Studies on quality canyon phenomenon in macro-quality improvement

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Abstract: The quality canyon phenomenon in enterprises discovers the complex relationships between quality level (QL) and return on quality investment (QROI) in quality improvement. However, the phenomenon has been few examined quantitatively. In addition, whether the phenomenon may exist in the macro-level quality improvement, such as national quality, is not clear. These questions are critical for the enterprises and countries, whose strategies are transferring from high speed to high quality. Referring to the Kano model, a quantitative model is built on the relationships between QL and QROI. To test the model in national quality improvement, 16 quality indicators are identified for the measurement scales of macro-quality based on the Global Competitiveness Report. Return on macro-quality is measured with the unit GDP per capita. A 'U-shaped' curve relationship is found between macro QL and macro QROI. Some suggestions are proposed for the countries on how to improve their competitiveness through quality improvement.

Keywords: quality economics; canyon phenomenon; macro-quality.

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1   Introduction

The quality canyon phenomenon was found in the product quality improving process in enterprises. It discovers a complex relationship between the return on quality investment (QROI) and the quality level (QL) (Park et al., 2007). The relationships show a high QROI in the low and high QL, but a low QROI in the middle QL. Studies on the quality canyon can help formulate quality improving plans and give suggestions on how to cross the bottom of the canyon. Referring to the studies on quality canyon in enterprises, whether the quality canyon phenomenon exists in countries was examined in this study. This study defined the product, service, and project quality in enterprises as micro-quality; and the product, service, and project quality in countries as macro-quality (Cubo et al., 2021). There is close relationship between these two types of quality. For example, the high-level macro quality in one country requires the high-level micro quality in most enterprises of the country. To improve macro-quality, there are some requirements on national quality infrastructure, national quality culture, etc., which may be satisfied by countries, but not by enterprises. High quality development approach is an important approach for macro quality improvement. Different from the high-speed development strategy with focus on economic scales, the high-quality development strategy emphasises improving the economic vitality, national creativeness, and competitiveness (Berger, 2011; Jin, 2018).

The question targeted in this study is important for the countries who are implementing high quality development strategy. For example, China's '14th Five-Year Plan' puts forward a high-quality development strategy to promote the transformation and upgrading of China's manufacturing industry from a 'world factory' to a 'manufacturing power'. One important background of this transformation is that China's GDP has maintained rapid growth for many years and made a huge investment in quality improvement, but the national competitiveness has been stagnant for several years. The phenomenon that high investment does not bring high returns is similar to the quality canyon phenomenon. The question targeted in this study may provide a reference on how to face the challenges in China. Besides China, some other countries are also transforming their development strategy. For example, 'Made in India' aims to spur innovation in the manufacturing sector within India and make India the manufacturing hub in the world (Goswami and Daultani, 2021). Thailand was suggested to acquire and develop technological capabilities to stimulate the industry's transformation from low-to-high value-added activities (Intarakumnerd et al., 2016). On the other hand, some countries prosper in the competitiveness improvement, such as Korea (Fagerberg et al., 2018). It is possible to summarise their experiments on how to cross the bottom of quality canyon.

On the research methods, much qualitative research and some case studies can be found on quality canyon, but lacking quantitative models makes these studies on the quality canyon phenomenon troublesome. As a traditional method of quality management, the Kano model has been examined qualitatively and quantitatively. It examines the nonlinear relationship between the functional quality level and the contributions to the customer satisfaction (Kano et al., 1984). From the perspective of investors, customer satisfaction makes the enterprise's prospects brighter and attracts more capital investment (Grigoroudis et al., 2008). From the perspective of customers, increased customer satisfaction enhances price tolerance (Anderson, 1996), leading to higher unit value of the product or service. Additionally, customer satisfaction enhances

customer loyalty, leading to customers buying more products or services (Eklof et al., 2020). These two enhancements together lead to better economic performance for the enterprise. This study proposes to build the quantitative model on quality canyon referring to the Kano model based on the close relationship between economic performance and customer satisfaction in both individual customer level (Yu, 2007) and national level (Grigoroudis et al., 2008).

This reminder of the paper is organised as follows. Section 2 reviews the literature on the quality canyon phenomenon at the micro and macro levels. Section 3 established a quantitative model on the quality canyon, and an evaluation system on the macro-quality level and macro-quality ROI. Section 4 analyses the data and finds that the canyon phenomenon does exist in the process of macro-quality improvement. Section 5 discusses the generation reasons for the macro-quality canyon phenomenon. The conclusion is given in the final section.

2 Literature review

In this section, the thorough theoretical background on quality canyon between QL and QROI at the micro-level is firstly given. The second part introduces the concept of macro-quality.

