From knowledge sourcing to firms' productivity: investigating innovation value chain of Indonesian manufacturing firms

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Abstract

Purpose – *The purpose of this paper is to investigate the innovation value chain (IVC) that encompasses knowledge sourcing, transformation and exploitation activities among Indonesian manufacturing firms by using data from the Indonesia Innovation Survey.*

Design/methodology/approach – *A simple approach of single equation Probit model, Logit regression and Tobit regression are used in the first, second and third stages of IVC consecutively.*

Findings – *This study finds the existence of a synergistic relationship between internal and external sources of knowledge as well as among external sources of knowledge. In terms of the second link of the IVC, internal R&D plays an important role that positively influences knowledge transformation into all types of innovation and innovation success. External knowledge that has a similar pattern in shaping innovation mainly comes from market and open sources. Scientific institutions tend to contribute to innovation negatively, and few positive impacts on process innovation are observed from government R&D and non-profit R&D institutions. Informal knowledge is more likely to influence technological than non-technological innovation.*

Research limitations/implications – *Finally, the limitations of this study need to be acknowledged. Issues related to firms' sectors have not been discussed in this study, and as a result, sectors' effects on the three links of IVC cannot be detected. This study is a cross-sectional in nature, as a result, the dynamic of Indonesian manufacturing firms' IVC is missing. Hence, future studies may address this limitation by conducting a longitudinal study.*

Originality/value – *This study is different from the previous IVC studies owing to the following reasons. Firstly, in this study, a broader source of knowledge is tested. Secondly, the wider innovation (technological and non-technological innovation) is also assessed.*

Keywords *Indonesia, Productivity, Manufacturing firms, Innovation value chain*

Paper type *Research paper*

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1. Introduction

Interest in innovation studies has been increasing in general, with no exception in the case of developing countries. However, innovation in the context of developing countries cannot necessarily be explained using the same concepts applied to developed countries because developing countries are subject to different challenges in terms of the capital, infrastructure, intellectual and analytical foundations of innovation system analysis (Choi and Williams, 2013; Lorentzen, 2010; Metcalfe and Ramlogan, 2008; Mytelka, 2000). Da Silveira (2001) emphasises that it is important to study innovation in developing countries because most theories, approaches, mechanisms and technical changes associated with innovation that affect managerial practices and skills were developed based on evidence from developed countries. The relevancy and adaptability of any model, framework or construct of innovation studies that was developed, built and tested in developed countries need to be re-evaluated before being implemented in developing countries. This study aims

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to extend previous studies of innovation value chains (IVC) conducted in developed economies, such as North America and Europe (Hansen and Birkinshaw, 2007), Ireland (Roper *et al.*, 2008) and the UK (Ganotakis and Love, 2012; Love *et al.*, 2011), by using innovation survey data of manufacturing firms in the developing economy of Indonesia.

According to Hansen and Birkinshaw (2007, p. 122), the IVC is "a sequential, three-phase process that involves idea generation, idea development, and the diffusion of developed concepts". The IVC concept was derived from innovation research projects which interviewed 130 executives from 30 multi-national firms in North America and Europe. Extending Hansen and Birkinshaw's (2007) work, innovation survey-based IVC studies were conducted by other scholars (Doran and O'leary, 2011; Ganotakis and Love, 2012; Love *et al.*, 2011; Roper *et al.*, 2008; Roper and Arvanitis, 2012). Following these scholars, this study aims to investigate the IVCs of knowledge sourcing, transformation and exploitation activities performed by Indonesian manufacturing firms. This study focuses on the IVC in Indonesia context because to date, no previous study has looked at the IVC based on data derived from innovation surveys of Indonesian firms. This study intends to address previous studies' imbalance and to provide a new empirical contribution to the understanding of IVC activity based on a firm-level analysis of Indonesian manufacturing firms.

In Indonesia context, previous studies that investigate knowledge sourcing and using activities limited on case studies in a specific industry. For instances, collaboration and innovation adoption in small-scale industry clusters (Sandee and Rietveld, 2001); innovation and information flow in small-scale cottage industries in a rural area (Kristiansen, 2002); sources of knowledge in small furniture industries (Van Geenhuizen and Indarti, 2005); and innovation and cooperation activities of SMEs in food processing industry clusters (Najib and Kiminami, 2011). These studies reveal some important issues such as:

- the most innovation adopted is product innovation;
- collaboration among producers (inter-firm cooperation) in SMEs clusters play important role in their innovation activities;
- traditional knowledge sources such as in-house learning by doing and experiment, customers and competitors are the main knowledge sources in the innovation process; and
- factors that hamper innovation activities is lack of access to information on market and advanced technology, financial to fund innovation activities and social capital development.

More examples of knowledge sourcing is a qualitative study that investigates the role of academia as an external source of innovation in the Indonesian automotive industry (Aminullah and Adnan, 2012). The study found that consumers and competitors are the main sources of innovation in the Indonesian automotive industry, while universities and academia have a weak contribution as the sources of innovation. Therefore, this study intends to address this unbalance and to provide a new empirical contribution to the understanding of the IVC activity based on firm-level analysis of Indonesian manufacturing firms. Furthermore, this study also intends to build the IVC model based on innovation activities of the Indonesian manufacturing firms that encompass the three IVC activities (i.e. knowledge sourcing, transformation and exploitation). From a practical perspective, findings of this study are expected can be used by policymakers at government and firm levels to identify innovation activities as well as to detect any weak links in the IVC; therefore, relevant innovation policy and strategy can be formulated to foster innovation in Indonesia.

This study is different compared to the previous IVC studies in several ways. Firstly, in this study a wider range sources of knowledge that consists of R&D activities (internal and external R&D) and informal knowledge gains from market agents, scientific institutions,

associations and open sources. As argued by previous scholars that sourcing knowledge from diverse sources can increase the degree of innovation's novelty (Amara and Landry, 2005) and the difficulty to be replicated to generate sustainable competitive advantage (Henderson and Cockburn, 1996).

Second, a wider innovation classification such as organisational and marketing innovation are assessed (Battisti and Stoneman [2010] for innovation classification), while most innovation survey-based the IVC studies in developed countries context tend to focus on product and process innovations (Doran and O'Leary, 2011, Ganotakis and Love, 2012; Love *et al.*, 2011; Roper *et al.*, 2008; Roper and Arvanitis, 2012a). In the context of developing countries, innovation activities tend to focus on the market rather than on technology (Wamae, 2009). Innovation activities in developing countries that emphasise on minor and incremental changes on existing products or process innovation as well as innovative approaches to organisation and marketing is a major part of innovation (OECD/Eurostat, 2005). Therefore, it is expected that the study provides different findings compared to the existing IVC studies.

Research questions related to the IVC activities that are addressed in this study are as follows:

RQ1. To what extent are the various knowledge sources activities used by Indonesian manufacturing firms?

RQ2. To what extent the various knowledge sources are used in the knowledge transformation activity associated with diverse types of innovation?

RQ3. To what extent do the different types of innovation and innovation success influence firm performance that is proxied by productivity?

The rest of the paper is organised as follows. In Section 2, the conceptual foundation and hypotheses relate to the IVC activities are presented. In this section, the distinction between knowledge sourcing, transformation and exploitation activities is discussed. Section 3 explains the data and methods used in this study. Furthermore, Section 3 describes the data, variables and methods for testing the proposed hypotheses. Section 4 reports the results and details to what extent the proposed hypotheses have been confirmed. Section 5 contains a discussion and conclusions.

2. Conceptual foundation and hypotheses development

Previous studies have attempted to develop models and theoretical frameworks to capture the innovation process of firms. Previous models of the innovation process in the industrially advanced countries have been developed, for instances five generations of the innovation process (Rothwell, 1994), a stage-gate model of innovation (Cooper, 1989) and funnel model (Wheelwright and Clark, 1992). However, none of these models attempts to deal with the issue of developing countries catch up from behind the technology frontier because in the catch-up case innovation occurs based on minor improvements to existing process and product designs (Hobday, 2005). Therefore, the models may not be relevant to the Indonesian context. The concept of IVC is concerned with the innovation process whereby firms source knowledge, transform this knowledge into innovation output and finally exploit innovation output for performance gains (Hansen and Birkinshaw, 2007). Previous models of IVC in the industrially advanced countries have been developed. Using innovation survey data, the following scholars (Battisti and Stoneman, 2013; Doran and O'Leary, 2011; Ganotakis and Love, 2012; Love *et al.*, 2011; Roper *et al.*, 2008) have drawn the IVC model. However, their models tend to focus on internal R&D activity and a limited number of external linkages such as market and public R&D as the sources of knowledge. In addition, their models focussed on technological innovation (such as product and process

innovation), while in this study a wider innovation such as organisational and marketing innovation are included and analysed.

