a simultaneous consideration of clients' demand for quality while bearing in mind that the profit incentives for Singapore contractors have a continuous momentum for growth in innovation (interlocking feedbacks of Fig. 4, R3, Fig. 3, R1). Nevertheless, the regression results show that the higher the construction demand, the lower the level of innovation. This contradictory relationship may be due to the measurement of the quantity of demand rather than quality. Hence, higher quantity of demand may not stimulate innovation in construction. Rather, it is the demand for higher productivity and quality that will stimulate innovation.

### Suppliers

Liebing (2001, p. 10) described construction as "an amalgamation of thousands of diverse parts combined and blended together into a new entity, which is intended to provide a shelter or a function far different from individual parts." With their high dependence on other sectors, construction firms are largely technology followers (Hertog and Brouwer 2001). Therefore, numerous authors (such as Bernstein and Lemer 1996; Kangari and Miyatake 1997; and Langford and Dimitrijevic 2002) see the formation of cross-industry strategic alliances as a powerful combination with which to promote and sustain construction innovation. Brod and Shivakumar (1997) observed that the benefits of cooperative R&D include: Alleviating the under provision of R&D efforts that result from technological spillovers; avoiding duplication of efforts; sharing of risks; and exploitation of synergies. An example of a strategic alliance was formed between Shimizu Corporation and Mitsubishi Heavy Industries to develop the world's first automated intelligent system for high-rise building construction, the SMART system. Also, Honda's humanoid platform (P3) that is to be utilized as generic robotic construction operatives was developed in a collaborative research project.

The NSI model shows that high profits help to initiate collabo-



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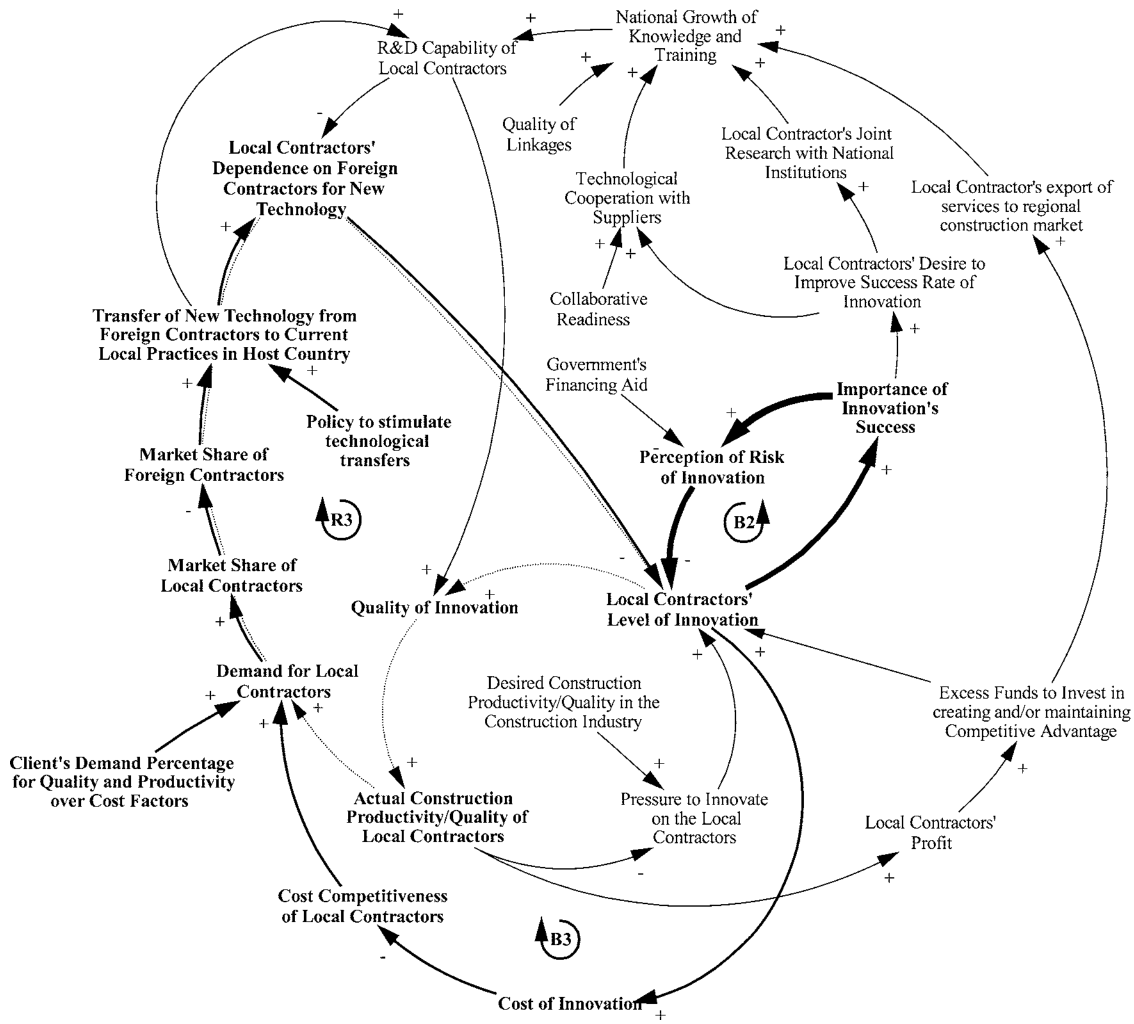


