A long-term investigation on global automakers' patents and quality

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Abstract: Adopting temporal and spatial factors, this study attempts to clarify the influence of quality management and other major determinants on innovation management. Considering the patenting activities and product quality of global vehicle manufacturers, long-term analyses demonstrate that firm quality management and the performance of technological innovation are recursively correlated. Technological innovation in year i enhances quality management in year i. Then, quality management in year i enhances technological innovation in year i + 1. Additionally, regression analyses show that automakers' technological innovations are strongly influenced by geographical location, Research and Development (R&D) expenditures and quality management performance.

Keywords: quality; innovation; recursive relationship; long-term investigation.

Reference to this paper should be made as follows: Lin, L-H. (2009) 'A long-term investigation on global automakers' patents and quality', *Int. J. Automotive Technology and Management*, Vol. 9, No. 3, pp.248–259.

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1 Introduction

During the past decade, novel approaches to innovation management have become the major drivers of various industries. As product life cycles shorten and substitute product offerings expand, product innovation has become increasingly important as a means to establish sustainable competitive advantage. In manufacturing, product quality is considered fundamental to innovation and is involved in the implementation of New Product Development (NPD) and Research and Development (R&D) projects.

Consequently, the connection and relationship between quality and innovation management must be identified before product innovation can be adequately assessed for all industries.

Regarding the connection between quality management and technological innovation, the results presented in the literature seem to be controvertible in recent years (Prajogo and Sohal, 2001; Mendonça and Dias, 2007). From continuous improvement to continuous innovation, Prajogo and Sohal (2006) confirmed that Total Quality Management (TQM) is significantly and positively associated with product innovation based on an investigation of 194 Australian managers. From the perspective of administrative innovation, Lin and Lu (2005) suggested (based on a survey of the Taiwanese electronics and information industries) that implementing process management improves the success of organisational structure innovation. Meanwhile, other studies (*e.g.*, Naveh and Erez, 2004; Singh and Smith, 2004) found no significant evidence of the relationship between quality improvement and technological innovation.

Koufteros *et al*. (2002) and Damanpour and Gopalakrishnan (2001) demonstrated that product innovation is largely limited to medium-sized industries. Additionally, oligopolistic firms conduct innovation to improve product quality. However, in the marketplace, industrial firms desire to enhance their innovativeness to strengthen their competitive advantage. In industries based on strong competition, firms introduce new products to stimulate consumers' willingness-to-buy. Meanwhile, in markets characterised by monopolies, monopolisers develop their innovativeness to ensure consumer diversification. Avoiding price wars, oligopolistic firms employ innovative products to distinguish themselves and boost their market shares. This study challenges this perspective and argues that firms will not undertake innovation activities unless they produce high-quality products. Innovation is determined by product quality, not industry size. Applying game theory models, Fishman and Rob (2002) and Debey and Wu (2002) proposed that firms attempt costly and risky innovative activities to enhance product quality. Koufteros *et al.* (2002) also demonstrated that innovations positively influence product quality according to the results of a study of 244 manufacturing companies. However, innovation which involves high risks during the initial stage is not necessary as a method to enhance product quality (Damanpour, 1991; Damanpour and Gopalakrishnan, 2001; Bossink, 2002). To clarify these confusing perspectives, this investigation attempts to apply long-term empirical analyses to verify how product quality and product innovation in the automotive industry are related.

To clarify the connection and relationship between quality and innovation management, this study attempts the following:

- clarify the nature of the relationship between product quality and product innovation by using long-term data on the global automotive industry
- test other major effects on other factors.

By adopting temporal and spatial factors, this work contributes to quality management by empirically analysing how some automakers achieve higher levels of innovation than others in the global automobile industry.