2.1 Quality canyon phenomenon

The quality canyon phenomenon was first put forward as a concept to describe the difficulties encountered by Samsung during improving the product quality (Zhou, 2020). The quality canyon phenomenon meant that an enterprise could get 15% QROI from selling low-quality and low-cost products and 35% to 38% from selling high-quality products; however, between low-quality and high-quality, enterprises would only achieve the QROI of only 2% (Sun, 2018), as Figure 1 shows. This phenomenon can explain that although the product quality level of an enterprise is improved significantly, the market and customers' impression of low-cost and low-quality products in the past are difficult to be changed simultaneously. This is also the key reason for many enterprises gave up quality improvements when experiencing the challenge of low QROI at the bottom of the canyon. If they cannot cross quality canyon, they have to stay with the production paradigm of low-quality and low profit and have no chance to enjoy the benefits of brand reshaping brought by quality improvement. The phenomenon on quality canyon can be explained from a different view, i.e., quality economics view, TQM view, quality management maturity grid view, etc.

2.1.1 Quality canyon in quality economics view

To calculate QROI, it is necessary to calculate the quality cost, which is the sum of non-conformance and conformance costs (Schiffauerova and Thomson, 2006). There are several methods to evaluate the quality cost, such as prevention-appraisal-failure (PAF) model, Crosby's model, opportunity or intangible cost models, process cost models and activity-based cost (ABC) model, etc. (Cooper and Kaplan, 1988; Vaxevanidis et al., 2009). In the PAF model, the prevention and appraisal cost increases with the increasing quality level, while failure costs decrease with the increasing quality level. When

combining prevention, appraisal, and failure cost, the total cost is not monotonically decreasing or increasing, which means the relations between quality level and the quality cost are not monotonous. When calculating QROI, the quality cost is the denominator, and the enterprise net income generates from quality investment is the numerator. Some studies show that the enterprise net income or profit is high when the quality level is very small or big (Bagwell and Riordan, 1991; Gill, 2009; Kinser, 2015). With the nonlinear changing of numerator and denominator, the quality canyon phenomenon needs to be further quantitatively examined.

Figure 1   The quality canyon phenomenon
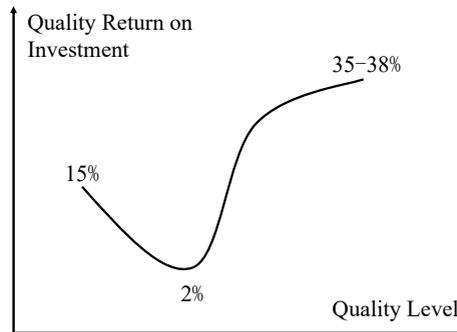
2.1.2 Quality canyon in TQM implementation

quality canyon is often found during implementing total quality management (TQM). For example, Hendricks and Singhal (2000) select stock returns, operating income, sales, and costs to measure an enterprise's financial performance, and examines the relationships between TQM implementation and QROI. It is found that enterprises that effectively implement TQM will have a significant increase in wealth compared with those that do not adopt quality management. In addition, the small enterprises are more effective than the large ones in achieving the expected ROI in the quality improvement (Hendricks and Singhal, 2001). Hansson and Eriksson (2002) add total assets and employees' numbers as extra-financial performance indicators, in the case of Swedish quality award-winning enterprises, and finds out that TQM has an implementation period, after which, enterprises will perform better than their competitors. This result implies that in the implementation of TQM, the enterprises will go through quality canyon, a period of seemingly unrewarded. Insisting on quality improvement is important for enterprises that are not positively affected by quality management.

2.1.3 Quality canyon in quality management maturity grid

As a supplement theory of the quality canyon phenomenon, the hypothesis of upward 'U-shaped' trend between financial performance and quality management activities (Roca-Puig and Escrig-Tena, 2017) is supported by several scholars. Crosby puts forward a five-stage 'quality management maturity grid' and increasing degrees of transition requirements (Maier et al., 2006). The greatest QROI will be achieved at the most mature stage of quality certainty, which means numerous investments. However, Thomas recommends enterprises to have a more equilibrium scale of investment on quality in that

the net present value of the latest investment will decrease to zero point during the expansion of the investment scale (Chemmanur et al., 2009). Unlike simply establishing a positive coefficient of structural equation modelling between quality and finance (Sila, 2018), Chemmanur et al. suggest that quality investment may have a negative impact in different stages of enterprise development. Shahin (2011) also emphasises the stages of quality activities are limitations of the existing research fields. When the enterprise is in financial distress, its willingness to invest in quality is weakened, resulting in a lower product pricing (Phillips and Sertsios, 2013). Therefore, it is necessary to study the different stages of the enterprise's QL and the impact of adherence to quality management on financial performance, especially in developing countries or emerging economies (Chaudary et al., 2015).