**Fig. 4.** Feedbacks involving construction firms

rative efforts with CD suppliers (Fig. 5, R4). Nonetheless, this has to be combined with contractors' desires to improve the success of innovation. However, such desires are often associated only with large R&D projects, such that a contractors' level of innovation has to be large enough for its success to be considered to be important.

In addition, Fig. 5 shows that social pressure has no growth effect on the technological cooperation between local contractors and suppliers. Instead, it presents obstacles to innovation, an oscillating cycle in the level of innovation by local contractors (Fig. 5, B4) which hinders long-term cooperation. It may also lead to the perception among local contractors that only short-term collaboration is essential or beneficial for business competitiveness.

## *National Research Institutions*

It is often assumed that there is a linear flow from basic science to applied science to technology (Rashid 2000). Nonetheless, with the range of knowledge required for the development of new products and processes generally beyond the capacity of the individual innovating firm, there must be access to information, ideas, and systems from knowledge-intensive actors such as national research institutions, universities, and research laboratories (Capron and Meeusen 2000). Within the NSI, the national research institutions provide the basic knowledge that forms the "advanced factor" (Porter 1990, p. 77) of the NSI which, as compared to the basic factor of unskilled workers and low or established technology, sustains competitive advantage through continuous growth of knowledge and training. This will in turn increase the R&D capabilities of local contractors that will increase their profits and hence their level of innovation (Fig. 6, R5). This relationship between R&D capability of local contractors and their level of innovation is supported by the correlation and regression analyses.

There have been several examples of such collaboration in many countries. For instance, Australia's Cooperative Research Centre for Construction Innovation and the United Kingdom's CRISP are joint industry and government panels that identify and develop priorities for research flinders. They also help set the agendas for construction research and innovation. However for Singapore, the descriptive statistics in Table 2 show that there is a low level of joint ventures between contractors and national institutions. Hence, there is a need for Singapore to effectively utilize further collaborative mechanisms to reduce the dependence of Singapore contractors on the Government and also to reap the benefits of higher innovation levels.

The impact of social pressure to innovate on local contractors indicates that although initial high pressure will lead to more joint ventures with national research institutions in an attempt to im-