2 An explorative investigation on the nature of quality and innovation

2.1 Does quality improve innovation or does innovation improve quality?

Although the pertinent literature provides extensive evidence, the debate continues regarding the causal relationship between quality and innovation since most previous studies were based on cross-section approaches. From a long-term and macro perspective, most organisational phenomena are clearly affected or shaped by time, although time is rarely a consideration in organisational models (House *et al.*, 1995). The distinction between the two viewpoints discussed above is not related to which perspective is most accurate, since both perspectives contain value. Different factors, processes and perspectives may have different effects. Thus, a need remains for scholars of both quality and innovation management to carefully specify the time factor in their research models. Numerous organisational phenomena are unidirectional in terms of the uni-level or cross-sectional analyses, but long-term relationships are more complicated. Viewing time as a boundary condition or moderator, Kozlowski and Klein (2000) believed that "over time the relationship between phenomena at different levels may prove bi-directional or reciprocal".

Besides, the differences in time scales influence the nature of relationships among levels (Simon, 1973). For example, efforts to increase organisational performance via TQM training have focused on the transfer of training to the performance setting. The transfer climate (high level) improves transfer in such a manner that TQM training immediately affects performance (Rouiller and Goldstein, 1993; Prabhushankar *et al.*, 2008). However, manufacturing worker (low level, or individual level) TQM training affects organisational performance relatively slowly (Kozlowski and Salas, 1997; Maniak and Midler, 2008). Thus, top-down linkages should be revealed within a shorter time frame, whereas bottom-up linkages should require a longer time frame before they become apparent (Kozlowski and Klein, 2000).

On the one hand, quality and innovation affect each other over the long-term when time is seen as a boundary condition. Restated, quality may influence firm innovation activities during the first stage and the innovation results, particularly in the dimension of process innovation, may enhance product quality performance in the next stage. On the other hand, the speed of effects on quality management and organisational innovation may differ when quality management and organisational innovation are considered different analysis levels. The success of innovation requires the efforts of all organisation members, including the compilation of engineer creativity, support of different departments and encouragement from top managers. Thus, innovation can be considered an organisational phenomenon. Moreover, concerning quality management, production worker training and manufacturing department performance are relatively important. Thus, quality management can be seen at the level of the group or department. Based on this assumption, the remainder of this section tests whether quality management and organisation innovation in global automotive companies are recursively influenced in different time frames.

2.2 *An investigation to clarify the direction of the relationship between quality and innovation*

To verify the preliminary assumptions concerning quality management and organisational innovation, this study introduces an investigation by analysing the long-term data of global automotive companies. This empirical analysis requires the measurement of the innovativeness and quality activities of automobile industry firms. Product quality is generally considered the ability of a firm to provide products that satisfy the customer and the market and is often separated into eight dimensions, including performance, features, reliability, conformance, durability, serviceability, aesthetics and perceived quality (Garvin, 1987). For simplicity and objectivity, this investigation introduces the general error (problems) in products sold and used by customers (Cole, 2002). Information on the automobile quality of each company was sourced from the 2000 to 2006 Initial Quality Studies (IQS) of JD Power and Associates. According to the IQS reports by JD Power and Associates, 26 major global vehicle makers were examined to determine the quality of the products they produced.

Large numbers of patents indicate a highly innovative company and vice versa. The patents data used in this study were collected from 1999 to 2006. The situations of companies' quality and patent performance are presented in Figures 1 and 2.

Figure 1 The patents issued by auto firms in different countries from 1999 to 2006 (see online version for colours)