2.2 National macro-quality conception

Macro-quality is a summary of the overall quality phenomenon of a country or region (Wiig et al., 2014). Macro-quality can provide the environment that promotes the favourable development of micro-quality. On the other hand, micro-quality can also constitute a macro-quality (Song et al., 2018). Macro-quality has three main characteristics as follows:

1   to measure macro-quality, it is usual to use macro-level variables making macro-observations (Wagner, 2012)

2   to build macro-quality index model, many scholars retain the structure of measuring enterprise quality management at the micro level (Li et al., 2016)

3   when considering the allocation and improvement of resources in the future, macro-quality can be used as an effective reference (Hsiao and Hsiao, 2021).

Countries or economies are always the strong promoters and beneficiaries other macro-quality fields (Brown et al., 2014). Countries usually formulate policies to help create a macro-quality development environment. In return, national income indicators such as GDP are used to measure quality development performance. The United Nations put forward 17 sustainable development goals (SDGs) for 2030, which gives priority to quality education and consciousness (Friedman et al., 2020). To achieve these goals, there are two stages:

1   small to bigger: increase scale through expansion

2   bigger to better: improve quality systematically (Yoshikawa et al., 2018).

This is also the path for the Four Asian Tigers (South Korea, Taiwan, Singapore, and Hong Kong) to become emerging high-income economies at the beginning of the 21st century. In 2020, challenged by the VID-19 pandemic, Singapore still benefits from its high-quality public services and held low fatalities in the world (Woo, 2020). China, as an emerging economy, is now in the transition period of two stages. Since 2016, China attached more importance to carrying out the revolution on macro-quality, which indeed validated the economic growth (Wang and Mao, 2020). China's GDP per capita rose from $5, 618 in 2012 to $10, 262 in 2019. However, at the same time, China's global competitiveness ranking was not as successful as the economy, hovering in 28th place in the world according to GCR. Judging from the QROI of developed economies, it can be

inferred that macro-quality improvement may not always be smooth. Moreover, only when the macro-quality level reaches a certain stage, these investments will bring considerable returns, leading to quality canyon in the macro field.

In the micro field, quality canyon brings inevitable challenges to enterprises, however, there is still lacking measurement from quantitative models. In the macro field, emerging economies, such as China, are experiencing the dilemma that quality investment cannot get the corresponding return. In other words, there are low QROI and stagnant QL. In the end, enterprises are labelled as 'low-quality' and gradually lose their competitiveness, so as do the macro economies. Therefore, it is necessary to study the quality canyon phenomenon in the macro field and provide experience for specific countries.

3   Research methods

In this section, a quantitative model is established on quality canyon firstly. Next, the indicators are selected to measure the macro-quality level and the data sources used to test the model are introduced. Finally, the analysis methods on the model are introduced.

3.1   The quantitative model on quality canyon

To build the quantitative model on quality canyon, the quantitative Kano model is referred to measure the quality level and return on quality investment. The variables used in this section are described in Table 1.

Table 1   Variable description

Model	Variable symbol	Description
Quantitative Kano model (Wang and Ji, 2010)	O	One-dimensional product function
	A	Attractive product function
	M	Must-be product function
	j	The jth product function, positive integer
	CS_j	Customer satisfaction coefficient of the jth product function
	DS_j	Customer dissatisfaction coefficient of the jth product function
	$CRFV$	Customer requirement fulfilment value of product function
	$S_jT\ (T = O, A, M)$	Customer satisfaction degree of product function
Quantitative model on quality canyon	QL	Quality level
	$d(CRFV)$	Derivative of customer requirement fulfilment value
	k_1	Coefficient of $d(CRFV)$, positive value
	QI	Quality investment
	$n1, n2, n3$	The enterprise develops $n1$ kind of one-dimensional quality (O), $n2$ kind of attractive quality (A), and $n3$ kind of must-be quality (M)
	dS_jT	Derivative of customer satisfaction degree

Table 1 Variable description (continued)

Model	Variable symbol	Description
Quantitative model on quality canyon	k_2	Coefficient of dS_jT, positive value
	$\sum_{j}^{n1+n2+n3} S_j T$	Customer satisfaction degree of O, A, M quality investment
	ER	Enterprise revenue
	$QROI_jT\ (T = O, A, M)$	Return on O, A, M quality investment
	a	Coefficient of $QROIO$, positive value
	b	Coefficient of $QROIA$, positive value
	c	Coefficient of $QROIM$, positive value
	d	Return on indifferent (I) and reverse (R) quality investment
	$QROI$	Return on quality investment

3.1.1 The quantitative Kano model

Since the qualitative Kano's model was proposed, it has been widely accepted in academy and industry Fields (Chen and Chuang, 2008; Xu et al., 2009). The Kano model considers five types of product function, i.e., one-dimensional (O), attractive (A), must-be (M), indifferent (I), and reverse (R) function (Kano et al., 1984). Since indifferent (I) and reverse (R) function do not have a huge impact on improving customer satisfaction, they are ignored in the measurement of customer satisfaction (Lin et al., 2010). Thus, for the jth product function, the difference among one-dimensional (O), attractive (A), and must-be (M) product functions are their contribution to customer satisfaction coefficient (CS_j) and customer dissatisfaction coefficient (DS_j). In this section, we will use the following example, where portability is the fifth product function of ballpoint pens. Portability is the must-be (M) product function, the S_5 is 0.5 ad the DS_5 is –0.7 according to the customer survey.