2.1 Knowledge sourcing activity

In the first link of the IVC, knowledge is sourced from both inside and outside the firms (Hansen and Birkinshaw, 2007). Therefore, the main task in this activity is to assemble the knowledge used for innovation (Roper *et al.*, 2008). In terms of the degree of externalisation, Frenz and Ietto-Gillies (2009, p. 1126) explain that internal R&D is the knowledge generated inside a firm, while knowledge from external R&D, from informal and open networks, and cooperation activities are "external to the enterprise to various degrees, depending on their ownership and the contractual structures of the relationship between our enterprise and the other party or parties to the transfer". Knowledge from external linkages can be differentiated based on the form of access, whether informal or formal and the knowledge content being transferred (Monjon and Waelbroeck, 2003). Storper (1997) classified formal cooperation as that which involves more formalised interactions among firms. In contrast, informal interactions, which normally involve informal relations, "might explain the spatial concentration of innovative industries and activities" (Tödtling *et al.*, 2009, p. 61).

Informal linkages can include "personal contacts or communities of practice or simply arise in the normal course of business", while formal linkages "can be organised by business organisations such as chambers of commerce, research associations, technology services companies, consultants, universities or public research organisations or sponsored by local, regional or central governments" (OECD/Eurostat, 2005, p. 79). Internal firm capabilities are necessary to access and absorb knowledge from informal linkages, while formal cooperation activity is associated with the use of knowledge resulting from access to resources and innovative capabilities of partners (Freitas *et al.*, 2011).

Several previous studies have investigated the interaction among sources of knowledge used for innovation activities. One of the main discussions in these studies is whether complementary or substitution relationships exist between internal and external knowledge sourcing strategies in innovation activities. Some scholars argue that studies of such relationships remain unclear and inconclusive (Hagedoorn and Wang, 2012; Schmiedeberg, 2008). On the one hand, some studies reveal a complementary relationship between internal R&D and external knowledge in knowledge sourcing activities (Cassiman and Veugelers, 2002; Hagedoorn and Wang, 2012; Roper *et al.*, 2008; Schmiedeberg, 2008; Veugelers and Cassiman, 2005). On the other hand, other empirical studies identify a substitution relationship in these activities (Hess and Rothaermel, 2011; Laursen and Salter, 2006; Love and Roper, 2001; Xu *et al.*, 2013). In this study, the term "complementarity" is used interchangeably with "synergistic", which means that the implementation of one strategy increases the marginal returns from another (Milgrom and Roberts, 1995).

Turning to the Indonesia context, there are a few insights related to synergistic or substitution strategies in innovation activities performed by Indonesian firms. In general, as in any other developing country, advanced knowledge of technology is accessed by importing from the advanced industrial countries, and the international technology transfer process mostly takes place in the private sector (Wie, 2005) because public support for R&D is minimal (Hill and Tandon, 2010). Wie (2005) identifies two major channels of international technology transfer to Indonesia:

1. a formal or market-mediated channel that includes FDI; technology licencing agreements; imports of capital goods; foreign education and training; turnkey plants; and technical consultancies; and

2. an informal or non-market mediated channel composed of technical assistance by foreign buyers and foreign vendors; copying or reverse engineering; information from trade journals; and technical information services provided by public agencies.

Apart from imported technology, the use of various sources of knowledge by Indonesian firms has also been studied. For example, Indonesian small furniture firms tend to generate knowledge through in-house learning by experimentation as well as from customers (Van Geenhuizen and Indarti, 2005). The cooperative activity was also found positively related to innovation in a cluster of Indonesian small food processors (Najib and Kiminami, 2011) and small scale roof tile firms (Sandee and Rietveld, 2001). Collaboration within Indonesian small firm clusters is also effective for sharing costs and risks (Sandee and Rietveld, 2001). As an example of Indonesian high-technology industry, the automotive industry develops innovation mainly from inside the organisation and competitors are the main source of external knowledge to support the creation of new products in a competitive market (Aminullah and Adnan, 2012). On the other hand, universities and public research institutions contribute little external knowledge to the Indonesian automotive industry (Aminullah and Adnan, 2012). Although literature that discusses the involvement of external actors as sources of knowledge in the innovation process is scaring, a synergistic relationship between internal and external knowledge may exist to some extent.

The complementary relationship also exists between internal and external knowledge sourcing activities in recent studies. In the context of a developing economy, Majidpour (2017) finds that the complementary relationship between Iranian firms' catch-up through indigenous R&D and overseas technology sources. Complementary relationships are also found between internal and external R&D in firms from high-technology industries in manufacturing firms across European countries (Paula and Da Silva, 2018). While, a complementary relationship also exists between Irish SMEs internal and external knowledge sourcing activities, especially between R&D and linkages with customers and public knowledge sources (Doran *et al.*, 2019). Based on this, a hypothesis is proposed:

H1. In knowledge sourcing activities, a synergistic relationship exists between internal R&D and external sources of knowledge.

2.2 Knowledge transformation activity

In the second link of the IVC, different sources of knowledge used in the innovation activities are transformed into different types of innovation (Hansen and Birkinshaw, 2007; Roper *et al.*, 2008). This involves innovation or knowledge production in which the success of knowledge transforming activities relies on the firms' knowledge sources (Griliches, 1992; Love and Roper, 1999). Therefore, the main issue addressed in this stage is comparative impact of various sources of knowledge on different types of innovations (product, process, organisational and marketing).

Innovation is a complex phenomenon and normally firms use several sources of information simultaneously (Freitas *et al.*, 2011). The link between various sources of knowledge and the adoption of different innovations has been investigated (Amara and Landry, 2005; Srholec and Verspagen, 2012; Tödtling *et al.*, 2009). Previous scholars (Amara and Landry, 2005; Tödtling *et al.*, 2009) find that advanced innovations that are new to the market need a higher level of extended internal R&D, patent and more knowledge from universities and research organisations to stimulate and support them. Meanwhile, less advanced innovations, such as business services (Tödtling *et al.*, 2009) and market innovations (Amara and Landry, 2005), require knowledge links with less research-based input.

A majority of previous IVC studies in advanced economies reveal that internal R&D activities are positively and significantly associated with innovation adoption (Doran and O'leary, 2011; Ganotakis and Love, 2012; Roper *et al.*, 2008; Roper and Arvanitis, 2012). Apart from the IVC studies, other studies in industrialised countries at the firm level show positive links

among R&D, innovation and productivity (Griffith *et al.*, 2004, 2006; Mohnen *et al.*, 2006). Evidence from developing and newly industrialised countries also show a positive association between R&D, innovation and productivity, with examples including Argentina (Chudnovsky *et al.*, 2006), Malaysia (Hegde and Shapira, 2007), China (Jefferson *et al.*, 2006) and Taiwan (Aw *et al.*, 2011). Firms that have higher levels of investment in R&D are more likely to introduce technological innovation as was found in Brazil (Raffo *et al.*, 2008) and Chile (Alvarez *et al.*, 2010). Based on this, a second hypothesis is proposed:

H2a. Internal R&D positively influences innovation and innovation success.

The use of informal knowledge as input for the innovation process comes mainly from external information sources gained without any formal arrangements (Garcia-Torres and Hollanders, 2009). The informal link between certain actors and types of innovation has been investigated in previous studies. Past subjects of investigation have included the role and involvement of *customers* in the innovation process (Franke and Schreier, 2002; von Hippel and Katz, 2002; Joshi and Sharma, 2004); key *suppliers* and their roles in product innovation development (Amara and Landry, 2005; Nieto and Santamaría, 2007; Smith and Tranfield, 2005); the role of *competitors* in knowledge transfer and innovation (Malmberg and Maskell, 2002); and fostering advanced technological innovation (Gnyawali and Park, 2011). Open-source information and knowledge from *scientific publications* prove beneficial for firms (Caloghirou *et al.*, 2004). Recent empirical evidence shows that different external sources of knowledge used by firms influence innovation adoption (Doran *et al.*, 2019; Simao and Franco, 2018).