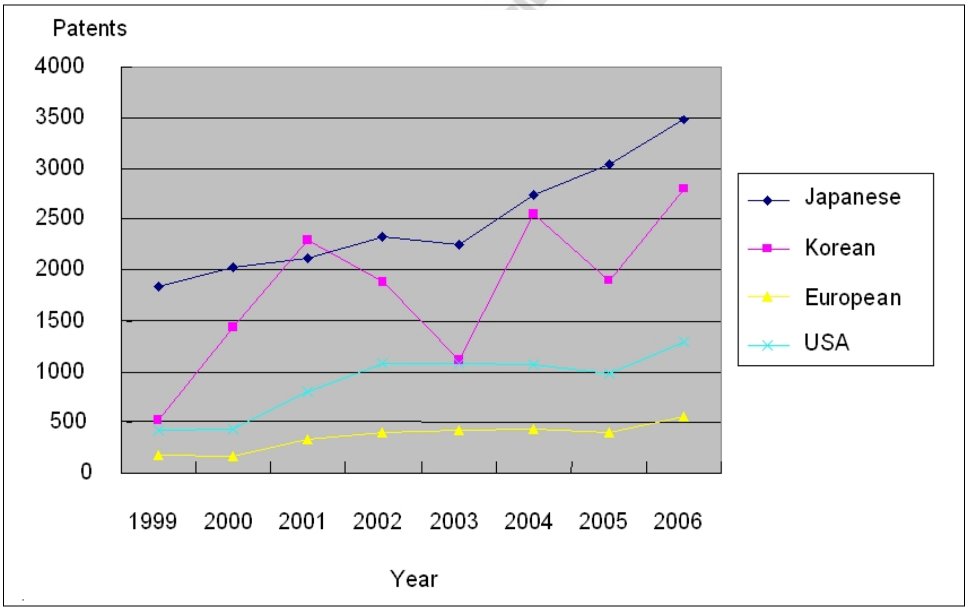
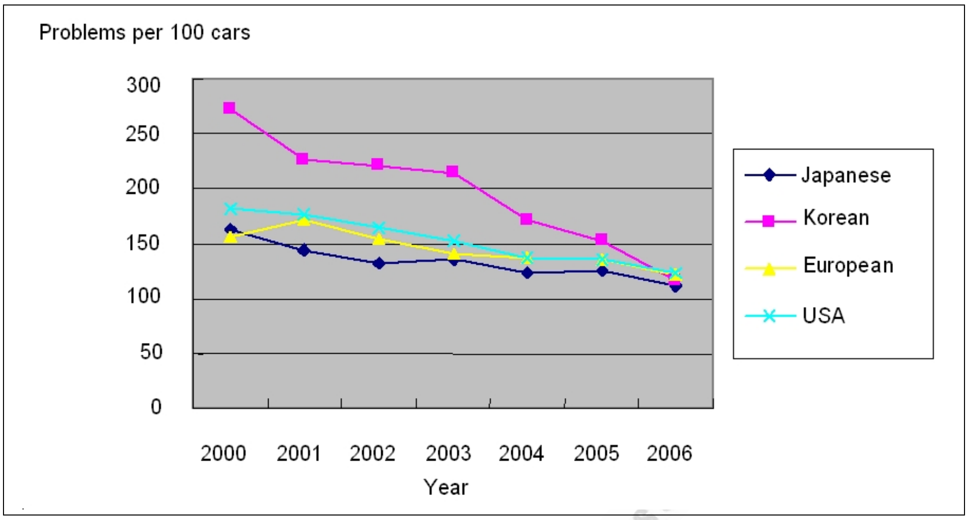


Figure 2 Problems per 100 cars caused by auto firms in different countries from 2000 to 2006 (see online version for colours)



From Figures 1 and 2, it is clear that the long-term trend of issued patents increased from 1999 to 2006, whereas the long-term trend of product problems decreased from 2000 to 2006. These imply that quality and innovation performance are positively related. To discuss the assumptions further, four possible models were suggested to test the fitness of the relationship direction and time frame between quality and patent activities. But note that at most, two possible models are reasonable in this study.

Model 1 Technological innovation in year i will enhance quality management in year i.

Model 2 Technological innovation in year i will enhance quality management in year $i + 1$.

Model 3 Quality management in year i will enhance technological innovation in year i.

Model 4 Quality management in year i will enhance technological innovation in year $i + 1$.

To test these candidate models, simple linear regressions and correlation analyses were employed in Table 1. Evidence reveals that the possible models are Models 1 (comparing Models 1 and 2) and 4 (comparing Models 3 and 4); that is, the influence of innovation on quality is immediate, whereas the influence of quality on innovation is much slower. Put in another way, the influence of innovation on quality is more direct than the influence of quality on innovation. This also implies that a recursive relationship occurs in this industry. Technological innovation in year i will enhance quality management in year i. Then, quality management in year i will enhance technological innovation in year $i + 1$. Thus, quality and innovation management form a recursive loop which indicates that both quality and innovation management must be paid attention to simultaneously.