Recent studies try to transform the qualitative finding of Kano's model and to gain an in-depth understanding of the relationship between product functions, customer requirements, and customer satisfaction, Wang and Ji (2010) claim that an enterprise's understanding of each product function corresponds to a customer requirement fulfilment value ($CRFV$). The $CRFV$ equals 1 if a certain product function exists and fully meets customer expectations. The $CRFV$ equals 0 if the product function exists but does not meet any customer expectations at all. In other words, adding this product function is ineffective in improving customer satisfaction. Thus, each $CRFV$ corresponds to a customer satisfaction degree (S). For example, S_jO stands for the customer satisfaction degree achieved by fulfilling jth one-dimensional customer requirements. Then, Wang and Ji (2010) puts forward the quantitative expression of exponential function between $CRFV$ and S_jO, S_jA, S_jM, as equations (1) to (3) show. The Kano quantitative model, shown in Figure 2, bridges the gap between quality levels and customer satisfaction, and even corporate revenue.

$$S_jO = (CS_j - DS_j) * CRFV * DS_j \tag{1}$$

$$S_j A = (CS_j - DS_j) * e^{CRFV}/(e-1) - (CS_j - e * D_j)/(e-1) \qquad (2)$$

$$S_j M = -e * (CS_i - DS_j) * e^{-CRFV}/(e-1) + (e * CS_j - DS_j)/(e-1) \qquad (3)$$

As mentioned at the beginning of this section, portability is a must-be (M) product function, whose CS_5 is 0.5 and DS_5 is –0.7. According to equation (3), if the CRFV is 0.5, S_5M equals 0.0470, which means portability contributes negligibly to customer satisfaction degree (S) when the ballpoint pen manufacturer fulfils 50% of customer requirement for portability. If the CRFV is 0.8, then S_5M equals 0.3454, which means portability plays a positive role in customer satisfaction degree (S) when the manufacturer fulfils 80% of customer requirements for portability.

Figure 2   The quantitative Kano model (see online version for colours)
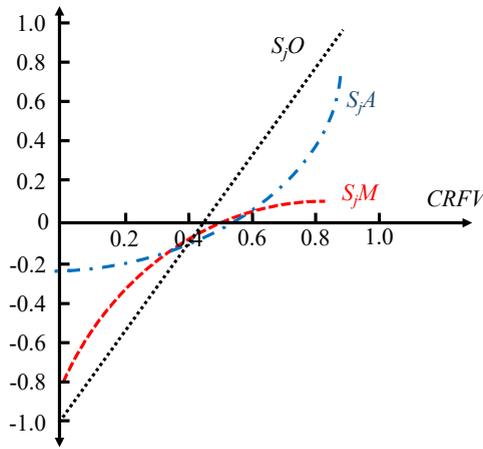
Source: Wang and Ji (2010)

3.1.2 Quality level in quality canyon

The independent variable considered by the quality canyon is the quality level of the products produced by enterprises. If a product or service can be circulated in the market, it means that it meets the lowest standard and is accepted by customers. Therefore, this study does not discuss products with unacceptable quality levels. The process of striving for a higher quality level for an enterprise is the process of better fulfilling customers' requirements, exceeding their expectations, and improving the customer satisfaction (Lai et al., 2012). Since the CRFV in the quantitative Kano model helps enterprises to evaluate the contribution of different product functions to customer satisfaction and even corporate revenue quantitatively, the quantitative model on quality canyon takes customer requirement fulfilment value (CRFV) as an independent variable, which is quality level (QL) (Wang and Ji, 2010).