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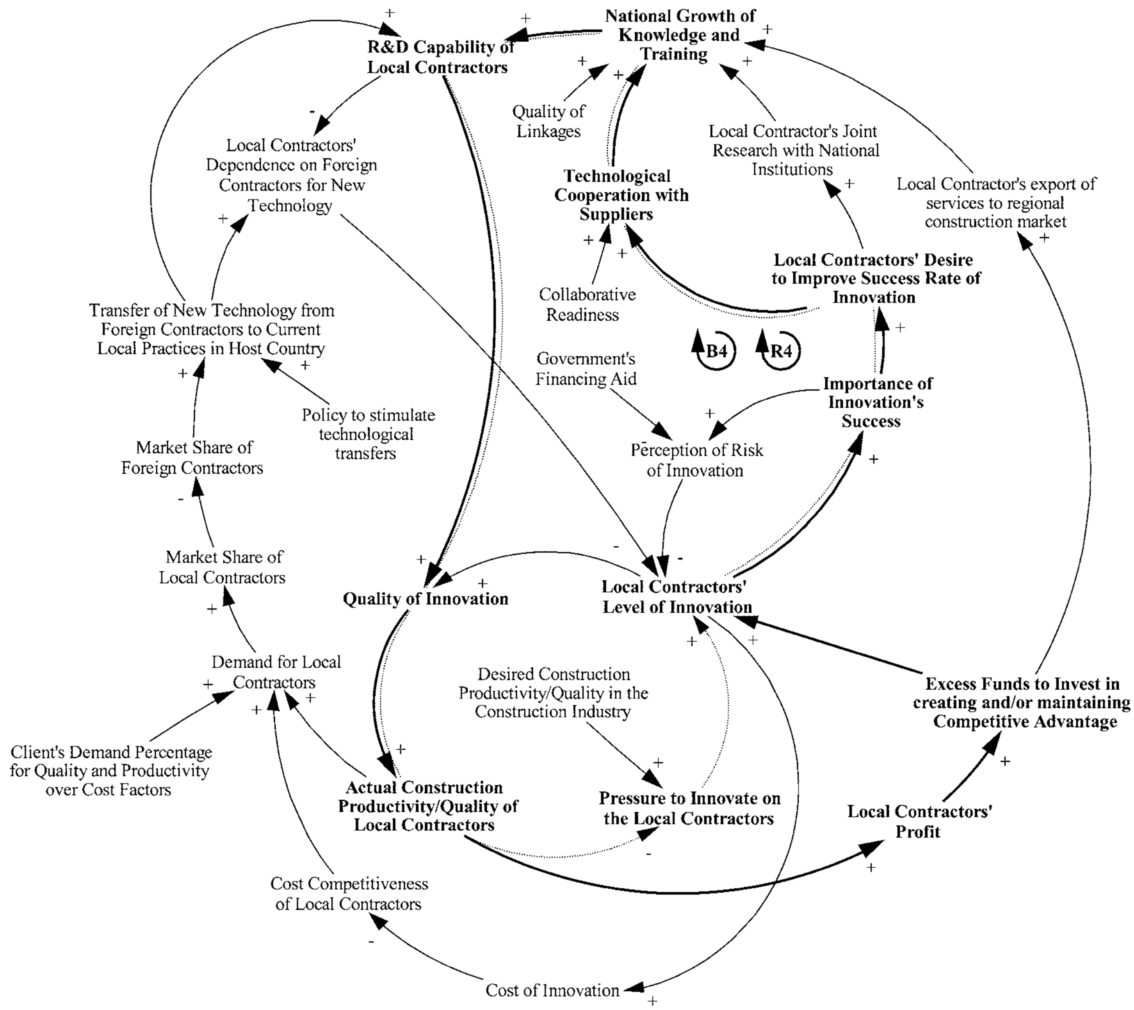


**Fig. 5.** Feedbacks involving suppliers

prove the success of innovation, it will inevitably lead to oscillations in the level of innovation by local contractors (Fig. 6, B5). This can be corrected into a continuous impetus to innovate by the local contractors by constantly reviewing the social desirability of construction quality and productivity through policies and regulations that convey such information. This view is supported by the results of the correlation analysis which show that the higher the collaboration between national research institutions and local contractors, the higher the local firm's level of innovations.

## Foreign Contractors

In today's globalized economies, the growing proximity and potential tension among national systems increase the demand for nation-specific systemic differences and impacts of innovation practices that relate to international trade to be understood (Ostry and Nelson 1995). Studies show that in Singapore, the competitive edge of foreign firms over local firms is due to their ability to deliver cost efficient, higher quality work, with superior project management and technological expertise (Ho 1987).

