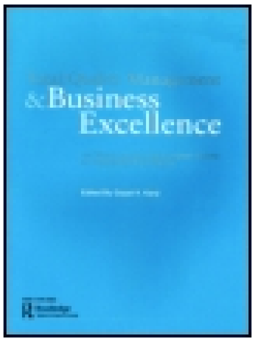

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Total quality management, knowledge management, and innovation: an empirical study in R&D units

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The purpose of this paper is to examine the reciprocal relation between total quality management (TQM) and knowledge management (KM) and their impact on process and product innovation. The data were collected from a survey of 190 research and development (R&D) unit managers in Malaysia. Confirmatory factor analysis was used to assess the reliability and validity of the measurement model, and in the next step, structural analysis was performed to evaluate the research model. The results revealed that there is a reciprocal relationship between TQM and KM. Additionally, TQM and KM showed a positive association with process and product innovation. Regarding the controversy of the relationship between TQM and innovation, this study supports the positive association between TQM and innovation. This study is among the first studies which provide empirical evidence to a reciprocal relationship between TQM and KM. The analysis shows that R&D firms by implementing TQM alongside KM not only are able to manage their activities efficiently, but also are able to effectively perform in an innovative manner.

Keywords: total quality management; knowledge management; process innovation; product innovation; reciprocal relationship

1. Introduction

Global organisations developed indices and criteria to assess the national competitiveness of countries. The World Economic Forum (WEF) has based its competitiveness analysis on the Global Competitiveness Index, a comprehensive tool that measures the microeconomic and macroeconomic foundations of national competitiveness (Wef, 2014). Based on its 12 indices and adjusted with economic theory of stages of development, the WEF defines three stages of competitiveness. According to WEF (2014) in the first stage, the economy is factor-driven and countries compete based on unskilled labour and natural resources. Companies compete on the basis of price and sell basic products or commodities, with their low productivity reflected in low wages. Countries will then move into the efficiency-driven stage of development, when they must begin to develop more efficient production processes and increase product quality because wages will have risen and they cannot increase prices. Finally, as countries move into the innovation-driven stage, wages will have risen so much that they will be able to sustain those higher wages and the associated standard of living only if their businesses are able to compete with new and unique products. At this stage, companies must compete by producing new and different goods. Many scholars have been attracted to study the innovation and the factors that have an impact on it. Malaysian economy and the related organisations

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aim to improve their performance by increasing the innovative outputs. But according to the last published knowledge and innovation assessment report in 2005, there are substantial gaps in terms of technology adoption rates and level of innovation at the firm and industry levels as well as between large and small firms, and domestic and foreign ones. Firms need to make the transition from being good adopters and adaptors of technology to being good innovators (Epu, 2005). However, to move towards an innovation-based economy, it would be wise to investigate among antecedents and forerunners of innovation inside the organisations. This paper aims to find whether companies from the second stage of development, with the basis of quality and productivity culture, are able to move towards being innovative companies based on their existing quality management approach?

To wrap it up, based on an extensive literature review, it has been revealed that there are three major gaps in the subject area of this research: firstly, the inconsistent results of the studies that have investigated the relationship between total quality management (TQM) and innovation; secondly, the contradictory results in the relationship between knowledge management (KM) and innovation; and the third gap refers to shortage of empirical studies that examine the TQM–KM relationship in addition to various outcomes of the published researches in this field.

2. Literature review

Innovation, as a pivotal source of competitive advantage, has been considered in a wide range of studies (Augusto, Lisboa, & Yasin, 2014; Damanpour, 1991). There are many studies which have investigated the factors affecting innovation. Among all the factors that affect innovation, TQM and KM have attracted a notable consideration in scholarly researches (Hung, Lien, Yang, Wu, & Kuo, 2011). During the last two decades, TQM is regarded as a management practice which guarantees an organisation with enhanced performance (Laosirihongthong, Teh, & Adebanjo, 2013; Pinho, 2008). Simultaneously, a large number of studies have discussed the relationship between TQM and innovation (Lee & Ooi, 2015; Prajogo & Sohal, 2003). Although the number of studies that have considered the association between TQM and innovation has increased, due to the complexity of their link, there is a disagreement over TQM and innovation relationship (Singh & Smith, 2004; Trivellas & Santouridis, 2009). This lack of consensus mirrors the mixed results found in the literature relating TQM practices and innovation (Manders, de Vries, & Blind, 2015). Two schools of thought can be distinguished in the TQM–innovation related literature (Trivellas & Santouridis, 2009). The first school identifies TQM as an antecedent of innovation. According to Perdomo-Ortiz, Gonzalez-Benito, and Galende (2009), the positive effects of TQM on innovation can be conceptualised in three aspects. The first comprises market orientation and customer focus-related practices which provide organisations with the customer needs information that leads to new ideas to meet these demands (Perdomo-Ortiz, González-Benito, & Galende, 2006). The next contribution of TQM to innovation is related to continuous improvement. This practice aids to improve the know-how within the organisation by recognising the necessary changes in processes (Satish & Srinivasan, 2010). The final aspect comprises teamwork, employee empowerment, and people management which encourage autonomy and sharing ideas among employees that consequently lead to innovation (Perdomo-Ortiz et al., 2009). For instance, Prajogo and Sohal (2003) stated that TQM is significantly and positively associated with innovation. Recently, several studies verified the positive effect of TQM on innovation (Hung et al., 2011; Perdomo-Ortiz et al., 2009). The extent to which research and development (R&D) activity impacts innovation is related to the extent to which a firm exceeds the minimum requirements of quality certification (Wang, 2014). On the other hand, the alternative school argues that TQM does not contribute to innovation (Abrunhosa & Moura E Sá, 2008; Pinho, 2008; Singh & Smith, 2004). According to Prajogo and Sohal (2001), this view of the TQM–innovation relationship is based on six main reasons. Firstly, TQM focuses on current customers and this will cause only incremental innovations in current products or services (Harari, 1993; Wind & Mahajan, 1997). In addition, customer focus-related practices result in narrow-minded organisations that follow short-term needs of customers (Slater & Narver, 1998). The next obstacle is related to imitation problem. Based on this reason, the organisations that practice TQM are more likely to become imitator or follower organisations because TQM does not motivate organisations to consider radical products. The fourth reason is based on standardised processes in TQM that hinder creativity and entrap people into keeping what is workable (Prajogo & Sohal, 2001). As Prajogo and Sohal (2001) stated, TQM enhances single-loop learning rather than double-loop learning and its concentration on cost efficiency would confine the capability and opportunity for innovation in organizations. For instance, Singh and Smith (2004) failed to confirm the existence of a significant and positive relationship between TQM and innovation.