3.1.3 Return on quality investment in quality canyon

The dependent variable considered by the quality canyon is the return on quality investment (QROI) performed by enterprises. QROI means the ratio of an enterprise

revenue (*ER*) to the quality investment (*QI*). Customers qualitatively describe their requirements, and enterprises transform them into quantifiable levels of *CRFV*. For example, in customer-driven product engineering, enterprises develop detailed quality improvement plans in accordance with *CRFV*. Each unit of quality improvement will undoubtedly result in an increase in quality investment, or quality investment. Therefore, this study assumes that there is a positive correlation (Yadav and Goel, 2008) between *QI* and increment customer requirement fulfilment value (*d(CRFV)*) with coefficient k_1, as shown in equation (4), where $k_1 > 0$.

$$QI = k_1 * d(CRFV) \tag{4}$$

By developing the jth one-dimensional product functions (*O*), the enterprise linearly improves customer satisfaction (*S$_j$O*). By developing j^{th} attractive product functions (*A*), the enterprise exponentially improves customer satisfaction (*S$_j$A*). By developing j^{th} must-be product functions (*M*), the enterprise logarithmically improves customer satisfaction (*S$_j$M*). Thereby customer acceptance of product prices increases (Anderson, 1996; Huber et al., 2001). Additionally, customer loyalty increases, which brings more sales volume (Eklof et al., 2020). Thus, with the improvement of customer satisfaction, enterprises can obtain more revenues from selling their high-quality products to improve product quality again. This virtuous cycle model increases enterprise revenue eventually (Xie et al., 2017). Therefore, this study assumes that there is a positive correlation between enterprise revenue (*ER*) and increment customer satisfaction (*dS$_j$T*) brought by each unit of functional improvement with coefficient k_2, as shown in equation (5), where $k_2 > 0$.

$$ER = k_2 * dS_j T \tag{5}$$

The enterprise continuously invests in the quality to strive for the products to fully meet the requirements of customers (Chaudha et al., 2011), so that the customer satisfaction is the highest, which is $\lim\limits_{CRFV \to 1} \sum_{T=O,A,M} S_j T$. Among them, every improvement in product performance, even a small one, corresponds to a cost of quality. Based on the above derivation, the return on quality investment (*QROI$_j$O*, *QROI$_j$A*, *QROI$_j$M*) is established based on the quantitative expression of exponential function between *CRFV* and *S$_j$O*, *S$_j$A*, *S$_j$M*. For equations (1) to (3), the *CRFV* is derived, as shown in equations (6) to (8). The quantitative model on quality canyon takes increment customer requirement fulfilment value (*d(CRFV)*) as the denominator in the dependent variable, which is the investment of quality (*QI*).

$$QROI_j O = \frac{k_2}{k_1} * \frac{dS_j O}{d(CRFV)} = \frac{k_2}{k_1} * \left(CS_j - DS_j \right) \tag{6}$$

$$QROI_j A = \frac{k_2}{k_1} * \frac{dS_j A}{d(CRFV)} = \frac{k_2}{k_1} * \left(CS_j - DS_j \right) * e^{CRFV} / (e-1) \tag{7}$$

$$QROI_j M = \frac{k_2}{k_1} * \frac{dS_j M}{d(CRRFV)} = \frac{k_2}{k_1} * \left(CS_j - DS_j \right) * e^{-CRFV+1} / (e-1) \tag{8}$$

As mentioned at the beginning of this section, portability is a must-be (M) product function, whose CS_5 is 0.5 and DS_5 is –0.7. According to equation (8), if the $CRFV$ is 0.5, $QROI_5M$ equals 1.1514. If the $CRFV$ is 0.8, then $QROI_5M$ equals 0.8530. This means that the manufacturer's $QROI_jM$ decreases as the $CRFV$ increases.

### 3.1.4   Quantitative expression of quality canyon

Any QL should be simultaneously composed of the five function types (O, A, M, I, R) defined in the Kano model. In the quantitative model on quality canyon, the return on investing in these five qualities is parallel and independent of each other (Witell and Löfgren, 2007). Assuming that the products or services produced by the enterprise have developed $n1$ kind of one-dimensional quality (O), $n2$ kind of attractive quality (A), and $n3$ kind of must-be quality (M), then $QROI$ is the sum of $QROIO$, $QROIA$, $QROIM$ and the constant d. d represents the return on indifferent (I) and reverse (R) quality investment. Although these two qualities have little impact on customer satisfaction (Lin et al., 2010), enterprises may also invest in them, so they are re-considered in the calculation of $QROI$. Since CS_j and DS_j are both derived from customer questionnaires and are irrelevant to quality level (QL) and return on quality investment ($QROI$). CS_j and DS_j are replaced by constants a, b and c in the expression, as shown in equation (9), where $QL \in (0, 1)$, $a, b, c > 0, d < 0$.

$$
\begin{aligned}
QROIj &= \sum_{j}^{n1+n2+n3} QROI_jT + d \\
&= \sum_{j=0}^{n1} QROI_jT + \sum_{j=n1+1}^{n2} QROI_jT + \sum_{j=n2+1}^{n3} QROI_jT + d \\
&= \frac{k_2}{k_1} * \left(\sum_{j=0}^{n1}(CS_j - DS_j) + \sum_{j=n1+1}^{n2}(CS_j - DS_j) * e^{QL}/(e-1) \right. \\
&\quad \left. + \sum_{j=n2+1}^{n3}(CS_j - DS_j) * e^{-QL+1}/(e-1) \right) + d \\
&= QROIO + QROIA + QROIM + d \\
&= a + b * e^{QL}/(e-1) + c * e^{-QL+1}/(e-1) + d
\end{aligned}
\tag{9}
$$