For instance, Shimizu Corporation, a Japanese construction firm, won the contract for the redevelopment of the Marco Polo Hotel into a luxury condominium although Shimizu was the highest bidder. The developers, Marco Polo Developments Limited, explained that this was because they believed that Shimizu would provide the best quality of work and safety standards. Similarly, Dragages Singapore Pte Ltd., a French construction firm, was engaged by the joint venture between SC Global Development and First Capital Corporation to undertake The Ladyhill project, another top-class luxurious condominium, due to the assurance of quality although Dragages was one of the highest bidders.

The foreign contractors operating in Singapore bring with them new technologies that can be transferred to local contractors. This would allow improvements in local contractors' level of productivity and quality (Fig. 4, R3). At the broad, national level, this strategy is not new to countries such as Singapore, Hong Kong, and Malaysia that have, for several decades, leveraged on FDI by multinational corporations for their economic growth (Mahmood and Singh 2003). Further, Singapore's trade openness, as measured by the ratio of total trade to GDP, is among the highest in the world (Wong 2003), making the country a natural candidate for stimulation of innovation through a competitive economy. However, the NSI model indicates that this transfer of new technologies is dependent on both clients' demands, for quality and the contractor's cost competitiveness. The interlocking nature of B3 and B6 in Figs. 4 and 7, respectively, shows that the dominance of either feedback depends on the client's demand for quality over cost considerations. The effect of the dominant loop would be further emphasized by the growth feedback of R3 (Fig. 4).



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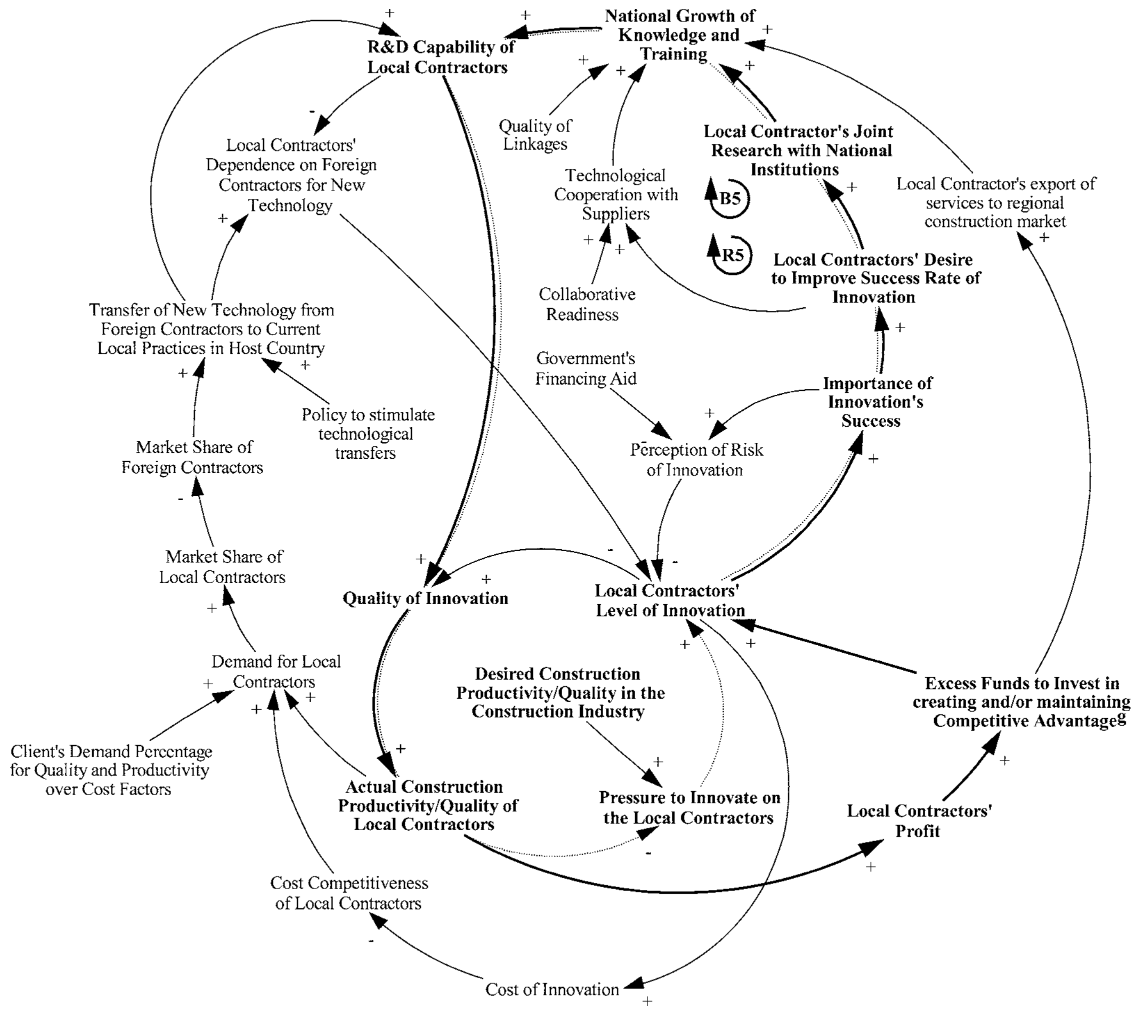