Table 1 The regression results of Models 1–4

	Problems		*Patents*	
Variable	*Model 1*	*Model 2*	*Model 3*	*Model 4*
Constant	160.17(36.33)**	158.50(34.09)**	4596.44(8.25)**	5053.27(7.96)**
Problems			–20.98(–5.62)**	–22.68(–5.55)**
Patents	–0.011(–5.62)**	–0.009(–4.67)**		
R	–0.48**	–0.38**	–0.44**	–0.53**
R^2	0.24**	0.14**	0.20**	0.28**
F	32.62	36.95	31.62	30.75

Notes: () indicates t-value. * $p < 0.01$, ** $p < 0.001$.

3 An exploration of the determinants of technological innovation

3.1 Methods and sample

The sample was drawn from the 1999 to 2006 IQS reports of JD Power and Associates, the authoritative quality survey for the automotive industry. According to these IQS reports, 26 major global vehicle makers were examined to determine the quality of the products they produced. The IQS reports were based on the responses from over 52 000 purchasers and lessees of new cars and trucks, surveyed after 90 days of ownership. This study employed the background information and data from the IQS reports, which contained 26 automakers: 10 firms from Japan, 3 from the USA, 10 from Europe and 3 from Korea. The long-term sample consists of 120 sample points. Other information was obtained from the annual reports for separate automakers and the *Wall Street Journal Index*.

3.2 Measures

3.2.1 Primary variables

Technological innovation

Regarding firm-generated technological innovations, this investigation obtained data on worldwide automotive invention patents, including data from the USPTO, the EPO and the WIPO. Firms in the automobile industry actively patent, particularly given the increasing global strength of intellectual property protection. Patents are considered an objective measurement of product innovation (Sørensen and Stuard, 2000; Benner and Tushman, 2002; 2003). The numbers of patents issued in 2006 was the dependent variable introduced in this section.

Product quality

The firms' quality performance was introduced as the result of firms' quality management. To test *H1*, quality performance in 2005 should be selected here to serve as the main independent variable. The 2005 IQS of JD Power and Associates provided in-depth diagnostic information on the quality of new vehicles. The measurement results of IQS were presented using a problems-per-100 vehicles (PP100) metric, often referred to as 'things gone wrong'. The IQS report included company data for companies from the USA, Europe, Japan and Korea. This study measured product quality in terms of the problems per new car discovered by the consumers. Overall, the sampled automobile companies generated an average of 1.33 problems per new car in 2005. Large numbers of problems indicate a low quality manufacturing company and vice versa.

Organisational factors

The age and size of a firm were the control variables considered herein. Firm age was measured as the number of years a firm had existed and firm size was measured as the total number of full-time employees in the firm. Both variables are widely used measures of age and size. The tenure factor reveals the years of professional tenure for the firms' CEOs. The R&D factor indicates the expenditure for each firm on R&D projects.

Environment factors

It is reasonable to introduce region as a control variable in this study. For this qualitative predictor variable, '0' represents the automobile brands from Asian countries, including Japan and Korea, while '1' represents the brands from Western countries, including the USA and Europe. Profit performance accounts the Return on Assets (ROA) index. Finally, the environmental variables included the number of major global competitors (Kimberly and Evanisko, 1981).

4 Results

This study applied hierarchical regression analyses to test the contingency hypothesis. Before interactions were introduced, all dependent, independent and control variables were standardised to avert roundoff errors in normal calculations and admit comparisons among the coefficients estimated in different units. Prior to the discussion on correlation and regression analyses, refined diagnostics were applied to verify the adequacy of the regression models. Normal probability plots were checked to confirm the normality of the regression error terms, the scatter plots of all variables verified the nonmulticollinearity of independent and control variables and residual plots confirmed the constancy and independence of errors. The resulting average Variance Inflation Factor (VIF) associated with each coefficient of Regression Models 1, 2 and 3, introduced in Table 2, were 1.125, 1.230 and 1.230, respectively. All of the VIFs of the control variables, independent variables and interactions ranged from 1.09 to 1.38, suggesting the unimportance of multicollinearity. Moreover, the Dubin-Watson test statistics for Regression Models 1, 2 and 3 were 2.24, 2.19 and 1.96, respectively, which also supports the assumption of random error terms. Three sample data were moderately outlying with respect to their dependent or independent values and were removed according to the methods of DFFITS (Difference between the fitted valve and the predicted value), DFBETAS (Difference between the fitted valve and the beta value) and Cook's distance values.