In the case of Indonesian firms, studies of informal knowledge usage for innovation have been conducted and the results show that different sources of external knowledge contribute to diverse benefits for the firms. External actors apart from the market, for example, *foreign suppliers*, have very important roles in the development of technological capability and innovation in Indonesian firms (Wie, 2005). *Foreign buyers* also contribute technical and managerial assistance for many Indonesian SMEs (Wie, 2005). *Competitors* support the development of new products in the competitive market (Aminullah and Adnan, 2012). However, there is no single study in the Indonesia context that links diverse knowledge of innovation and adoption of different types of innovation with innovation success achieved by Indonesian manufacturing firms. In this study, informal knowledge derived from the IIS 2011 is grouped into *market*, including suppliers, customers, competitors, consultants and commercial labs; *science institutions*, including universities, polytechnic institutes, government R&D and non-profit R&D *associations*, including industry associations, investors and entrepreneurs; and *open sources*, including events, scientific publications and the internet. Therefore, another hypothesis is proposed:

H2b. Different levels of informal knowledge influence innovation adoption differently.

2.3 Knowledge exploitation activities

The final link in the IVC is knowledge exploitation that generates value for the firm. Starting with the work of Geroski *et al.* (1993), previous scholars such as Ganotakis and Love (2012), Love *et al.* (2011) and Roper *et al.* (2008) argue that, in the knowledge exploitation stage, firm performance is affected by innovation output as the result of codified knowledge gained through knowledge sourcing activities. They state that the innovation output needs to be determined prior to knowledge exploitation. Therefore, the main interest at this stage is how firms gain business productivity or profitability from the exploitation of adopted innovation. In this study, productivity (indicated by total sales/number of employees) is used to measure how innovation affects overall firms' performance. Prior IVC studies find that innovation output in the form of process innovation (Doran *et al.*, 2019), product and process innovation (Ganotakis and Love, 2012; Roper *et al.*, 2008) significantly and positively influence innovation performance as measured by sales and employment growth.

Surprisingly, both a negative impact (Roper *et al.*, 2008) and no relationship (Ganotakis and Love, 2012) of product innovation success on productivity have been found. Therefore, in this study, the involvement of wider innovation is expected to provide a different view compared to previous IVC studies. Hence, an additional hypothesis is proposed:

H3. In knowledge exploitation activity, innovation and innovation success positively affects a firm's performance.

3. Data and methods

3.1 Data

The empirical analysis in this study is derived from the Indonesia Innovation Survey (IIS) 2011 that covers 2009–2010. In terms of firm size, the IIS 2011 surveyed only medium (20–99 employees) and large (more than 99 employees) Indonesian manufacturing firms. The surveyed firms are classified based on the International Standard Industrial Classification (ISIC) Rev. 3.1. Multi-stage random sampling was used to collect data from 1,500 firms, and a total of 1,375 questions were successfully collected. Of the returned questionnaires, 1,179 were usable. Face-to-face interviews with R&D or production managers were conducted to collect the data. The IIS 2011 used the Oslo Manual (OECD/Eurostat, 2005) as the guideline for collecting and interpreting innovation data and adjustments were made to facilitate innovation activities in Indonesia that may differ from those in developed economies. For example, the innovation activity and internal sources of knowledge variables in the IIS 2011 have broader categories than the same variables in the UK CIS. Unfortunately, Indonesia has three waves of innovation survey only (2008, 2011 and 2014) and no continuity of the survey. As a result, there is no update data on the innovation survey. The number of samples in the last innovation survey (2014) nearly a half of the second wave of the survey (2011) and the sample covers business firms only. As a result, it may not represent Indonesian firms in general. Therefore, the 2011 innovation survey is used in this study.

3.2 Methods

In the knowledge sourcing activity, the main issue that is addressed is the behaviour of Indonesian manufacturing firms in sourcing knowledge from various sources. More specifically, synergistic or substitution relationships among the three groups of knowledge are tested. Following Roper *et al.* (2008), a simple approach of single equation probit model is used to test *H1* with the dependent variables being a series of sources of knowledge. This allows for a detailed analysis of the impact of 17 various knowledge sources.

In the knowledge transformation link, an innovation or knowledge production function is used to model the knowledge transformation activities (Geroski, 1990; Harris and Trainor, 1995). Logit regression is used to test *H2* with the dependent variables being different types of innovation. Tobit regression is used when the dependent variable is innovation success (the proportion of sales derived from product innovation new to the market) that has both upper and lower bounds (0 to 100%). In the knowledge exploitation stage, OLS regression is used to test *H3*, and the dependent variable is the firms' productivity, which is a measure of how innovation affects overall firm performance.

4. Results

4.1 Descriptive statistics

Table 1 presents descriptive statistics for the IIS 2011. Following the 3rd Oslo Manual, the IIS 2011 defines innovation as "the implementation of a new or significantly improved product (good or services), or process, a new marketing method, or a new organisational method in business practices, workplace organisation or external

Table 1 Descriptive statistics

Variables	*Obs*	*Mean*	*SD*	*Min*	*Max*
Firm performance					
Productivity (total sales/number of employee) (IDR)	1179	1312.096	8399.761	0.088	125000
Innovation performance					
Innovation success (% sales of product innovation new to the market)	1179	8.43	16.99	0	100
Innovation output					
Product innovation (0/1)	1179	0.377	0.485	0	1
Product innovation new to the market (0/1)	1179	0.288	0.453	0	1
Product innovation new to the firms (0/1)	1179	0.358	0.480	0	1
Process innovation (0/1)	1179	0.322	0.468	0	1
Organisational innovation (0/1)	1179	0.310	0.463	0	1
Marketing innovation (0/1)	1179	0.428	0.495	0	1
R&D activities					
Internal R&D (0/1)	1179	0.292	0.455	0	1
External R&D (0/1)	1179	0.032	0.177	0	1
Market agents (highly important)					
Suppliers (0/1)	1179	0.191	0.393	0	1
Customers (0/1)	1188	0.344	0.475	0	1
Competitors (0/1)	1179	0.225	0.418	0	1
Consultant (0/1)	1179	0.041	0.198	0	1
Commercial labs (0/1)	1179	0.042	0.200	0	1
Science institutions (highly important)					
University (0/1)	1179	0.031	0.174	0	1
Polytechnic (0/1)	1179	0.027	0.163	0	1
Government R&D institutions (0/1)	1179	0.041	0.198	0	1
Non-profit R&D institutions (0/1)	1179	0.036	0.185	0	1
Associations (highly important)					
Investors (0/1)	1179	0.091	0.287	0	1
Industry association (0/1)	1179	0.065	0.247	0	1
Entrepreneurs (0/1)	1179	0.146	0.353	0	1
Open sources (highly important)					
Events (0/1)	1188	0.109	0.312	0	1
Science publication (0/1)	1188	0.067	0.251	0	1
Internet (0/1)	1179	0.113	0.316	0	1
Firms resources					
Size (number of employee)	1179	174.608	1318.078	20	32977
Firms' age (years)	1179	21.077	12.704	0	84
Export (%)	1179	9.726	25.106	0	100
Ownership national (0/1)	1179	0.899	0.301	0	1
Ownership multi-national (0/1)	1179	0.059	0.235	0	1
Ownership joint venture (0/1)	1179	0.042	0.202	0	1
Operation plant (0/1)	1179	0.092	0.289	0	1
Operation head quarter (0/1)	1179	0.908	0.289	0	1
Education under high school (%)	1179	56.247	36.423	0	100
Education high school (%)	1179	36.430	31.492	0	100
Education diploma (%)	1179	3.246	6.779	0	55
Education undergraduate (%)	1179	4.077	8.623	0	90
Employees' proportion in R&D dept (%)	1179	2.986	6.717	0	57
Low technology (0/1)	1179	0.735	0.442	0	1
Medium-low technology (0/1)	1179	0.174	0.379	0	1
Medium-high technology (0/1)	1179	0.082	0.275	0	1
High technology (0/1)	1179	0.009	0.096	0	1

relations" (OECD/Eurostat, 2005, p. 46). Based on the definition that covers a broad range of possible innovations, the IIS 2011 then defines an innovative firm as a firm that performed any product, process, organisational or marketing innovation from 2009 to 2010. According to Table 1, the mean of productivity (total sales/number of employees) is approximately IDR 1.3tn. The highest proportion is marketing innovation (42.8%), while the lowest is organisational innovation (31%). The mean of product innovations that are new to the market is lower than the same innovations that are new to the firm and account for 28.8% versus 35.8% respectively. The mean of innovation success as the proportion of launched products new to the market accounted for 8.43%. The fact that marketing innovation outnumbered other innovation is typical in developing countries that tend to focus on the market rather than on the technology (Wamae, 2009).