**Fig. 6.** Feedbacks involving National Research Institutions

For example, as Singapore clients give preference to cost and this forms the basis of competition in the industry, this will allow B3 (Fig. 4) to dominate over B6 (Fig. 7). Therefore, local contractors will experience low demand if they engage in innovation. Hence, the increase of Singapore contractors' dependence on transfer of technology from foreign firms to maintain their level of competitiveness and gain adequate profit. This effect will diffuse into R3 (Fig. 4), which will amplify this negative impact, creating a continuous lowering of local contractors' levels of innovation and further increase in the dependence on technology transfer. It will also lead to a continuous decrease in contractor's profit through the interlocking feedback of R3 (Fig. 4) with R1 (Fig. 3), hence, further lowering the contractors' levels of innovation.

On the other hand, if clients' demands for quality increase, B6 will dominate over B3. Hence, demand for the services of local contractors will be high if they engage in innovation. This effect will diffuse into R3 (Fig. 4), which will amplify this positive impact into continuous growth of contractors' level of innovation and lowering of the dependence on transfer of technology. It will also lead to a continuous increase in contractors' profit through the interlocking feedback of R3 (Fig. 4) with R1 (Fig. 3).

Nonetheless, with reference to B6 (Fig. 7), the increase in contractors' levels of innovation through inward FDI is due to an increase in the R&D capabilities of the local contractors through technology transfers. However, this affiliation is not sustainable because when local contractors improve, there will be a decrease in technological transfers as foreign firms shift to protect their competitive edge. Therefore, local construction firms should utilize their improved R&D capability, shifting slowly from imitating technologies to developing their own. This strategy can be facilitated by outward FDI into the countries in the South-East Asia region.

In Fig. 7, R7, through outbound FDI, home firms cannot only maintain or boost their profits, but also improve their R&D capabilities through increased experience. With increased profits and capabilities, they will be able to engage in their own innovation. These relationships are supported by the regression analysis that demonstrates the positive relationship between the level of innovation with the value of exports of construction services and contractors' R&D capabilities. Moreover, through this strategy, local contractors will be able to carve their own niches through strategic innovations, boosting their competitive edge in the regional market through outward FDI.

## Oscillating Cycle of the Level of Construction Innovation Caused by Social Pressure to Innovate

The oscillating feedbacks that obstruct the continuous growth of construction innovation are mainly due to the socially desired level of construction productivity and quality remaining constant