When the enterprise develops all three qualities with the same weight regardless of the QL stages, and if the constant d is not considered, the three $QROIT$ curves and $QROI$ curve are obtained in Figure 3. If the constant d is considered, the $QROI$ curve will be shifted down by d units and the shape will remain the same. $QROIO$ is marked by dot line, $QROIA$ is marked by dot-dash line, $QROIM$ is marked by dash line. The $QROI$ is calculated and marked by the solid line, which represents the quality canyon phenomenon, showing an inverted parabolic trend.

Figure 3 The established quantitative model on quality canyon (see online version for colours)
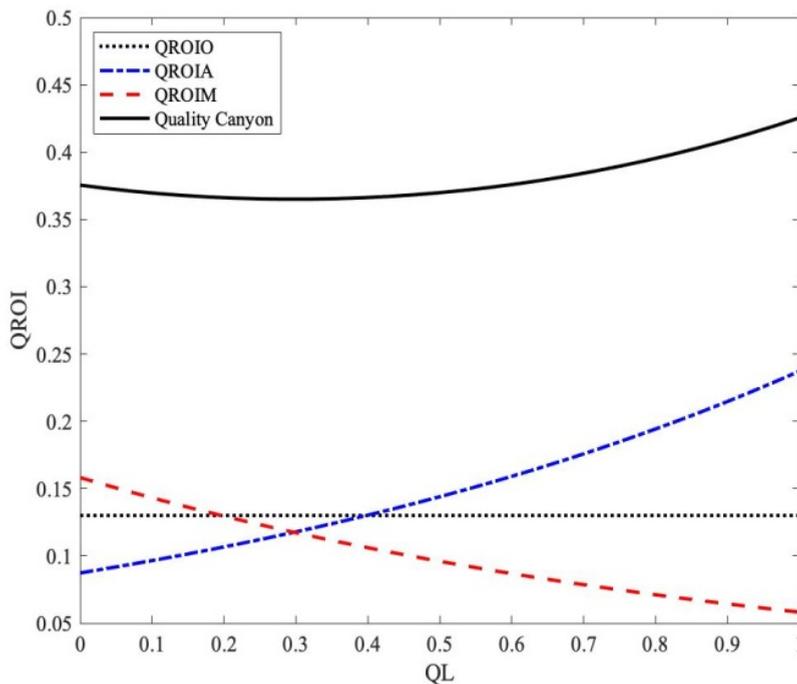
3.2 Data source and measurement scales on macro-quality

Since not all quality management practices can achieve performance (Rich, 2008), it is of significance to measure macro-quality level and macro-quality investment separately (Agus and Sagir, 2001). Five experts on quality management were invited to have a discussion and select the indicators from the annual Global Competitiveness Report (GCR) released by World Economy Forum (WEF) to measure macro-quality level index (*MQLI*) and macro-quality investment index (*MQII*). The GCR benchmarks the performance of over 140 countries, measuring different facets of competitiveness from 2006 to 2018, which involved both statistical and survey data (Schwab, 2018). According to the report from Schwab, the Global Competitiveness Index (GCI) is composed of 3 types of element indicators, which are basic requirements, efficiency enhancers, and innovation and sophistication. There are 12 competition pillars in the measurement scales, i.e., institutions, infrastructure, macroeconomic environment, health and primary education, higher education and training, goods market efficiency, labour market efficiency, financial market development, technological readiness, market size, business sophistication, and innovation. Each of these 12 pillars has 7 to 19 secondary indicators (Schwab, 2018). There are 114 indicators in GCR indicators. A GCR code is defined for the secondary indicators. For example, 'quality of the education system' is the third secondary indicator under pillar 5, thus, '5.03' is its GCR code. In 2018, WEF introduced the new GCR 4.0, incorporating the concept of the fourth industrial revolution into the measurement, to provide a long-term forecast of the competitiveness (Schwab, 2020). Because of the change in the scoring structure, data from 2018 to 2020 are not selected

for the following analysis. Moreover, there is a lack of variables that are originally selected to measure the national quality. Therefore, in this study, GCR 3.0 is chosen to provide a national competitiveness measurement during the three years in the duration of 2015–2016 (Schwab, 2016), 2016–2017 (Schwab, 2017), and 2017–2018 (Schwab, 2018).

3.2.1 Macro-quality level index

The *MQLI* shown in Table 2 is measured from four primary dimensions, i.e., education, manufacturing, supplier, and research. There are six secondary indicators under four primary indicators.