Turning to knowledge sourcing activities, approximately 29% of firms report generating their own knowledge from internal R&D, while only 3.2% of firms source knowledge from external R&D. Firms report market as more important than other sources of knowledge, including suppliers, competitors and customers which represent 19.1%, 22.5% and 34.4%, respectively. These are followed by open sources (internet) and associations (entrepreneurs) that account for 11.3% and 14.6%, respectively. In contrast, less than 5% of firms source science-based knowledge from universities, polytechnic, government and non-profit R&D institutions.

The mean of firm size as indicated by the number of employees is nearly 175 people. Of surveyed firms, mature firms (more than 20 years) dominate in the IIS 2011 data. The proportion of national firms is significantly higher at 90%, compared to multi-nationals and joint ventures, at 6% and 4.2%, respectively. Most of the surveyed firms operate in their headquarters, not in the manufacturing plants (91% versus 9.2%). Labour education levels are low. More than 50% of employees have no high school degree, which indicates the low level of education of the firms' human resources. In contrast, less than 5% of employees hold undergraduate degrees.

4.2 Knowledge sourcing activity

The empirical analysis in the first stage of IVC follows the approach of Roper *et al.* (2008), and it allows for a detailed analysis of the interdependence of various knowledge sources. The following equation is estimated using a series of probit models:

$$KS_{ji} = KS_{ki}\beta_0 + X_{1i}\beta_1 + \varepsilon_{1i} \quad \text{if } y_{0i} = 1$$

where KS_{ji} represents firm *i*'s knowledge sourcing activity *j* during the reference period. KS_{ki} represents firm *i*'s knowledge sourcing activity *k* where $j \neq k$, X_{1i} is a vector of explanatory variables, β_{1i} is the associated coefficient vector, and ε_{1i} is the error term. When sourcing knowledge H1 suggests that a complementary/synergistic relationship exists between internal R&D and external knowledge sourcing activities. Therefore, if $\beta_0 > 0$ this implies that firms which engage in one type of knowledge sourcing (e.g. R&D) are more likely to engage in other types of knowledge sourcing (e.g. customers, suppliers and competitors). This provides a direct test of *H1*.

Table 2 indicates a synergistic relationship between internal and external R&D and this in line with previous findings (Cassiman and Veugelers, 2002, 2006; Ganotakis and Love, 2012; Schmiedeberg, 2008). Firms are more likely to perform external R&D if they also generate their own knowledge from internal R&D. The same relationship also exists between IN_RD and external agents from market (customers, competitors and commercial labs) and from associations, such as industry associations and entrepreneurs. However, the firms interact less with external networks from science institutions and open sources. Firms also

Table 2 Knowledge sourcing activity – (IV: R&D and informal knowledge)

Independent variables	*Model 1 IN_RD*	*Model 2 EXT_RD*	*Model 3 SUPPLIER*	*Model 4 CUSTOM*	*Model 5 COMPET*	*Model 6 CONSUL*	*Model 7 COMMLAB*	*Model 8 UNIVERSITY*	*Model 9 POLTECH*
INTERNAL_RD	-	*0.088***(0.017)*	−0.021 (0.029)	*0.059**(0.026)*	*0.045**(0.023)*	0.018 (0.011)	*0.023**(0.011)*	*0.019**(0.009)*	0.006 (0.008)
EXTERNAL_RDa	*0.568***(0.098)*	–	0.012 (0.065)	−0.032 (0.060)	0.021 (0.051)	−0.002 (0.021)	0.019 (0.020)	−0.003 (0.016)	0.010 (0.013)
Market									
SUPPLIERS	−0.023 (0.030)	0.006 (0.013)	–	0.031 (0.028)	−0.005 (0.026)	−0.008 (0.014)	*0.025**(0.012)*	−0.003 (0.011)	0.005 (0.009)
CUSTOMERS	*0.077***(0.028)*	−0.006 (0.012)	0.041 (0.029)	–	*0.287***(0.018)*	*−0.023*(0.014)*	0.000 (0.013)	0.006 (0.010)	−0.003 (0.009)
COMPETITORS	0.044 (0.030)	0.005 (0.011)	−0.004 (0.032)	*0.329***(0.022)*	–	*0.031***(0.012)*	0.016 (0.012)	−0.003 (0.010)	0.006 (0.008)
CONSULTANT	0.081 (0.063)	−0.003 (0.019)	−0.043 (0.066)	*−0.158**(0.063)*	*0.109**(0.047)*	–	*0.072***(0.016)*	0.008 (0.014)	0.008 (0.012)
COMMLAB	0.085 (0.063)	0.031 (0.019)	*0.121*(0.062)*	−0.017(0.066)	0.050 (0.051)	*0.069***(0.016)*	–	*0.042***(0.013)*	−0.005 (0.012)
Science									
UNIVERSITIES	*0.176**(0.076)*	−0.027 (0.026)	0.0004 (0.077)	0.023 (0.077)	−0.075 (0.063)	0.020 (0.020)	*0.065***(0.019)*	–	*0.042***(0.011)*
POLYTECHNIC	−0.036 (0.083)	0.015 (0.025)	0.046 (0.084)	−0.134 (0.085)	0.018 (0.062)	−0.003 (0.023)	−0.016 (0.024)	*0.047***(0.015)*	–
GOV_RD	−0.013 (0.071)	*−0.051*(0.029)*	−0.014 (0.078)	−0.038 (0.073)	−0.025 (0.057)	0.001 (0.021)	*0.036*(0.021)*	*0.024*(0.013)*	*0.037***(0.011)*
NON_PROFITRD	−0.012 (0.072)	*0.048**(0.023)*	−0.034 (0.077)	*0.224***(0.078)*	−0.037 (0.055)	0.030 (0.020)	0.021 (0.020)	0.012 (0.013)	*0.019*(0.010)*
Associations									
INVESTORS	0.033 (0.045)	*0.024*(0.014)*	0.017 (0.045)	0.045 (0.045)	0.031 (0.035)	0.013 (0.014)	−0.001 (0.015)	*0.019*(0.011)*	−0.015 (0.011)
IND_ASSOC	0.051 (0.050)	−0.011 (0.017)	−0.043 (0.053)	0.031 (0.054)	0.007 (0.041)	*0.030**(0.015)*	0.004 (0.016)	*0.025**(0.011)*	0.006 (0.010)
ENTREPRENEURS	*0.176***(0.037)*	−0.006 (0.013)	−0.021 (0.040)	*0.125***(0.036)*	*0.064**(0.030)*	0.003 (0.014)	0.012 (0.014)	−0.010 (0.012)	0.010 (0.009)
Open sources									
EVENTS	−0.003 (0.043)	0.004 (0.015)	0.041 (0.043)	*0.177***(0.044)*	*0.064**(0.033)*	0.001 (0.015)	−0.005 (0.015)	0.009 (0.011)	−0.002 (0.009)
SCIENCE_PUB	−0.026 (0.053)	0.0003 (0.017)	−0.060 (0.053)	*0.215***(0.061)*	0.039 (0.039)	0.018 (0.016)	*0.033**(0.015)*	−0.014 (0.013)	*0.029***(0.010)*
INTERNET	*0.229***(0.037)*	0.011 (0.012)	0.050 (0.040)	*0.177***(0.037)*	−0.048 (0.031)	*0.029**(0.013)*	−0.022 (0.015)	−0.004 (0.011)	0.009 (0.008)
Firm resources									
SIZE	−0.0002(0.0003)	−0.0003(0.0003)	0.0002(0.0001)	−0.0001(0.0001)	−0.0003(0.0003)	−0.0003(0.0004)	−0.0003(0.0002)	−0.0001(0.0002)	−0.0002(0.0003)
AGE	−0.00006(0.001)	−0.0003(0.0004)	0.001(0.001)	0.001(0.001)	0.0001(0.001)	0.0003(0.0004)	−0.001(0.0005)	−0.001(0.0004)	0.0002 (0.0003)
EXPORT	−0.0003(0.0005)	0.00002(0.0002)	*0.001**(0.0004)*	0.0004(0.0004)	−0.0001(0.0004)	0.0002(0.0002)	0.0002(0.0002)	−0.0003(0.0002)	0.00003(0.0001)
OWN_NATIONAL	0.098(0.064)	0.007(0.030)	0.034(0.059)	−0.029(0.057)	−0.003(0.051)	0.013(0.030)	0.042(0.033)	−0.002(0.021)	0.014(0.024)
OWN_MULTI	0.123(0.077)	−0.0002(0.037)	0.102(0.072)	−0.005(0.071)	−0.067(0.068)	0.017(0.036)	–	0.014(0.024)	0.004 0.029)
OWN_JOIN	–	–	–	–	–	–	–	–	–
OPS_PLANT	−0.002 (0.043)	−0.020 (0.022)	0.016 (0.041)	−0.031 (0.040)	−0.013 (0.038)	−0.001 (0.019)	−0.027 (0.027)	0.009 (0.013)	0.012 (0.011)
OPS_HEAD	–	–	–	–	–	–	–	–	–
LOW_TECH	–	–	–	–	–	–	–	–	–
MEDLOW_TECH	−0.071 (0.029)	0.012 (0.016)	0.032 (0.031)	0.027 (0.029)	−0.032 (0.027)	0.025 (0.016)	0.007 (0.014)	*−0.024***(0.008)*	0.010 (0.012)
MEDHIGH_TECH	0.004 (0.044)	*−0.025**(0.010)*	0.005 (0.042)	0.036 (0.041)	−0.036 (0.037)	−0.006 (0.017)	0.014 (0.023)	−0.001 (0.015)	0.008 (0.016)
HIGH_TECH	−0.049 (0.109)	–	−0.045 (0.095)	0.188 (0.137)	−0.095 (0.082)	–	–	0.002 (0.037)	–
EDU_UNDERHS	−0.0003 (0.001)	−0.001 (0.001)	−0.0004 (0.001)	−0.0005 (0.001)	−0.001 (0.001)	−0.001 (0.001)	0.001(0.001)	−0.0002(0.0005)	0.001(0.001)
EDU_HIGHSCHOOL	−0.0004 (0.002)	−0.001 (0.001)	0.001 (0.001)	−0.0002 (0.001)	−0.001 (0.001)	−0.001 (0.001)	0.001(0.001)	−0.0003(0.001)	0.0005(0.001)
EDU_DIPLOMA	−0.001 (0.003)	−0.0004 (0.001)	0.001 (0.003)	0.001 (0.003)	0.000 (0.002)	0.000 (0.001)	0.001(0.001)	−0.0002(0.001)	0.0004(0.001)
EDU_UNDERGRAD	–	–	–	–	–	–	–	–	–
RD_STAFF	0.0001 (0.002)	*−0.002*(0.001)*	*0.006***(0.002)*	−0.002 (0.002)	0.000 (0.002)	0.000 (0.001)	0.000 (0.001)	−0.0002 (0.001)	0.000 (0.001)
Observation	1,179	1,168	1,179	1,179	1,179	1,168	1,119	1,179	1,168
LR chi2(29)	297.2	98.16	53.52	498.23	352.76	136.41	154.75	154.13	162.17
Prob > chi2	0.000	0.000	0.0037	0.000	0.000	0.000	0.000	0.000	0.000
Pseudo R2	0.209	0.293	0.047	0.327	0.281	0.341	0.385	0.469	0.553
Log likelihood	-563.198	-118.462	-547.930	-511.940	-451.881	-132.001	-123.827	-87.424	-65.588
Mean VIF	2.76	2.77	2.78	2.74	2.75	2.76	2.76	2.75	2.75