KM is among the fast-growing area of management research that has been the scope of numerous studies. A number of academic studies have identified a positive relationship between KM and innovation (Darroch, 2005; Liao & Wu, 2010). Johnston and Paladino (2007) found that the use of KM techniques is a primary activity in their surveyed firms. It was reported that a significant association between the use of KM techniques and involvement in innovations existed. However, some studies also found evidence pointing towards mixed innovation accrued from KM processes. Gloet and Terziovski (2004, p. 404) revealed that 'elements of IT focus on technological advancement to KM' or hard KM paradigm does not have a significant association with innovation performance. It was revealed that this approach to KM has a negative correlation with innovation performance. In contrast, a soft approach or 'humanist approaches to KM' have a significant association and positive correlation with innovation performance. Information technology enables organisations to access electronic libraries; however, people should learn and participate in using these repositories (McDermott, 2000). Also, there are some studies that reported the failure of KM implementation in fulfilling the expected results. The findings show that a large amount of KM projects (more than 50%) fail or do not achieve their stated goals (Prusak & Weiss, 2007), for instance productivity, effectiveness, and performance improvement.

Although TQM and KM have common aims and positions concerning management, it seems that both TQM and KM are interrelated, if not congruous (Waddell & Stewart, 2008). Both are long-lasting practices for the purpose of attaining competitive advantage and innovation. They hold a number of common fundamental assumptions, for example, the vitality of cultural alterations and process enhancement (Dvir, 2002). Recently, a few researchers have demonstrated some interest in the relationship of TQM and KM. However, they have not reached a consensus to conceptualise this relation. Hung, Lien, Fang, and McLean (2010) regarded this relationship with innovation as the criterion, while in Molina, Llorens-Montes, and Ruiz-Moreno (2007), performance is the criterion. Even so, these findings have diverse settings regarding the nature of the relationship. Hung et al. (2010) revealed that TQM is a mediator in the relationship between KM and innovation. Conversely, Molina et al. (2007) contemplated knowledge transfer as the mediator between TQM and performance. Regarding the methodological aspect of the mediator concept, the mediator 'represents the generative mechanism through which the focal independent variable is able to influence the dependent variable of interest' (Baron & Kenny, 1986, p. 1173), which ensures that not only TQM causes KM in respect of performance, but also KM generates TQM with respect to innovation. Although some researchers perceived KM as a facilitator of TQM (Barber, Munive-Hernandez, & Keane, 2006; Stewart & Waddell, 2008), other scholars concerned TQM as an antecedent for KM (Colurcio, 2009; Jayawarna & Holt, 2009; Molina et al., 2007). Diverse outcomes and inadequate empirical research in this field emphasise the importance of examining this relationship more profoundly.

As a wrap up, three issues were found in the literature which this research aims to study: firstly, the inconsistent results of the studies that have investigated the relationship between TQM and innovation; secondly, the contradictory results in the relationship between KM and innovation; and thirdly, the shortage of the empirical studies which examine the relationship between TQM and KM.