Table 2   Macro-quality level index (MQLI) measurement scale

Primary dimensions	Secondary indicators	GCR code	Series
Education (Friedman et al., 2020; Sun et al., 2020)	L1	5.03	Quality of the education system
	L2	5.04	Quality of math and science education
	L3	5.05	Quality of management schools
Manufacturing (Cadogan et al., 2008; Lai et al., 2012)	L4	6.15	Degree of customer orientation
Supplier (Flynn et al., 1995; Sila, 2018; Tarí et al., 2007)	L5	11.02	Local supplier quality
Research (Liu et al., 2018)	L6	12.02	Quality of scientific research institutions

Referring to the scoring logic in GCR, the mean value of *L*1, *L*2 and *L*3 represents country-level quality education. Quality education is listed as the fourth goal of the United Nations SDGs. Whose targets mention providing equal access to a quality education system including technical, engineering, scientific and tertiary by 2030. Education quality is not only a future pursuit but also an ongoing progress (Friedman et al., 2020). Sun studies listed enterprises in China and finds that employees with a high level of education will have a positive impact on corporate social responsibility and even an enterprise's sustainable development in the future (Sun et al., 2020). The attitude of enterprises in the country towards customers is reflected by *L*4 and *L*5, which are the quality of manufacturing factories and local suppliers in the business field. The excellent customer-oriented behaviour of enterprises is the key factor affecting the quality of the enterprise behaviour (Cadogan et al., 2008). Nowadays, actively meeting the needs of customers reflects the quality level of the organisation (Lai et al., 2012). At the same time, high-quality suppliers mean that manufacturing enterprises in the region have high-quality partners (Sila, 2018). This contributes to the continuous improvement of quality management activities in the region, thereby providing profitability. *L*6 represents the quality of scientific research institutions in the field of innovation. According to the 2018 nature index, China ranks second in scientific research, just behind the United States, benefiting from the Chinese Government's strategies of 'high-quality development' and 'rejuvenating the country through science and education' (Liu et al., 2018).

The *MQLI** is calculated using equation (10) and normalised in the scale of 0 to 1 using equation (11). The same weight is allocated on each primary dimension by following the same weight allocation strategy used in GCR competitiveness pillars calculation (Schwab, 2018). For example, in 2017–2018, China's *MQLI* value equals 0.5487 after normalisation.

$$MQLI^* = \frac{[1/3*(L1+L2+L3)+L4+L5+L6]}{4} \tag{10}$$

$$MQLI = \frac{MQLI^* - \min(MQLI^*)}{\max(MQLI^*) - \min(MQLI^*)} \tag{11}$$

3.2.2 Macro-quality investment index

The *MQII* is measured from seven primary dimensions as shown in Table 3, i.e., IP, infrastructure, training, policy, technology, production, and R&D. Totally, there are ten secondary indicators under seven primary indicators. Macro-quality investment means how many sources and methods that country devotes to improving the quality level.

Table 3 Macro-quality investment index (MQII) measurement scale

Primary dimensions	Secondary indicators	GCR code	Series
IP (Autio and Acs, 2010; Gold et al., 2019)	$I1$	1.02	Intellectual property protection
Infrastructure (Amador-Jimenez and Willis, 2012)	$I2$	2.01	Quality of overall infrastructure
Training (Chapman and Al-Khawaldeh, 2002; Hassan et al., 2015)	$I3$	5.08	Extent of staff training
Policy (Yoshikawa et al., 2018)	$I4$	6.03	Effectiveness of anti-monopoly policy
Technology (Prasetyo and Siswantari, 2020)	$I5$	9.01	Availability of latest technologies
	$I6$	9.02	Firm-level technology absorption
Production (York and Miree, 2004; Anand et al., 2012)	$I7$	11.07	Production process sophistication
R&D (Antunes et al., 2017; Schniederjans and Schniederjans, 2015)	$I8$	12.03	Company spending on R&D
	$I9$	12.06	Availability of scientists and engineers
	$I10$	12.07	PCT patents, applications/million pop

$I1$ represents the Intellectual property (IP) protection level. IP protection encourages entrepreneurs with different qualifications to achieve specialisation, thereby improving the country-level technological development (Autio and Acs, 2010). Additionally, IP protection will result in more technology transfer, thereby improving the national quality level. $I2$ represents infrastructure quality symmetrically. There is a synergistic effect when different infrastructures work together. The more extensive the infrastructure is, the more relevant it is to the development of the country (Amador-Jimenez and Willis, 2012).