Notes: Significant levels $^{*}p \leq 0.10$; $^{**}p \leq 0.05$; and $^{***}p \leq 0.001$. All figures in the tables are marginal effects generated from probit models

Sources: External R&D in this study is grouped in R&D activities along with internal R&D, however, based on the degree of externalisation, external R&D, informal and open networks and cooperation activities "are external to the enterprise to various degrees, depending on their ownership and the contractual structures of the relationship between our enterprise and the other party or parties to the transfer" (Frenz and Ietto-Gillies, 2009, p. 1126). Significant levels $^{*}p \leq 0.10$; $^{**}p \leq 0.05$; $^{***}p \leq 0.001$. All figures in the tables are marginal effects generated from probit models

(*continued*)

Table 2 Continued

Independent variables	Model 10 GOV_RD	Model 11 NPROFIT_RD	Model 12 INVESTOR	Model 13 TRADE_ASSOC	Model 14 ENTREPRENEUR	Model 15 EVENTS	Model 16 SCIENCE_PUB	Model 17 INTERNET
INTERNAL_RD	0.004 (0.009)	0.001 (0.010)	0.025 (0.015)	*0.030***(*0.013*)	*0.087****(*0.016*)	0.010 (0.016)	0.003 (0.013)	*0.112****(*0.016*)
EXTERNAL_RDa	−0.022 (0.018)	*0.030**(*0.017*)	*0.048**(*0.028*)	−0.011 (0.025)	−0.020 (0.035)	0.014 (0.031)	0.010 (0.025)	0.030 (0.032)
Market								
SUPPLIERS	−0.001 (0.011)	−0.007 (0.012)	0.004 (0.017)	−0.009 (0.015)	−0.014 (0.020)	0.017 (0.018)	−0.020 (0.015)	0.025 (0.020)
CUSTOMERS	0.002 (0.010)	*0.041****(*0.013*)	*0.037***(*0.017*)	0.013 (0.015)	*0.084****(*0.018*)	*0.078****(*0.018*)	*0.071**** (*0.016*)	*0.087****(*0.018*)
COMPETITORS	−0.003 (0.009)	−0.010 (0.010)	0.016 (0.016)	*0.024**(*0.014*)	*0.047****(*0.017*)	*0.039***(*0.016*)	0.019 (0.013)	−0.009 (0.018)
CONSULTANT	−0.000004 (0.015)	0.008 (0.017)	0.012 (0.028)	*0.042***(*0.021*)	0.020 (0.035)	−0.003 (0.031)	0.019 (0.022)	*0.080***(*0.033*)
COMMLAB	*0.023** (*0.014*)	0.010 (0.015)	−0.009 (0.028)	−0.012 (0.023)	0.045 (0.033)	−0.005 (0.030)	*0.048***(*0.021*)	−0.039 (0.037)
Science								
UNIVERSITIES	*0.023** (*0.013*)	0.013 (0.015)	*0.065***(*0.032*)	*0.045**(*0.024*)	−0.030 (0.042)	0.029 (0.035)	*−0.045**(*0.027*)	−0.019 (0.040)
POLYTECHNIC	*0.050****(*0.015*)	0.019 (0.016)	*−0.105***(*0.042*)	0.001 (0.027)	*0.079**(*0.044*)	−0.031 (0.036)	*0.081****(*0.024*)	0.044 (0.041)
GOV_RD	–	*0.071****(*0.015*)	*0.130****(*0.030*)	0.032 (0.022)	−0.036 (0.038)	0.046 (0.031)	0.000 (0.024)	0.055 (0.038)
NON_PROFITRD	*0.061****(*0.012*)	–	0.009 (0.024)	*0.036***(*0.017*)	−0.029 (0.028)	−0.005 (0.022)	0.015 (0.017)	−0.028 (0.029)
Associations								
INVESTORS	*0.043****(*0.011*)	−0.001 (0.013)	–	*0.046****(*0.015*)	*0.164****(*0.021*)	*0.058***(*0.023*)	0.024 (0.017)	0.013 (0.023)
IND_ASSOC	0.013 (0.010)	*0.022**(*0.012*)	*0.058****(*0.021*)	–	*0.085****(*0.020*)	*0.077****(*0.018*)	−0.017 (0.016)	*0.072****(*0.020*)
ENTREPRENEURS	−0.010 (0.011)	−0.001 (0.012)	*0.123****(*0.017*)	0.018 (0.015)	–	0.009 (0.030)	0.029 (0.021)	−0.062 (0.040)
Open sources								
EVENTS	0.016 (0.010)	0.002 (0.012)	−0.018 (0.031)	0.026 (0.022)	−0.010 (0.039)	–	*0.096****(*0.013*)	0.033 (0.023)
SCIENCE_PUB	−0.0001 (0.011)	*0.026***(*0.012*)	−0.019 (0.021)	*0.036***(*0.015*)	*0.099****(*0.022*)	*0.145****(*0.019*)	–	*0.057***(*0.025*)
INTERNET	*0.019**(*0.010*)	−0.015 (0.013)	0.008 (0.018)	*0.034***(*0.014*)	0.039 (0.027)	0.030 (0.019)	−0.007 (0.016)	–
Firm resources								
SIZE	0.00001(0.00003)	−0.00001(0.00003)	0.00002(0.00001)	−0.00001(0.00002)	−0.00004(0.00003)	0.00002(0.00001)	−0.00002(0.00001)	0.00003(0.00001)
AGE	−0.0004 (0.0004)	0.0001 (0.0004)	0.0002(0.001)	−0.001(0.0005)	0.001(0.001)	−0.001(0.001)	−0.0002(0.0005)	−0.0004 (0.001)
EXPORT	−0.00003 (0.0002)	−0.0002 (0.0002)	−0.00001(0.0003)	0.0002(0.0002)	*0.001***(*0.0003*)	−0.0003(0.0003)	−0.0002(0.0002)	−0.00001(0.0003)
OWN_NATIONAL	0.022(0.025)	−0.01 (0.020)	*−0.061***(*0.031*)	0.033(0.035)	*0.105***(*0.048*)	−0.047(0.033)	0.008(0.029)	*−0.067**(*0.035*)
OWN_MULTI	0.003(0.030)	0.007(0.025)	*−0.078***(*0.042*)	*0.069**(*0.039*)	*0.105**(*0.056*)	−0.030(0.043)	−0.009(0.039)	−0.054(0.045)
OWN_JOIN	–	–	–	–	–	–	–	–
OPS_PLANT	−0.016(0.020)	0.002(0.017)	−0.030(0.027)	−0.021(0.024)	0.042(0.027)	−0.008(0.027)	0.005(0.021)	0.005(0.028)
OPS_HEAD	–	–	–	–	–	–	–	–
LOW_TECH	–	–	–	–	–	–	–	–
MEDLOW_TECH	−0.006(0.011)	*0.0100(0.010)***	−0.005(0.018)	0.002(0.016)	0.023(023)	−0.026(0.019)	−0.011(0.016)	0.014(0.022)
MEDHIGH_TECH	0.001(0.015)	–	0.018 (0.029)	*0.048(0.028)**	−0.0003(0.029)	−0.027)	0.027(0.025)	0.027(0.031)
HIGH_TECH	0.0111(0.103)	−0.005(0.034)	−0.055 (0.037)	0.049(0.076)	0.015(0.072)	0.082 (0.090)	–	−0.038(0.061)
EDU_UNDERHS	−0.0004(0.0004)	0.001(0.001)	−0.001(0.001)	0.001(0.001)	−0.0001(0.001)	0.002(0.001)	−0.001(0.001)	0.000(0.001)
EDU_HIGHSCHOOL	−0.0004(0.0005)	0.001(0.001)	−0.001(0.001)	0.002(0.001)	0.0003 (0.001)	0.002 (0.001)	*−0.001**(*0.001*)	0.000(0.001)
EDU_DIPLOMA	−0.0003(0.001)	0.002(0.001)	−0.0001(0.002)	0.001(0.002)	−0.002 (0.002)	0.002 (0.002)	−0.001 (0.001)	0.000(0.002)
EDU_UNDERGRAD	–	–	–	–	–	–	–	–
RD_STAFF	−0.0004(0.001)	0.001(0.001)	0.001(0.001)	0.001(0.001)	−0.0004(0.001)	0.00 (0.001)	0.0002 (0.001)	−0.002(0.001)
Observation	1179	1082	1179	1179	1179	1179	1168	1179
LR chi2(29)	226.89	172.32	249.06	210.13	405.55	326.27	251.48	252.34
Prob > chi2	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Pseudo R2	0.565	0.485	0.347	0.369	0.414	0.399	0.431	0.304
Log likelihood	-87.225	-91.467	-234.216	-179.467	-287.107	-246.055	-165.938	-289.245
Mean VIF	1.34	2.75	2.75	2.76	2.75	2.75	2.75	2.76