Table 2 Results of the regression analysis

	Model 5		*Model 6*		*Model 7*	
Variables	*b*	*t*	*b*	*t*	*b*	*t*
Age	.11	.57	.04	.23	–.08	.56
Size	.05	.25	.14	.74	.18	1.08
Tenure	–.08	–.43	–.09	–.58	–.07	–.53
R&D	.58	3.18**	.45	2.55*	.31	2.01*
Region	–.50	–3.12**	–.41	–2.77**	–2.16	–2.83**
Competitor	–.08	–.51	–.10	–.74	–.09	–.73
Profit	–.06	–.40	.10	.64	.15	1.03
Quality problems			–.36	–2.28*	–.67	–3.45**
Region × Quality problems					1.79	2.32*
R^2 *(adjusted)*	.56		.65		.72	
ΔR^2			.09**		.07**	
F	5.59**		6.69**		8.07**	

Notes: *b*-values are standardised coefficients. * $p < 0.05$, ** $p < 0.01$.

The correlation matrix in Table 3 implies that product problems (r = –0.62, $p < 0.01$) and R&D expenditure (r = 0.68, $p < 0.01$) are significantly highly correlated with technological innovation. Region is moderately correlated with technological innovation (r = 0.46, $p < 0.05$). As for quality management, R&D expenditure (r = –0.46, $p < 0.05$) and profit (r = 0.53, $p < 0.01$) are moderately correlated with the firm's technological innovation. The lack of significant linear relationships among the other variables also supports the independence of associated variables.

Table 3 The correlation matrix

	1	*2*	*3*	*4*	*5*	*6*	*7*	*8*
1. Patents								
2. Quality problems	–.62**							
3. Age	.08	–.26						
4. Size	.38	–.20	.26					
5. Tenure	–.07	.06	.10	.48*				
6. R&D	.68**	–.46*	.31	.62**	.13			
7. Region	–.46*	.13	.52**	.05	.12	–.05		
8. Competitor	–.06	.05	–.31	.16	.38	.01	–.15	
9. Profit	.29	–.53**	.38	.31	.11	.37	.13	–.17

Notes: * $p < 0.05$, ** $p < 0.01$.

Table 2 presents a series of regression models associated with a firm's technological innovation. Please note that 'b' indicates the standardised coefficient of an independent variable in the regression model and 't' reveals the *t*-value of a statistical test. In Model 6, the quality problem is negatively related to technological innovation (b = –0.36, $p < 0.05$). Adding this independent variable can increase the adjusted multiple squared correlation coefficient R^2 (adjusted) by 9% over that in Model 1 ($\Delta R^2 = 0.09$, $p < 0.01$). This fact implies the direct effect of quality. In fact, the control variables of age, size, tenure, strategy and competitor do not seem to affect the firm's innovation activities. Furthermore, introducing the interaction terms to Model 7 increased the multiple squared correlation coefficient by 7% ($\Delta R^2 = 0.07$, $p < 0.05$) from that for Model 2, supporting the existence of a moderating effect. Checking the coefficients of the interaction terms reveals that region positively moderates the relationship between product quality and technological innovation (b = 1.79, $p < 0.05$). These results all support the main hypothesis.

5 Conclusions

As shown in Figure 2, Korean automanufacturers, primarily driven by Hyundai and Kia Motors, have aggressively reduced their quality problems by a startling 55% during the last seven years. This dramatic performance represents a stark contrast to automakers of other nationalities. In terms of problems per hundred cars, Korean firms now lead European firms by five problems per 100 cars, the US firms by six problems and trail Japanese firms by only six problems.