3. Hypotheses and model development

Opponents of the positive effect of TQM on innovation argue that TQM focuses on current customers and this will cause only incremental innovations in current products or services (Moreno-Luzon, Gil-Marques, & Valls-Pasola, 2013). In addition, customer focus-related practices result in narrow-minded organisations that follow short-term needs of customers (Slater & Narver, 1998). However, the other school identifies TQM as an antecedent of innovation. According to Perdomo-Ortiz et al. (2009), the positive impacts of TQM on innovation can be conceptualised based on three main reasons: firstly, market orientation and customer focus-related practices which make essential information about the customer needs available that triggers new ideas in order to fulfil the customer requirement (Fuentes, Montes, & Fernández, 2006; Hoang, Igel, & Laosirihongthong, 2006). Secondly, the contribution of TQM to innovation is mostly about continuous enhancement. This practice assists in improving the know-how within the organisation by identifying the required alterations in processes (Perdomo-Ortiz et al., 2009; Prajogo & Sohal, 2004). Finally, teamwork, employee empowerment, and people management promote autonomy and idea sharing among employees that consequently result in innovation (Kuo, Kuo, & Ho, 2014). There are several studies that support the positive association between TQM and innovation (Hung et al., 2011; Prajogo & Sohal, 2004; Trivellas & Santouridis, 2009). For instance, Lee et al. (2010) found a strong structural relationship between TQM and innovation. In another study, Sadikoglu and Zehir (2010) found significant and positive relationships among TQM practices and innovation. According to Murat and Baki (2011), high levels of employee involvement and cross-functional teamwork may lead to enhanced product innovation. Process management involves repeating routines and enhancing them. Routines involve diverse procedures and skills which help employees in enhancing their administrative system functions. Thus, firms which repeat and improve routines are more likely to be process innovators (Kim, Kumar, & Kumar, 2012). Increasing the efficiency of the processes will facilitate the process of new product development from idea generation. In addition, some slack time will be created by improving the efficiency of the organisational processes, which opens the door for responding to customer needs by either modifying the existing products or developing new products (Kim et al., 2012). Hence the following hypothesis is formulated:

H1: TQM positively associates with innovation.

H1a: TQM positively associates with product innovation.

H1b: TQM positively associates with process innovation.

A large body of academic researchers have found a positive relationship between KM and innovation (Choo, Linderman, & Schroeder, 2007; Gloet & Terziovski, 2004; Liao, Fei, & Chen, 2007). The association between the KM processes and innovation is well established in the literature. Acquiring knowledge from inside and outside of the organisation advances the knowledge assets within the organisation, which leads to knowledge modification (Chen & Huang, 2009). This process increases the innovative outcomes (Chen & Huang, 2009). Knowledge dissemination, transferring and sharing tacit and explicit knowledge among the organisation, entails learning and modifying existing knowledge that consequently enhance innovation (Chen & Huang, 2009; Hung et al., 2011; Liao & Wu, 2010). Likewise using knowledge leads to learning, which expands the firm's knowledge stock (Nonaka, 1995). Applying new knowledge by means of solving problems and embodying knowledge to new products is directly related to innovation (Huang & Li, 2009). Based on Grant's (1996) discussion, firms survive as far as they can better utilise specialised knowledge and preserve it from imitation by competitors. The application of knowledge enables knowledge to be more effective and applicable for the firm in creating values, including new product development and performance enhancement (Grant, 1996; Huang & Li, 2009; Lin & Lee, 2005). Johnston and Paladino (2007) found that the use of KM techniques is a primary activity in their surveyed firms and a significant association between the use of KM techniques and involvement in innovations exists. Based on Grant (1996), there are three main methods of knowledge application, namely, directives, organisational routines, and self-contained task teams. 'Directives specific set of rules, standards, procedures, and instructions developed through the conversion of specialists' tacit knowledge to explicit and integrated knowledge for efficient communication to non-specialists' (Alavi & Leidner, 2001, p. 122). This process leads to the establishment of new standards, workflow, or procedures. Additionally, self-contained task teams are individuals with essential knowledge gathered for problem-solving. The aim of the team can be set from new product development to cost reduction mechanisms. Thus, the following hypothesis is formulated:

H2: KM positively associates with innovation.

H2a: KM positively associates with product innovation.

H2b: KM positively associates with process innovation.

By applying TQM, organisations are motivated to enhance their relationship with suppliers and customers. Doing so, they need to acquire comprehensive knowledge about them, and improve their relationship, which brings about acquiring knowledge from outside and within the organisation. Furthermore, they should disseminate knowledge within their organisation and with their suppliers (Ooi, 2012). In addition, they should adapt their current knowledge and apply new knowledge to deal with customer requirements. In order to meet such aims, identifying and resolving the issues to advance the processes of the organisations should be carried out by creating teams, developing collaboration among employees, and training the employees. Barber et al. (2006) addressed the role of KM systems in supporting continuous improvement. They demonstrated that a KM system allows constant enhancement by 'utilization of accessible data already held within the company's management databases'. Therefore, formal and informal KM practices, which result in the storage of information in the organisation, make the organisation informed about the environmental alterations and consequently help them to improve their reactions. Undoubtedly, more knowledge of customers and suppliers triggers improved management of the relationship with them. Additionally, awareness of the knowledge capability of the organisation leads to resolving the problems and, therefore, enhancing the processes. Jayawarna and Holt (2009) analysed the relationship between knowledge generation and transformation in the R&D context. According to their case study research, they concluded that TQM practices enhanced knowledge creation and transformation. Based on a *post hoc* analysis, Honarpour, Jusoh, and Md Nor (2012) stated that half of all explained variances in empirical studies that considered the relationship between TQM and KM ignoring the criteria are accounted for in the joint variance of TQM and KM processes. Therefore, the following hypothesis is formulated:

H3: There is a reciprocal causation between TQM and KM.