interact less with external actors if they already perform external R&D. Based on this finding, the first hypothesis is supported.

Turning to informal knowledge (Table 2), it can be observed that firms that source knowledge from market tend to interact with other market networks, associations and open sources. However, these firms interact less with scientific institutions, with the exception that firms sourcing knowledge from commercial labs tend to interact with universities and government R&D. Firms that source knowledge from suppliers and competitors are more likely to source from associations. In addition, firms tend to source knowledge from open sources if they already source from customers. To sum up, in the market groups, synergistic relationships tend to exist among market; between market and associations; and between market and open sources networks.

In relation to scientific institutions, a synergistic relationship can also be identified among the institutions and between the institutions and associations. However, there are few negative and significant associations, and these are shown only between polytechnic and investors and between universities and science publication. This may indicate that firms that already source knowledge from polytechnic tend not to interact with investors, while firms that source knowledge from universities tend to cite knowledge from science publication. Finally, firms that source knowledge from associations and open sources networks are more likely to interact with all external knowledge networks proportionally.

Turning to control variables, exporters tend to rely on knowledge that is sourced from suppliers and entrepreneurs. Both national and multi-national firms are similar in that they have positive and significant associations with entrepreneurs. In contrast, both national and multi-national firms have negative and significant associations with investors and the internet. It is striking that high technology firms do not have positive associations with R&D activities. A speculative reason for this phenomenon is that these firms tend to import advanced technology from advanced countries as shown in Wie (2005) study. However, it is important to note that all the coefficient values among firm resources and a wide range of sources of knowledge tend to show weak relationships.

4.3 Knowledge transformation activity

The main interest in this section is how various sources of knowledge contribute to innovation. Table 3 shows that internal R&D has positive and significant effects on any type of innovation and innovation success. By contrast, external R&D has no significant impacts on innovation and innovation success. Evidence that internal R&D is the only source of knowledge that positively and significantly affects all types of innovation and innovation success may suggest that internal R&D plays a more important role than the rest of the sources of knowledge. Therefore, based on this finding, *H2a* is supported.

Turning to informal knowledge, different sources of informal knowledge used in the innovation transformation activity have different impacts on types of innovation and innovation success. Among market networks, knowledge transformed from *customers* positively and significantly affects product innovation, product innovation new to the firm, marketing innovation and innovation success. While knowledge transformed from *competitors* positively and significantly affects product innovation new to the market, process innovation and marketing innovation. Surprisingly, knowledge from science institutions only influences process innovation and this finding differs compared from most previous studies that show a positive influence of science institutions on radical innovation. The knowledge that is generated from the association (industry association and entrepreneurs) is more likely to influence innovation and innovation success in significant and negative ways. Open sources (events) contribute positively to product innovation, product innovation that new to the market, product innovation that new to the firms and innovation success.