This study also demonstrated how automobile makers and geographic region affect innovation performance. Asian (Japan and South Korea) automakers have recently generated more patents and reported fewer quality problems than their Western competitors. There seems to be a general consensus that automakers should locate their R&D and production centres in Asia. One of the main reasons for this is the plentiful supply of highly educated employees in this region, in addition to the advanced process management practices in Asian countries such as Japan, Korea and Taiwan. Additionally, Asian automobile brands frequently maintain four-year product life cycles, which are about two years shorter than those of the Western automakers. The shorter NPD should translate to earlier market entry, creating significant advantages over later entrants. Product innovation speed has become a core competence in the global automobile industry. Both the direct and moderating effects of the region factor demonstrate the differences between Asian and Western automakers. Furthermore, long-term analyses of the patenting and product quality of global vehicle manufacturers reveal a recursive correlation between firm quality management and the performance of technological innovation. Regression analyses demonstrate that automakers' technological innovation is strongly influenced by geographical location, R&D expenditure during the same year and quality management performance during the previous year.

Adopting a long-term perspective, this study suggested that a recursive relationship exists between product quality and product innovation and the influence of innovation on quality is immediate, whereas that of quality on innovation is relatively slow. This finding might provide some clues regarding how to eliminate the confusing results from past studies. For example, the efforts to increase organisational innovation via TQM training focus on the transfer of training to the performance setting. The transfer climate (high level) enhances transfer such that the effects of TQM training on innovation are immediate (Rouiller and Goldstein, 1993). However, the effects of the TQM training of manufacturing workers (low level) on organisational innovation are slower (Kozlowski and Salas, 1997). Thus, top-down linkages should be revealed within a shorter time frame, whereas bottom-up linkages should need longer time frames (Kozlowski and Klein, 2000). Viewing time as a boundary condition or moderator, Kozlowski and Klein (2000) considered that "over time the relationship between phenomena at different levels may prove bi-directional or reciprocal". On the one hand, quality and innovation affect each other in the long-term owing to time being a boundary condition. Restated, quality might affect firm innovation activities during the first stage and innovation results, particularly in the dimension of process innovation, can enhance product quality performance during the next stage. On the other hand, the difference in the speed of effects on quality management and organisational innovation may be significant when quality management and organisational innovation are regarded as different levels of analyses.

Finally, this study identified the possible directions for future research. First, research on organisational innovation has suggested that as firms' manufacturing or service processes become more repeated and controlled, these firms tend to conduct exploitative innovation (March, 1991; Benner and Tushman, 2002). From the organisational innovation perspective, the main source of product innovations is the external environment and, thus, customer satisfaction is expected to increase the professionalism of process managers and increase their innovativeness (Sørensen and Stuard, 2000; Chang, 2003). Thus, the investigation of process management and product innovation is a worthy direction for future studies. Second, the increasingly important role of the service industry has increased the importance of service innovation (Aa and Elfring, 2002). Previous studies have examined product innovation characteristics. However, knowledge of service innovations is scarce. Service innovation is difficult to understand based on traditional theories and typologies. There is still a lack of generalised mathematical methods for evaluating all innovative services. Consequently, more generalised explorations based on model building or cross-industry surveys are extremely important for future research. The third focus of future research will be on the role of Information Technology (IT) in achieving service and product innovations. Radical product innovation undoubtedly is highly risky and innovation should be considered from both the technological and business perspectives. Business and corporate strategy-related studies have demonstrated that companies must transact with the environment to survive and grow (Kraut *et al*., 1999; Garcia and Calantone, 2002). Companies must make strategic choices before introducing new products or services. As a key source of environmental and technological change, IT is not merely an environmental phenomenon, but also an important competence for any company when discussing innovation strategies.

Acknowledgement

The author would like to thank the National Science Council in Taiwan, Republic of China, for financially supporting this research under Contract No. NSC 95-2221-E-151-001.

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LIN, Liang-Hung. A long-term investigation on global automakers' patents and quality. **International Journal of Automotive Technology and Management**, v. 9, n. 3 p. 248 - 259 , 2009. Disponível em: www.inderscience.metapress.com. Acesso em: 9 nov. 2009.