Based on the above literature review, a research framework was developed to examine the relationship between TQM practices and KM and innovation. The links between these constructs are illustrated in Figure 1. Based on this model, TQM can be seen as a powerful setting or an important resource which can be used to improvise knowledge-related processes towards innovation. The reciprocal relation between TQM and KM can be seen as a synergetic relationship which can make the innovative activities more reachable.

4. Procedures and sample

The scope of the study includes organsations which participated in the 2011 Malaysian National Survey of R&D. The only source of such firms or units is the Malaysian Science and Technology Information Centre (MASTIC) in the Ministry of Science, Technology, and Innovation. Since 1994 every two years, MASTIC implements the collection of R&D activities of the country to obtain the status, trends, and statistics of national R&D activities conducted by the public sector (institutions of higher learning and research institutes) and the private sector/industry for a period of financial year. According to WEF (2014), Malaysia is in the transition stage from an efficiency-driven economy to an innovation-driven economy with a rich background of quality management approaches of its companies. In the context of this study, the Government of Malaysia moves to become a much more knowledge- and technology-intensive economy. The knowledge-based economy will contribute towards improving economic stability, as it will establish the basis for endogenously generated growth caused by Malaysia's strengthened capability to carry out R&D. The Government of Malaysia envisages that a knowledge-based economy will provide the platform to sustain a rapid rate of economic growth and enhance the international competitiveness of the country (Epu, 2005). The knowledge-based economy will also contribute towards strengthening economic resilience. It will set the foundation for endogenously generated growth, resulting from Malaysia's

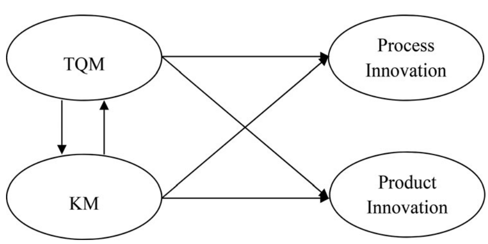

Figure 1. Conceptual framework.

strengthened capability to conduct R&D, innovate and create indigenous technology, design and develop new products, as well as move up the value chain. Because of the limitation in resources, especially human resources and time, solely this country is being chosen for this research.

To have an inclusive viewpoint and reliable results, the study covers Malaysian firms from private and public sectors which contributed to R&D activities which is equal to 1033. Considering the knowledge of the topic of interest, the R&D manager or operational manager of the firm is the respondent who is aware of the quality of the processes, knowledge processes, and innovation in R&D activities in the organisation. So the sampling units of this study are R&D managers or operational managers of the R&D firms or units. A random sample of 800 organisations was selected from the population. Follow-up letters, emails, and phone calls were done to appeal for participation. Of the returned surveys, 204 were returned and 190 were usable, giving us a 23.8% usable response rate.

3.1. *Variable measurements*

TQM was measured by the degree of using its practices, namely, leadership, people management, process management, information and analysis, customer focus, and supplier management in the organisation. A total of 36 questions asked were adopted from the literature based on the works of Zeitz, Johannesson, and Ritchie (1997), Grandzol and Gershon (1998), Samson and Terziovski (1999), and Saraph, Benson, and Schroeder (1989). Considering the context of the study, some modifications have been made to relate the questions to the R&D activities. Then three experts in the subject area have examined the validity of the scale and the modifications that had been added.

The KM construct measures KM practices and processes in the organisation, namely, knowledge acquisition, knowledge dissemination, and knowledge application. The questions have been adopted from Lin and Lee (2005).

The product innovation construct covers new products or services that are initiated for customers. The construct process innovation pertains to new elements introduced to organisational processes and operations (Damanpour, 1991). Basically all the 10 questions in this section were adopted from Gunday, Ulusoy, Kilic, and Alpkan (2011).

Respondents were asked to respond to the statement using a seven-point Likert scale ranging from strongly disagree, which is weighted as 1, to strongly agree, weighted as 7. Since using a single data-gathering method can lead to common method bias, Harman's one-factor test is carried out to address the common method variance. The results show that the largest factor accounted for 42.89% (i.e. less than 50%) of the total variance and imply that no single factor emerged as the dominant factor. Hence, the common method variance bias in the data would not be significant (Lam, Lee, Ooi, & Phusavat, 2012).

5. Data analysis and results

The analysis of the final sample profile showed a higher number of male (115) respondents than female (75), representing a ratio of 60.5% and 39.5%, respectively. Regarding the size of the R&D units, 63 units have less than 10 employees, 41 units between 10 and 20, 28 between 20 and 40, and 58 more than 40. Twenty-four units were aged less than 3 years, 34 units were between 3 and 5 years, 59 were between 5 and 10 years, 53 units were between 10 and 20 years, and 20 units were working for more than 20 years.