Table 3 Knowledge transformation activity

INDEPENDENT VARIABLES	*Model 1 Product Innov*	*Model 2 Prod. Innov. New to market*[1]	*Model 3 Prod. Innov. New to firms*[2]	*Model 4 Process Innov*	*Model 5 Organisational Innov*	*Model 6 Marketing Innov*	*Model 7 Innovation Success*[3]
INTERNAL_RD	*0.133*** (0.022)*	*0.069*** (0.023)*	*0.126*** (0.022)*	*0.188*** (0.019)*	*0.231*** (0.018)*	*0.162*** (0.022)*	*8.342** (3.295)*
EXTERNAL_RD	0.039(0.065)	0.077(0.057)	0.080(0.067)	0.093(0.074)	0.096(0.074)	−0.091(0.069)	6.853(7.118)
Market							
SUPPLIERS	−0.027(0.027)	−0.026(0.027)	−0.021(0.027)	−0.004(0.027)	−0.007(0.026)	0.017(0.027)	-5.139(3.724)
CUSTOMERS	*0.062** (0.025)*	0.039 (0.025)	*0.053** (0.025)*	−0.027(0.025)	−0.036(0.025)	*0.099*** (0.025)*	*6.122* (3.470)*
COMPETITORS	−0.003(0.025)	*0.046* (0.024)*	0.004(0.025)	*0.042* (0.024)*	0.001(0.025)	*0.053** (0.026)*	3.970(3.364)
CONSULTANTS	0.001(0.051)	−0.012(0.048)	0.009(0.052)	−0.075(0.049)	−0.002(0.052)	0.003(0.053)	-5.513(6.529)
COMMLAB	0.043(0.053)	0.013(0.049)	0.067(0.054)	0.060(0.050)	−0.004(0.049)	0.022(0.054)	3.486(6.499)
Science							
UNIVERSITIES	0.030(0.063)	0.059(0.058)	0.061(0.065)	*−0.123** (0.059)*	−0.041(0.061)	0.036(0.068)	6.438(7.874)
POLYTECHNIC	0.053(0.073)	0.033(0.068)	0.001(0.071)	*−0.132* (0.068)*	0.055(0.066)	−0.006(0.070)	6.574(8.503)
GOVERNMENT_RD	−0.098(0.060)	−0.030(0.059)	−0.073(0.061)	*0.109* (0.064)*	−0.028(0.060)	−0.050(0.064)	-1.260(7.652)
NON_PROFIT_RD	−0.022(0.022)	0.026(0.053)	−0.032(0.056)	*0.149*** (0.057)*	−0.045(0.058)	0.057(0.061)	6.800(7.084)
Associations							
INVESTORS	0.057(0.057)	0.036(0.034)	*0.068* (0.036)*	*0.058* (0.035)*	0.056(0.035)	−0.048(0.036)	0.776(4.696)
IND_ASSOC	−0.056(0.041)	*−0.095** (0.039)*	*−0.087** (0.041)*	−0.036(0.040)	0.058(0.043)	−0.017(0.044)	-8.185(5.473)
ENTREPRENEURS	*−0.059** (0.031)	−0.043(0.031)	−0.051(0.031)	−0.017(0.030)	0.013(0.031)	−0.049(0.032)	*-6.954* (4.188)*
Open resources							
EVENTS	*0.189*** (0.038)*	*0.164*** (0.033)*	*0.174*** (0.037)*	0.028(0.033)	0.044(0.035)	0.026(0.036)	*16.800*** (4.387)*
SCIENCE_PUB	−0.033(0.044)	−0.047(0.041)	−0.010(0.044)	−0.022(0.040)	−0.040(0.043)	−0.012(0.045)	-5.755(5.279)
INTERNET	−0.039(0.032)	−0.029(0.031)	−0.040(0.032)	−0.024(0.031)	0.023(0.032)	−0.031(0.034)	-2.148(4.210)
Firm resources							
SIZE	−0.00002(0.000)	−0.00003(0.000)	−0.00001(0.000)	0.00004(0.000)	−0.00002(0.000)	−0.00001(0.000)	−0.001(0.004)
AGE	0.00 (0.001)	0.0001(0.001)	0.0002(0.001)	−0.001(0.001)	0.0003(0.001)	*−0.001* (0.001)*	0.009(0.114)
EXPORT	0.0004(0.000)	0.001(0.000)	0.001(0.000)	0.00004(0.000)	−0.001(0.000)	0.00002(0.000)	0.056(0.054)
OWN_NATIONAL	0.038(0.062)	0.001(0.060)	0.049(0.062)	0.037(0.060)	−0.064(0.055)	0.049(0.059)	1.596(7.825)
OWN_MULTI	0.006(0.073)	−0.049(0.074)	0.006(0.073)	0.007(0.073)	*−0.130* (0.070)*	0.011(0.072)	-4.198(9.789)

(*continued*)

Table 3

INDEPENDENT VARIABLES	*Model 1 Product Innov*	*Model 2 Prod. Innov. New to market*[1]	*Model 3 Prod. Innov. New to firms*[2]	*Model 4 Process Innov*	*Model 5 Organisational Innov*	*Model 6 Marketing Innov*	*Model 7 Innovation Success*[3]
OWN_JOIN	–	–	–	–	–	–	–
OPS_PLANT	0.027(0.039)	0.010(0.040)	0.051(0.040)	0.004(0.039)	−0.014(0.039)	0.031(0.039)	0.601(5.286)
OPS_HEAD	–	–	–	–	–	–	–
LOW_TECH	–	–	–	–	–	–	–
MED_LOW TECH	*0.051(0.029)**	0.036(0.030)	*0.058(0.029)***	−0.009(0.029)	0.012(0.030)	−0.010(0.029)	4.267(3.988)
MED_HIGH TECH	0.036(0.038)	*0.063(0.038)**	0.041(0.038)	0.014(0.038)	−0.046(0.037)	0.049(0.037)	5.827(5.206)
HIGH_TECH	0.106(0.110)	0.171(0.118)	0.130(0.108)	*−0.175(0.095)**	0.039(0.109)	0.010(0.122)	13.248(14.064)
EDU_UNDERHS	−0.001(0.001)	−0.001(0.001)	−0.002(0.001)	−0.0001(0.001)	−0.0004(0.001)	−0.0002(0.001)	−0.235(0.172)
EDU_HIGHSCHOOL	−0.001(0.001)	−0.002(0.001)	−0.002(0.001)	−0.0003(0.001)	−0.0003(0.001)	−0.002(0.001)	−0.201(0.182)
EDU_DIPLOMA	−0.003(0.003)	−0.002(0.002)	−0.004(0.002)	−0.003(0.002)	−0.002(0.003)	−0.002(0.003)	−0.225(0.330)
EDU_UNDERGRAD	–	–	–	–	–	–	–
RD_STAFF	−0.001(0.002)	0.0003(0.002)	−0.002(0.002)	−0.001(0.002)	−0.001(0.002)	0.0001(0.002)	0.188(0.226)
Number of obs	1179	1179	1179	1179	1165	1170	1179
LR chi2(57)	685.65	546.38	652.18	641.39	572.46	720.65	517.02
Prob > chi2	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Pseudo R2	0.439	0.3862	0.4241	0.4327	0.401	0.4519	0.1192
Log likelihood	-438.107	-434.124	-442.875	-420.422	-427.534	-437.063	-1909.790
Mean VIF	3.50	3.50	3.50	3.50	3.50	3.50	3.50

Notes: *** $p < 0.001$, ** $p < 0.05$, * $p < 0.10$

In relation to firm resources, most variables have weak and negative effects on diverse types of innovation and innovation success. Only firms age and multi-national ownership influence innovation insignificant and negative directions. Firm age has a weak negative and significant association with marketing innovation. The same direction was found for the influence of multi-national firm status on organisation innovation.

4.4 Knowledge exploitation activity

Table 4 displays the statistical output of OLS regression for knowledge exploitation activity. Because data on sales and employee growth are not available in the IIS 2011, this study uses productivity as the only indicator of firm performance, as presented in Table 4. In the first model, product innovation is excluded. Strikingly, product innovation to new the market and new to the firms, as well as innovation success, have no significant effect on firms' performance that is proxied by productivity. When both product innovation and innovation success are excluded (Model 2), there is no significant influence of either product innovation to new the market or new to the firms on productivity. In the third model, in which product innovation to new the market and new to the firms are excluded, there is no significant effect of product innovation and innovation success on productivity. Another surprising finding is that, in contrast, non-product innovations including process innovation, organisational innovation and marketing innovation, significantly affect productivity in all models. Positive associations were found between both process innovation and

Table 4 Knowledge exploitation activity

Independent variables	*Model 1 PRODUCTIVITY*	*Model 2 PRODUCTIVITY*	*Model 3 PRODUCTIVITY*
Product innovation	–	–	268.160(716.413)
Prod. Innov. New to market	668.224(1122.881)	-289.371(832.420)	–
Prod. Innov. New to firms	-45.167(820.431)	48.857(817.301)	–
Process innovation	*1964.657***(631.219)*	*1985.895***(631.165)*	*1985.412***(629.213)*
Organisational innovation	*2511.089***(631.492)*	*2578.718***(629.410)*	*2518.678***(632.025)*
Marketing innovation	*-1756.931***(604.736)*	*-1767.292***(604.841)*	*-1746.373***(603.329)*
Innovation success	-29.379(23.128)	–	-21.282(18.660)
Firm resources			
Size	−0.074(0.184)	−0.077(0.184)	−0.075(0.184)
Age	-22.201(19.116)	-22.262(19.121)	-22.451(19.115)
Export	-7.785 9.670)	-7.583(9.672)	-7.678(9.661)
OWN_NATIONAL	362.853(1241.632)	371.125(1241.944)	351.187(1241.068)
OWN_MULTI	1109.779(1566.056)	1101.907(1566.458)	1076.938(1565.01)
OWN_JOIN	–	–	–
OPERATION_PLANT	-1003.043(879.703)	-986.841(879.843)	-997.590(879.377)
OPERATION _HEAD	–	–	–
LOW_TECH	–	–	–
MEDLOW_TECH	580.331(649.173)	580.257(649.345)	577.387(648.739)
MEDHIGH_TECH	*2005**(912.806)*	*2044.913**(912.506)*	*2025.741**(911.861)*
HIGH_TECH	2421.285(2542.052)	2457.057(2542.568)	2477.757(2539.589)
EDU_UNDERHS	-48.366(31.223)	-47.312(31.220)	-48.391(31.215)
EDU_HIGHSCHOOL	-43.934(33.014)	-43.345(33.020)	-44.058(33.000)
EDU_DIPLOMA	-44.996(58.843)	-44.698(58.858)	-45.006(58.821)
EDU_UNDERGRAD	–	–	–
RD_STAFF	11.331(37.141)	10.115(37.138)	11.454(37.121)
Obs	1179	1179	1179
F ( )	2.92	3.00	3.07
Prob > F	0.000	0.000	0.000
R^2	0.046	0.044	0.046
Adj. R^2	0.030	0.030	0.031
Root MSE	8272.30	8274.50	8270.00