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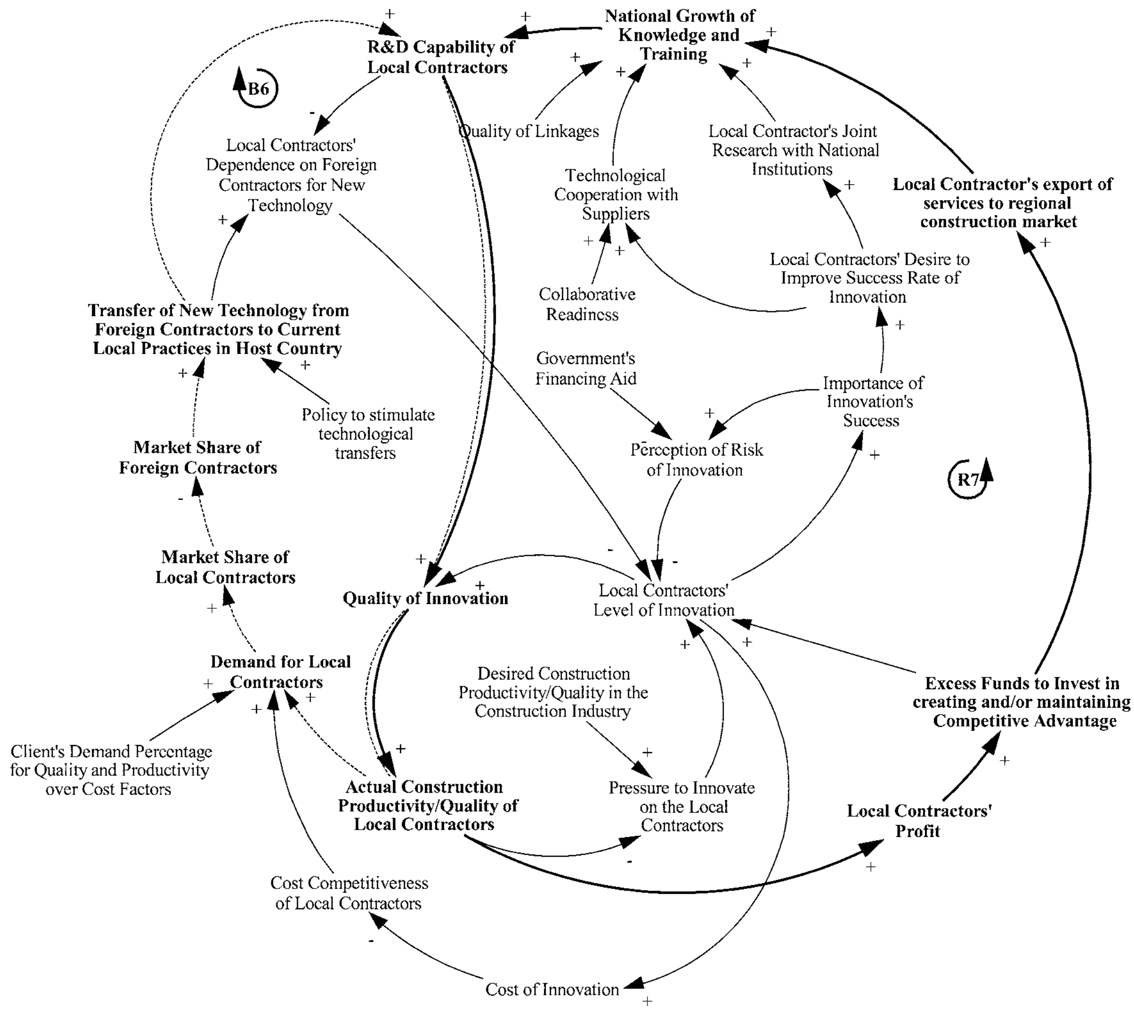


**Fig. 7.** Feedbacks involving foreign contractors and local export of construction services

throughout the interaction time. In the first cycle, high levels of innovation will induce improvements in actual construction quality and productivity. This will lead to lower pressures to innovate as the gap between social desire and actual private performance reduces. Hence, with lower pressure to innovate carried over into the second cycle, the level of innovation will be lower compared to that in the first cycle. This will lead to a lowering of the performance of local contractors, widening the gap between socially desired and actual construction quality and productivity, hence causing the pressure to innovate to oscillate upward once again into the third cycle. Therefore, to reduce the magnitude of the oscillation, it is important that social intentions are constantly reviewed as the construction industry develops, to convey the right signals to industry players.