Structural equation modelling (SEM) was used to examine the research model and hypotheses. The KM and TQM scales were assessed as second-order scales. Each of these multidimensional scales was first subjected to confirmatory factor analysis to demonstrate the underlying factors. Some items in each of the scales were necessarily removed. Three items from the KM scale, 10 items from the TQM scale, 1 item from process innovation, and an item from the product innovation scale were removed because of low loadings on their respective constructs. The remaining items in each of the dimensions were then imputed and those scores used as second-order measures of KM and TQM. Table 1 shows the assessment of KM and TQM as second-order measures. Relative χ^2 (chi-squared statistic divided by the degrees of freedom), goodness-of-fit (GFI) index, root mean square error of approximation (RMSEA), and comparative fit index (CFI) values were used to assess unidimensionality. Relative χ^2 values of less than or equal to 3.00, RMSEA values less than or equal to .10, CFI values greater than or equal to .90, and GFI values greater than .8 indicate a reasonable fit (Hair, Money, Samouel, & Page, 2007; Ooi, Cheah, Lin, & Teh, 2012; Zelbst, Green Jr, Abshire, & Sower, 2010). It is observed in Table 1 that the values for TQM and KM scales exceed the recommended levels.

In the next step, Cronbach's α and composite reliability were evaluated to test the reliability of the measurement model. The suggested cut-off points for Cronbach's α and composite reliability are .7 and .8, respectively. The reliability scores of the measurement model are shown in Table 2. As shown in Table 2, all constructs' indices had exceeded the respective common acceptance levels.

To establish construct validity, convergent validity and discriminant validity have been tested. Both factor loadings and the average variance extracted (AVE) are tested to assure convergent validity (Fornell & Larcker, 1981; Jiang & Li, 2009). In the first step, significant factor loadings that are more than .50 are considered acceptable. The recommended threshold level of 50% was proposed for an acceptable AVE (Bagozzi & Yi, 1988). As revealed by the results represented in Table 2, it could be noted that all of the constructs have exceeded the recommended threshold level.

Discriminant validity is normally tested by employing a common test as suggested by Bagozzi and Yi (1988). It is recommend that to obtain discriminant validity, AVE for each individual construct should be more than the squared correlation of that construct with other constructs (Bagozzi & Yi, 1988; Fornell & Larcker, 1981; Jiang & Li, 2009). Table 3 presents the discriminant validity analysis. In this table, the elements on the diagonal of the table are AVEs and other elements are squared correlation of the constructs. As it can be seen in this table, the required conditions have been met. In addition, model-fit indices of the measurement model as tabulated in Table 4 have all exceed the recommended thresholds.

In the last step, structural equation model was tested. To analyse the reciprocal relations between constructs using cross-sectional data with SEM, three rules should be

Table 1. Reliability, dimensionality, and convergent validity assessment results.

Scale	Cronbach's α	Relative χ^2	CFI	RMSEA	GFI
TQM	.952	1.946	.941	.071	.855
KM	.944	2.363	.973	.085	.936
Recommended value[a]	$\geq .7$	≤ 3	$\geq .9$	$\leq .1$	$\geq .8$

[a]Hair et al. (2007), Zelbst et al. (2010), and Ooi et al. (2012).

Table 2. Instrument reliability and convergent validity.

Construct	Indicators	Standardised loadings	AVE	Cronbach's α	Composite reliability
TQM	LDR	.848	.729	.932	.941
	PRCM	.963			
	SUPM	.674			
	PM	.916			
	IA	.733			
	CF	.948			
KM	KAP	.989	.902	.963	.965
	KAC	.892			
	KDS	.965			
Product innovation	PRDIN5	.753	.622	.877	.868
	PRDIN4	.813			
	PRDIN3	.843			
	PRDIN2	.74			
Process innovation	PRCIN4	.923	.743	.918	.920
	PRCIN2	.799			
	PRCIN1	.822			
	PRCIN5	.899			

LDR: Leadership, PRCM: Process management, SUPM: Supplier management, PM: People management, IA: Information and analysis, CF: Costumer focus, KAP: Knowledge application, KAC: Knowledge acquisition, KDS: Knowledge dissemination, PRDIN: Product innovation, PRCIN: Process innovation.

Table 3. Discriminant validity.

	TQM	KMM	PRDC	PRCS
TQM	.729			
KMM	.576	.902		
PRDC	.437	.460	.622	
PRCS	.508	.456	.530	.744

considered as suggested by Wong and Law (1999). Firstly, the covariance between the disturbance terms of the endogenous variables in the non-recursive model should be specified. The next rule is to identify the adequacy of the non-recursive model with the temporal stability of the true cross-lagged effects. The stronger the temporal stability, the more adequate the non-recursive model will be. Finally, specification of some instrumental variables which have an effect on the endogenous adequately should be carried out. To prevent a non-recursive model from being under-identified, exogenous variables with

Table 4. Model fit indices.

Model-fit index	Recommended value	Measurement model	Structural model
GFI	$\geq$0.8	0.866	0.856
CFI	$\geq$0.9	0.957	0.953
RMSEA	$\leq$0.1	0.085	0.074
χ^2-test statistics/d.f.	$\leq$3	2.352	2.033

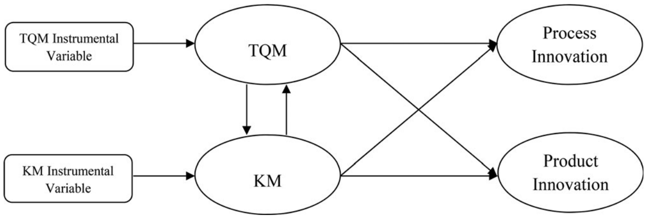

Figure 2. Final structural model.

structural paths pointing to these endogenous variables are essential for the model to be identified. These exogenous variables are usually referred to as instrumental variables. These variables have to predict only one of the endogenous variables in the model. Some authors have pointed out that these instrumental variables should be specified a priori based on sound theories (Wong & Law, 1999). Two questions have been used to measure the instrumental variables in this study. The first question is 'In our unit, does management acts as a role model to exhibit the desired behaviour (acquiring, disseminating and using knowledge)'. This variable is connected only with KM. The TQM related question is 'The quality objectives are included our mission, vision or strategic planning process'.