Notes: *** $p < 0.001$, ** $p < 0.05$, * $p < 0.10$

organisational innovation and productivity, while a negative association was found between marketing innovation and productivity. The evidence that innovation success has a negative and insignificant impact on productivity is in line with previous studies (Ganotakis and Love, 2012; Roper *et al.*, 2008; Roper and Arvanitis, 2012). Based on these findings, *H3* partially is supported.

Firm resources negatively and significantly affect productivity, but only in low-technology firms. Variables such as size, age, export and the lowest level of education have negative associations with productivity. In contrast, in high-tech firms, having employees with high school and undergraduate degrees is positively associated with productivity.

5. Discussion and conclusions

Key findings of this study are as follows. Firstly, in the first link of the IVC, this study finds the existence of strong synergistic relationships between internal R&D and external sources of knowledge as well as among external sources of knowledge. This may indicate a similar pattern of knowledge sourcing activity to that in developed countries, namely, the implementation of "open innovation strategy". The role of external networks tends to be less important when the firms already source knowledge for innovation from external R&D activities. External actors from market groups (i.e. customers and competitors) have important roles as knowledge providers if the firm also generates knowledge from internal R&D. In contrast, the firms' interactions with scientific institutions tend to be of lesser importance. The firms that source knowledge from market network interact less with scientific institutions, but they do interact with their own networks, associations and open sources. A synergistic relationship can also be found among science institutions. In relation to formal cooperation, firms tend to restrict cooperation with firms within the same group and with suppliers when they perform internal or external R&D activities. This finding supports the recent studies on the complementary relationship between internal and external knowledge sourcing activities (Bogers and Lhuillery, 2018; Doran *et al.*, 2019; Majidpour, 2017; Paula and Da Silva, 2018).

Secondly, in the second link of the IVC, internal R&D plays important roles and has strong positive impacts on all types of innovation and innovation success. External knowledge that shows similar patterns in shaping innovations mainly comes from informal knowledge from customers and competitors. Knowledge generated from scientific institutions makes no significant contribution to innovation and innovation success. Positive impacts on process innovation come only from government and non-profit R&D, while university and polytechnic sources contribute negatively to process innovation. This contradicts previous studies stating that novel and highly advanced innovation requires greater levels of R&D, patents or knowledge from science institutions such as universities and research centres (Amara and Landry, 2005; Tödtling *et al.*, 2009).

Third, the final link of the IVC relates to the impact of innovation on productivity provides surprising results. In general, product innovations new to the market and new to the firm as well as innovation success have no significant impact on productivity. The fact that innovation success is negatively associated with productivity may prompt questions related to the quality of innovative products that may be not able to disrupt the market and this may severely impact the firms' sales and further impact productivity.

The finding that neither product innovations new to the market and new to the firm nor innovation success lead to productivity, perhaps owing to the firms' efforts to detect and overcome any weak links in the IVC to boost productivity. First, sourcing activity that relies on the synergy between internal R&D and external networks, mainly from market, automatically influences the minimum usage of other sources of knowledge such as scientific institutions that may provide additional added value for firms. In this sense, a diverse open innovation strategy may need to be implemented with the hope that the use of more diverse and better-quality sources of knowledge able to overcome

the weak links in knowledge sourcing activities. Secondly, the low quality of firms' human resources may contribute to the success of knowledge sourcing, transformation and exploitation as indicated by no positive contributions to the three links of IVC. Thirdly, diverse of innovation barriers that hamper Indonesian manufacturing firms may affect the success of the IVC activities. Finally, environments external to the firms, or a weak conditional framework for innovation in Indonesia, may contribute indirectly to the success of the IVC activities.

5.1 Limitation of the study

This study is not without limitations. Firstly, issues related to firms' sectors have not been discussed in this study and as a result, sectors' effects on the three links of IVC cannot be detected. The variation among firm sectors is only derived from the classification of technology intensity. Secondly, this study is a cross-sectional in nature, i.e. the study only portrays IVC based on IIS 2011 data, as a result, dynamic of Indonesian manufacturing firms' IVC is missing. Hence, future studies may address this limitation by conducting a longitudinal study. Finally, specific issues related to each stage of the IVC importantly should be explored. In the knowledge sourcing activity stage, the issue related to formal cooperation with various external partners has not been addressed, hence it is recommended to test it in the future studies.

5.2 Innovation policy implication and theoretical contribution

Based on the findings from the first and second links of the IVC, relevant innovation policies may be proposed. The fact that Indonesia faces problems related to scientific institutions such as "low public and private investment in R&D", "a low-ranking higher education and training system" and "a small number of researchers and scientists for a country of its size" (OECD, 2013, p. 175), may present a problem for synergistic relationships between scientific institutions and other external agents. Further impact is clearly seen in the second link of the IVC in which the knowledge used from scientific institutions, both informally and formally, negatively impacts innovations. Therefore, government policy, for instance, promoting a triple helix strategy that involves university-industry-government interaction and partnership, may help address these challenges to improve knowledge transfer by integrating the three types of institutions. As argued by Tambunan (2005), triple helix implementation in Indonesia has been relatively slow. The Indonesian government initiated the development of incubators and science parks in 1990 with UNDP's support, but the development of these incubators has been very slow (Simamora, 2009). Public scientific institutions such as technoparks may be used by Indonesian firms to generate knowledge from R&D activities when they lack sufficient internal funds. In relation to the synergistic relationship between internal R&D and a wide range of external sources of knowledge, this study also suggests that rather than engaging exclusively in either R&D or external linkages, firms may adopt a hybrid strategy of leveraging knowledge from both sources of knowledge in the innovation process. It is believed that the proposed policies implication also relevant for firms in developing economies because firms in emerging economies tend to experience substantial institutional, resources and capability barriers that affect successful innovation (Fu *et al.*, 2014).

Findings from this study are expected to enrich the literature of innovation studies, especially innovation process framework in the context of developing countries, in several ways. Firstly, the fact that non-technological innovation (i.e. marketing innovation) is the highest proportion of innovation produced by Indonesian manufacturing firms support and confirm previous studies that reveal most firms in developing countries: tend to focus on market rather than technological innovation (Wamae, 2009), beyond the traditional focus on R&D (Srholec, 2011) and attempt to reach the technological frontier instead of achieving inventions that are new to the market (Hou and Mohnen, 2013). Secondly, the highest

proportion of knowledge sourced by Indonesian manufacturing firms mainly from an informal source of knowledge, e.g. customers and competitors. This also confirms previous innovation studies in Indonesia that reveal innovation in Indonesian manufacturing sectors generally as the results of learning through "informal experiences" not through "a formal scientific activity or R&D" (Aminullah, 2012; Aminullah *et al.*, 2014). Thirdly, this study also confirms the existence of complementary or synergy relationships between internal and external knowledge sourcing activities that have been tested as part of the innovation process framework in most studies conducted in developed economies.

In conclusion, this study investigates and models the IVC that encompasses knowledge sourcing, transformation and exploitation activities of Indonesia manufacturing firms using data from the IIS 2011. The literature on the IVC framework has been widely used to analyse inter-relationships among firm interaction, innovation, business growth and productivity in developed countries, however, based on the reviewed literature there is no empirical evidence to the IVC in the context of Indonesia. From a theoretical point of view, this study contributes some important insights on innovation process framework development by uncovered the nature of interrelationships within each stage and between linkages of the IVC performed by Indonesian firms.

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