## Toward Sustainable Stimulation of Construction Innovation Through the National System of Innovation

From the feedback, technological cooperation between suppliers and local contractors is driven by the profit motive. However, construction is often characterized by many interconnected and customized elements that are organized in a hierarchical way that often impedes innovation. This presents two major hindrances to efforts in construction innovation. First, as noted by Nam and Tatum (1992, p. 520), "material suppliers develop new materials, equipment suppliers develop new equipment and construction professionals are rarely aware of these developments; their focus is usually on reducing the material and labour requirements for a project." This is further aggravated by the typically large number of small-sized enterprises in construction and the highly fragmented industry that hinder innovation.

Second, present procurement methods and contractual arrangements based on standard forms of contract, bylaws, and codes of practice enforce differences in values, goals, and orientation among members of the construction project team (Bresnen and Marshall 2000). This, together with the contractual system that emphasizes the one-off project nature, often creates adversarial relationships among practitioners that further weaken the linkages among them. Therefore, although profit is the main driving force for collaboration between suppliers and contractors, the magnitude of the impacts that the observed industrial collaborative feedbacks have on construction innovation is largely dependent on the readiness of the parties involved to cooperate.

Similarly, technological cooperation with National Research Institutions is most feasible when local contractors are given profit incentives. However, this variable was noted to contribute insignificantly to Singapore contactors' level of innovation. Nonetheless, lessons from developed nations, such as Japan, the United Kingdom, and the United States, show that where levels of gov-



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ernment investments in national development are already high, any further investments in resources will yield meager if any, returns (Yusuf and Evenett 2002). Hence, there is a need for a reconfiguration of industry level strategies in construction (Yusuf 2002). For instance, the Japan Association of Representative General Contractors, comprised of 120 medium-sized contractors which receive no political protection from the State, aims to promote the modernization and rationalization of management, improve technical capabilities, and contribute to the effective development of the construction industry in Japan (Okamoto 2000). Likewise, in Canada, a consortium of major private building owners sponsored a major study of best repair practices for garages damaged by calcium chloride and in the United States the Electric Power Research Institute, a consortium of electrical power companies has sponsored research into dam construction (Seaden 1996).

Therefore, it may be suggested that to enable sustainable gains from collaborative relations, construction firms should tap into their own national factors of Suppliers and National Research Institutions to build "cluster specific environments for innovation" (Stern et al. 2000, p. 13). Clusters are "the geographical concentrations of interconnected companies, specialized suppliers, service providers, firms in related industries, and institutions in particular fields that compete but also cooperate" (Porter 1990, p. 199). The NSI model structures suppliers and national research institutions as parts of the national clusters that facilitate intellectual spillovers, and that maximize the collaborative and competitive powers within the clusters. This notion is in line with Porter (1990) who stated that nations gain factor-based comparative advantages and benefits in industries that make intensive use of the factors they possess in abundance. However, solitary dependence on such a strategy has been criticized as "old fashioned and misguided" (Rugman and Cruz 1993, p. 25). Dunning (1993) observed that to suggest that the competitive position of large corporations rests only on their access to the competitive advantage of their home countries is ludicrous. Hence, there is a need for further consideration of the impacts of globalization on various aspects of construction including innovation.

From the previous discussion on foreign contractors, the notion that only outward FDI is valuable in creating competitive advantage and that inward FDI is "not entirely healthy" as suggested by Porter (1990, p. 671) is unfounded. Dunning (1992) notes that inward FDI may lead to a socially unacceptable rate of depletion of natural resources, or a foreign firm may acquire technological capacity from a domestic firm at a socially unacceptable price. Nonetheless, the NSI model shows that inbound FDI can also bring in foreign capital and technology, facilitating the growth of the domestic industry. Further, it is often argued (Moon et al. 1998) that unwarranted limits on inward FDI can lead to the formation of a "shelter" for domestic firms. This "guarding" of local contractors' domestic markets may hurt home firms in the long run. In addition, the NSI model suggests that local contractors should export their construction services, hence developing a more sustainable competitive advantage and a stronger NSI at home.