Figure 2 shows the final structural model. The hypotheses were tested using a latent variable model, which included both latent variables and observed variables controlling the endogenous variables for age and size of the R&D units. AMOS 20, using the maximum likelihood estimation, was employed to estimate the coefficient and *p*-value.

The GFI indices, as presented in Table 4, reveal that the structural model fits the data well: CFI = .953; RMSEA = .074; χ^2/df = 2.033; GFI = .856. Table 5 shows the analysis results of the structural model. Overall results indicate that all five hypotheses were supported at the significance levels of 95–99%. It should be noted that, according to Table 5, the hypotheses related to TQM (*H1a*: β = .355; *H1b*: β = .475) were supported. A positive association between TQM and process innovation and between TQM and product innovation could be observed. The results also indicated that KM is a significant and direct predictor of product and process innovation, supporting *H2a* (β = .406) and *H2b* (β = .314).

Table 5. Hypotheses test.

H1a	Product innovation	←	TQM	.355***	Supported
H1b	Process innovation	←	TQM	.475***	Supported
H2a	Product innovation	←	KM	.406***	Supported
H2b	Process innovation	←	KM	.314***	Supported
H3	TQM	←	KM	.688***	Supported
	KM	←	TQM	.550*	
IR	TQM	←	TQM instrumental variable	.112*	Significant
IR	KM	←	KM instrumental variable	.484***	Significant
CVR1	Process innovation	←	Size	.005^{ns}	Not-significant
CVR1	Product innovation	←	Size	.039^{ns}	Not-significant
CVR1	Product innovation	←	Age	−.025^{ns}	Not-significant
CVR1	Process innovation	←	Age	−.01^{ns}	Not-significant

Note: CVR: control variable relationship; IR: instrumental relationship; ^{ns}non-significant.
*$p < .05$.
**$p < .01$.
***$p < .001$.

Further, it was found that the importance of TQM and KM varies with the type of innovation employed. The contribution of TQM was found to be less in the case of product innovation (coefficient: .355) as compared to process innovation (.475). It was noted that the relationship between KM and product innovation (coefficient: .406) is more than the relationship between KM and process innovation (.314).

As a highlight, one of the important findings of this study was that TQM and KM are significantly and reciprocally related to each other. In particular, there was a significant and positive reciprocal link between TQM and KM (the TQM effect on KM is equal to .550 and the KM impact on TQM was found to be .688).

6. Discussion and conclusion

The findings lend support to the prediction that TQM is positively associated with innovation and is a significant predictor of innovation in R&D firms. Regarding the controversy of the relationship between TQM and innovation, this study supports the results of the findings of the 'school of thought' which adheres to a positive relation between TQM and innovation. The results showed inconsistency with the findings of Singh and Smith (2004) which failed to support the existence of a significant and positive relation between TQM and innovation. In the context of R&D units, TQM can be highlighted as a major contributor of innovation. Since TQM and KM are determinants of innovation, as *H1* and *H2* confirmed, mutual interaction between them can have a substantial effect on innovation not only from their direct relation to innovation, but also from their indirect effect. The outcomes of this study confirm the findings of the other study in the literature that attempted to examine the relationship between TQM and KM (Ju, Lin, Lin, & Kuo, 2006). Ju et al. (2006) developed a set of questionnaires on themes of the relationship between TQM and KM, which were sent to 30 companies. They claimed that there is a potential interaction between TQM and KM. Accordingly, it can be concluded that TQM and KM are mutually related to each other and that this interaction can have a positive effect on innovation. Furthermore, this study provides empirical evidence to complement the qualitative findings of Honarpour et al. (2012) that KM and TQM are reciprocally related to each other. While some researchers considered KM as a facilitator of TQM (Barber et al., 2006; Hung et al., 2010; Stewart & Waddell, 2008), other scholars concerned TQM as an antecedent for KM (Colurcio, 2009; Jayawarna & Holt, 2009; Molina et al., 2007).

In addition, comparing the effects of innovation on the dimensions of innovation reveals that the magnitude of the impact of TQM on process innovation is greater than its impact on product innovation. This finding is not surprising given the fact that process innovation is related to 'new elements introduced into an organisation's production or service operation (e.g. input materials, task specifications, work and information flow mechanisms, and equipment) to produce a product or render a service' (Damanpour & Gopalakrishnan, 2001, p. 47), and TQM practices are related to improve supply management (input materials), people management (task specifications), and information and data analysis (work and information flow mechanisms). Considering this definition, it is understood that process innovations lead to lower production costs and, as a result, higher profit margins (Fritsch & Meschede, 2001). Therefore, TQM adoption can lead to efficient management of R&D activities along with improved innovative outcomes.