Thus, it is often not a question of whether domestically owned investments should be preferable to foreign-owned investments, but rather, the extent to which a country or its people are willing to trade a degree of economic sovereignty for economic progress, or their willingness to achieve this progress at the sacrifice of its economic independence (Dunning 1993). Singapore's success as a newly industrialized economy is leveraged on both inbound FDI that brings foreign capital and technology, as well as outbound FDI that allows Singapore-owned enterprises to gain access to cheap labor and natural resources, and thereby, maintain their global competitiveness. This success should be extended to the construction industry where the combination of the domestic and international position of Singapore's NSI will sustain the level of construction innovation by homegrown contractors. The positive impact of inbound FDI can be further enhanced if the change in clients' emphasis on lowest cost to higher construction productivity and quality is considered together with profit incentives for contractors.

## Policy Implications

From the feedbacks within the NSI, it may be suggested that policies aimed at stimulating innovation should first, focus on enabling the local contractors to attain higher profit levels due to the higher number of growth momentums they generate. Second, as FDI plays a significant role in today's globalized economies, local contractors should strategize and tap into this potential resource. Third, social pressure to innovate can be more efficiently utilized by undertaking regular reviews as the industry develops. This will convey the right signals to the industry players, hence reducing the oscillating effect of the pressure to innovate on the local contractors. It is pertinent to note that such conclusions are made on the restricted analysis of the number of feedback loops that each of the determinants of the NSI presents. This may not adequately represent the intensity and magnitude of the impacts of the feedbacks on construction innovation. Such magnitudes can only be investigated through quantitative analysis of the NSI model.

Caution should be exercised to moderate the profit initiatives toward construction innovation. Excessively high profit returns may build monopolistic characteristics in firms, and create high entry barriers. Similarly, putting excessive social pressures to innovate on the local contractors may have an adverse impact on the learning capabilities of the firms. When under such pressure, local contractors may superficially engage in a pick and mix exercise of R&D to demonstrate innovative behavior without any strategic learning or actual innovation. This is likely to result when government policies that are based on social desirability are without clear direction of social intentions or needs regarding technological improvements.

For FDI, a balance should be sought in enabling local firms to maintain a healthy adaptation of new technologies from foreign firms while engaging in further technological developments through R&D. Therefore, policies should ensure a construction industry with the right competitive mix of foreign and local contractors. Similarly, government can take a direct approach in determining the level of foreign investments within the industry through schemes such as the Preferential Margin Scheme which was introduced in Singapore in 1980 to promote technology transfer by encouraging joint ventures between local and foreign contractors. Such joint ventures with at least 25% of net local equity participation were offered a preferential margin, when tendering for major public projects, of up to 5% of the bid or \$5 million (Ofori 1994).

## Conclusion

In an effort to address the workings of the national economy and its interrelated impacts on construction innovation, the concept of



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the NSI was employed through qualitative systems thinking. A series of supporting logics for the possible development and implementation of effective policies towards stimulating higher levels of construction innovation by local contractors was developed. By identifying the logics underlying the workings of each of the components of the NSI, profit incentives and the social desire for higher construction productivity and quality were identified as two main driving forces within the NSI.

From further analysis of the NSI model, it was concluded that the profit incentive is a stronger driver of innovation within the NSI than social pressure. Therefore, although it is often argued in construction that clients can drive innovation only through the demand for higher quality, this study proves otherwise. It has been observed that the fundamental rule of profit creation for business should not be ignored in the process of innovation. Without the client's satisfaction with quality while maintaining profit incentives for the contractors, the latter's drive toward meeting clients' demands, for quality would be hindered. This does not imply that profit motivation should not be dogmatically applied without the consideration of its implications in the wider economy and the externalities that the process of profit maximization may create. To emphasize the effects of such externalities to the business sector, the government has to accentuate the social pressure for innovation through appropriate policies. This is because knowledge, product efficiency and quality, the outputs of innovation, produce positive externalities that can only be profited from by the society through government intervention.

Therefore, it has been demonstrated that the system approach can assist the government in developing more robust and responsive policy initiatives. However, the findings from this study need to be augmented with further research such as work aimed at quantifying each variable within the NSI. Further, this NSI model should be applied across several countries to obtain adequate empirical support for the magnitude and thus significance of each feedback on contractors' levels of innovation.

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