The results also suggest that an R&D firm with KM is likely to have favourable innovative outcomes. The findings of this study substantiate the speculation of academic research which have found a positive relationship between KM and innovation (Choo et al., 2007; Hung et al., 2010; Liao et al., 2007), which indicates that in the R&D units with the successful implementation of KM, product and process innovations are anticipated. In addition, comparing the effect of KM on the dimensions of innovation shows that the magnitude of the impact of KM on product innovation is greater than its impact on process innovation. Acquiring, disseminating, and applying new knowledge from competitors, suppliers, and customers can increase the idea generation among research teams, which can lead to advanced technical specifications and better functionalities of products, which in turn leads to developing new products with components and materials totally different from the current ones; in other words product innovation.

Empirically, this study demonstrates that there is reciprocal causation between TQM and KM regarding innovation as a criterion. It should be understood that KM plays an important role in TQM implementation and that there is a need for greater application and share of knowledge in the quality improvement process. To this end, KM acts as a window through which the process of quality improvement can be discerned, and ensures that innovation will be of the utmost importance in guiding organisational responses to market changes. Conversely, TQM should play a pivotal role in KM development. The results suggest that KM should have an increased chance of success through a TQM focus and the effective use of knowledge towards innovation. As an example of this reciprocal relation, after action review (AAR) is a KM technique to assess and acquire lessons learned upon finishing of a project or an issue. It enables project team members to individually explore what has happened, why it has happened, and how to maintain advantages and improve on weaknesses. The emphasis of the AAR is on learning, that is, determining lessons learned, instead of blaming people for wrong decisions or weak performance (Asian Productivity Organisation [APO], 2010). Interestingly, all of the TQM activities are founded on the Plan-Do-Check-Action circle, specifically the action phase is based on what is learned in the previous steps and uses the lessons learned to plan for new improvements.

Global organisations have developed indices and criteria to assess the national competitiveness of countries. APO, in line with the WEF, suggests that developing countries should commit some resources to innovation while they strive to strengthen their basic structures and efficiency. Regarding this aim, the Government of Malaysia envisages that a knowledge-based economy will provide the platform to sustain a rapid rate of economic growth and enhance the international competitiveness of the country (Epu, 2005). The knowledge-based economy will also contribute towards strengthening economic resilience. It will set the foundation for endogenously generated growth, resulting from Malaysia's strengthened capability to conduct R&D, innovate and create indigenous technology, design and develop new products, as well as move up the value chain. To reach to this goal, practitioners that aim to improve innovation are aiming to find support to apply TQM and KM, simultaneously. This is to improve the innovative activities in their organisations throughout the synergistic collaboration of TQM and KM. This will show how R&D units could maintain their efficiency and competitiveness and gain innovative competitive advantage by implementing TQM and KM. The wide space between quality management and R&D management is shortening due to overlapping requirements (Jayawarna & Holt, 2009). The consequence might be that R&D can be benefited from implementing quality systems to its functions insofar as these systems contribute to the exploration for and exploitation of strategically related knowledge. The adoption of quality systems within an R&D unit sometimes needs another management style compared to those found in manufacturing environments. According to Jayawarna and Holt (2009), the systematic clarity did assist firms in some measure to incorporate R&D activities with broader firm considerations. Those R&Ds which failed to obtain ISO quality qualifications in their study reported very inadequate process discipline and commonly recognised procedural frameworks because of rework, project variation, and the incapability to make effective utilisation of their good practice knowledge. Therefore, the research teams can stop their processes (and prevent spending more investment capital) whenever it gets to be clear that the selected invention is not expected to make it to market (Kiella & Golhar, 1997). Therefore, R&D firms by implementing TQM alongside KM not only are able to manage their activities efficiently, but also are able to effectively perform in an innovative manner.

Although this study has made some contributions to understanding the TQM, KM, and innovation relationship, it is not without some important limitations. It includes a number of limitations which have to be uncovered. Firstly, one potential limitation of the study is a high number of university R&Ds. This composition of sample may bias the result in terms of the industry effect on innovation. Thus, the results of this study should be interpreted cautiously. Secondly, since the reciprocal causation implies the temporal relation between two constructs, a longitudinal examination of the relationship between KM and TQM would more casually show the synergetic association between them. Finally, this study was conducted in Malaysia. The results may not be generalisable to R&Ds in other countries. The role of R&D units in value chain in these countries might not be the same as that in Malaysia, or TQM importance and implementation, which can be affected by culture, might be different. Therefore, it is possible that factors that are significant in this study might not be important to them. This study was limited in its scope and the body of knowledge could be expanded through further research along the same lines of inquiry. Contextual factors which affect the KM–TQM reciprocal relationship can be investigated in future studies. This can expand the body of knowledge by introducing new factors which might improve this reciprocal relationship.

Disclosure statement

No potential conflict of interest was reported by the authors.

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Appendix

Construct	Items
Leadership	(1) Senior executives share similar beliefs about the future direction of this R&D unit (L1) (2) Activities and projects that have long-term benefits receive little support from management (L2) (3) Employees have the opportunity to share in and are encouraged to help the unit to implement change (L3) (4) Managers usually allow researchers to take necessary action on their own (L4) (5) Managers anticipate change and make plans to accommodate it (L5) (6) R&D unit heads participate in the quality improvement process (L6) (7) Environmental 'green' protection issues are proactively managed at this unit (L7) (8) Managers here try to plan ahead for changes that might affect our performance (L8) (9) Vision, mission, and objectives on R&D are clearly communicated to me (L9)
Customer focus	(1) We know our customers' current and future requirements in terms of product characteristics (CF1) (2) In designing new products and services, we use the requirements of customers (CF2) (3) We have an effective process for resolving customers' feedback (CF3) (4) Customer feedbacks are used as a method to initiate improvements in our current processes (CF4) (5) We systematically and regularly measure customer satisfaction (CF5)
Process management	(1) The processes for designing new products/services in this R&D unit ensure quality (PCM1) (2) Employees involved in different processes know how to use process control methods to evaluate their processes (PCM2) (3) Explaining the variation in processes is frequently used as an analysis technique in this unit (PCM3) (4) We have well-established methods to measure the quality of our products and services (PCM4) (5) We have organisation-wide standardised and documented research procedures (PCM5) (6) The process ownership is clear in this unit (PCM6) (7) The main processes of research management (such as proposal, research, development, and commercialisation) are standardised (PCM7)
People management	(1) The concept of 'internal customer', that is, the next person or process down the line and including all employees, is well understood at this unit (PM1) (2) We have an organisation-wide training and development process, including career path planning, for all our employees (PM2) (3) Employee satisfaction is formally and regularly measured (PM3)

(*Continued*)

Appendix. Continued.

Construct	Items
	(4) All employees believe that quality is their responsibility (PM4) (5) Employees are compensated for superior quality performance (PM5) (6) Managers and supervisors create a work environment that encourages employees to perform to the best of their abilities (PM6) (7) This unit is serious in taking care of and retaining talented researchers (PM7)
Information and analysis	(1) This R&D unit keeps data to track work improvements (IA1) (2) Records or charts measuring the quality of work are available (IA2) (3) Up-to-date data and information are readily available (IA3) (4) The unit has a data and information management system that can effectively measure the research performance (IA4) (5) Data and information about the unit's research performance are used to make decisions on resources allocation (IA5) (6) The Information Technology System that we use is effective in searching and spreading the data/information related to research works (IA6)
Supplier relationship	(1) Suppliers are selected based on quality rather than price or schedule (SM1) (2) Long-term relationships are offered to suppliers (SM2) (3) We work closely with our suppliers to improve each other's processes (SM3) (4) Specifications provided to suppliers are clear (SM4) (5) The unit supports me to do collaboration research with other researchers from different disciplines (SM5) (6) The unit supports me to do collaboration research with other universities or research institutes (SM6) (7) The university supports me to do collaboration research with industries (SM7)
knowledge acquisition	(1) My organisation has processes for acquiring knowledge from inside and outside of the organisation (KA1) (2) My organisation has processes for capturing knowledge of our competitors (KA2) (3) My organisation has processes for capturing knowledge obtained from other industry sources such as industrial associations and clients (KA3) (4) My organisation has processes for acquiring customer knowledge (KA4) (5) My organisation has processes for acquiring knowledge on developing new products/services (KA5)
Knowledge dissemination	(1) My organisation has processes for distributing knowledge throughout the organisation (KD1) (2) My organisation has processes for distributing knowledge among our business partners (KD2)

(*Continued*)

Appendix. Continued.

Construct	Items
	(3) My organisation designs processes to facilitate knowledge sharing across functional boundaries (KD3)
Knowledge application	(1) My organisation has processes for integrating different sources and types of knowledge (KAP1)
	(2) My organisation has processes for transferring organisational knowledge to employees (KAP2)
	(3) My organisation has processes for filtering knowledge (KAP3)
	(4) My organisation has processes for applying experiential knowledge (KAP4)
	(5) My organisation has processes for applying knowledge to solve new problems (KAP5)
Product innovation	(1) Increasing manufacturing quality in components and materials of current products (PRDIN1)
	(2) Decreasing manufacturing cost in components and materials of current products (PRDIN2)
	(3) Developing newness for current products leading to improved ease of use for customers and to improved customer satisfaction (PRDIN3)
	(4) Developing new products with technical specifications and functionalities totally differing from the current ones (PRDIN4)
	(5) Developing new products with components and materials totally differing from the current ones (PRDIN5)
Process innovation	(1) Determining and eliminating non-value-adding activities in production processes (PRCIN1)
	(2) Decreasing variable cost components in manufacturing processes, techniques, machinery, and software (PRCIN2)
	(3) Increasing output quality in manufacturing processes, techniques, machinery, and software (PRCIN3)
	(4) Determining and eliminating non-value-adding activities in delivery-related processes (PRCIN4)
	(5) Decreasing variable cost and/or increasing delivery speed in delivery-related logistics processes (PRCIN5)

TQM constructs are adopted from Zeitz, Johannesson, and Ritchie (1997), Grandzol and Gershon (1998), Samson and Terziovski (1999),
and Saraph, Benson, and Schroeder (1989)
KM constructs are adopted from Lin and Lee (2005)
Innovation constructs are adopted from: Gunday, Ulusoy, Kilic, and Alpkan (2011).