The positive attitude towards staff training is represented by *I*3 represents from industrial view since education and training of employees can contribute around 80% to quality practices (Chapman and Al-Khawaldeh, 2002). To ensure the functionality of the distribution system, the importance of good governance (Yoshikawa et al., 2018) in the process of implementing macro-quality policies is represented by *I*4. *I*5 and *I*6 are combined to represent the development and absorption of the latest technology, which encourage innovation ambition (Prasetyo and Siswantari, 2020). *I*7 represents the production process and efficiency level. Lean production can be regarded as an example of eliminating redundant production processes and improving product quality. As a huge success, lean production adds complexity, reduces the production cost, and improves quality at the same time (York and Miree, 2004). *I*8, *I*9 and *I*10 represent R&D here, which covers investment in R&D, a reserve of scientists, engineers, and patents. Product innovation can improve organisational performance, while process innovation can bring additional operational improvements for example new quality management strategies (Schniederjans and Schniederjans, 2015).

The *MQII* is calculated using equation (12). The same weight is allocated on each primary dimension by following the same weight allocation strategy used in GCR competitiveness pillars calculation (Schwab, 2018). For example, in 2017–2018, China's *MQII* equals 4.3570.

$$MQII = \frac{[I1+I2+I3+I4+1/2*(I5+I6)+I7+1/3(I8+I9+I10]}{7} \tag{12}$$

3.2.3 Macro return on quality investment

In equation (13), GDP per capita (*GDP**) is normalised on the scale of 1 to 7, which is the same with secondary indicators from GCR. Macro-quality return is expressed by the country's GDP per capital (Frenda et al., 2014) and macro-quality investment is expressed by *MQII*. Therefore, *MQROI* is calculated using equation (14). For example, in 2017–2018, China's *GDP* equals 1.5028 and *MQROI* equals 0.3449.

$$GDP = 8*\frac{GDP^* - \min(GDP^*)}{\max(GDP^*) - \min(GDP^*)} - 1 \tag{13}$$

$$MQROI = \frac{GDP}{MQII} \tag{14}$$

3.3 Model establishment stages

Based on the quantitative model on quality canyon, three are three stages in data analysis when using the model on macro-quality.

In stage 1, since 'the methodology 1–7 (best)' is the most used logic for scoring indicators in GCR. Fourteen secondary indicators adopt this methodology originally. As for the other two secondary indicators, they are normalised on a scale of 1 to 7. After data pre-processing, variable statistical description is carried out.

In stage 2, firstly, robust fitting with bisquare weights is adopted. Curve fitting refers to selecting an appropriate curve type to fit the observation data and using the fitted curve equation to analyse the relationship between two variables. The prototype of the model

refs to equation (9). MATLAB R2020a software is used to perform ordinary least squares (OLS), bisquare weighted least square (WLS) regression fitting, and analysis between influencing factors and prediction objects. Since the basic assumption of OLS regression is all residuals come from populations with constant variance (homoscedasticity). Then it is necessary to calculate the residual first, then to verify whether the model has heteroscedasticity, and finally to correct the heteroscedasticity by choosing WLS as the statistical method. Bisquare weights is a method which first calculates the distance between the point and the fitted line, then gives the weight to each point correspondingly. Compared with OLS, the robust Bisquare weights method is more effective and weakens the influence of outliers on the fitted model (Podulka, 2020).

In stage 3, the efficient frontier graphically represents a set of portfolios that maximise the rate of return at different levels of investment risk (Hoang and Quang, 2019). Inspired by the concept of effective frontier of ROI, this study introduces a new term 'bottom-line', which is ineffective frontier to study *MQROI*.

4 Data analysis

4.1 Variables statistical analysis

By using the method introduced in Section 3, results from stages 1 to 3 are obtained. Excluding the zero value in the database, a total of 393 corresponding '*MQROI-MQLI*' data are obtained. The correlation coefficient among the three variables is tested, as Table 3 shows. Between the independent variable (*MQLI*) and the dependent variable (*MQROI*), there is a 0.648 correlation, which meet the requirements for further regression modelling.

Table 4   Variables statistical description

	Mean	*Standard deviation*	*Correlation coefficient*	
			MQLI	*MQROI*
MQLI	0.470	0.197	1.000	0.648
MQROI	0.437	0.160	-	1.000

### 4.2 WLS regression result analysis

After applying robust fitting with bisquare weights regression, the nonlinear formula between *MQLI* and *MQROI* is shown in equation (15). Compared with OLS, the goodness of fit increases to 0.79. The bottom point shown in Figure 4 is located at (0.318, 0.347). The value of *MQLI* shifts 0.12 units to the right, and the value of *MQROI* remains basically unchanged. Overall, the shape of the graph is 'U-shaped'.

$$MQROI = \frac{1.428 * e^{MQLI}}{e-1} + \frac{0.992 * e^{-MQLI+1}}{e-1} - 1.937 \tag{15}$$

Figure 4   Bisquare WLS regression between MQLI and MQROI (see online version for colours)
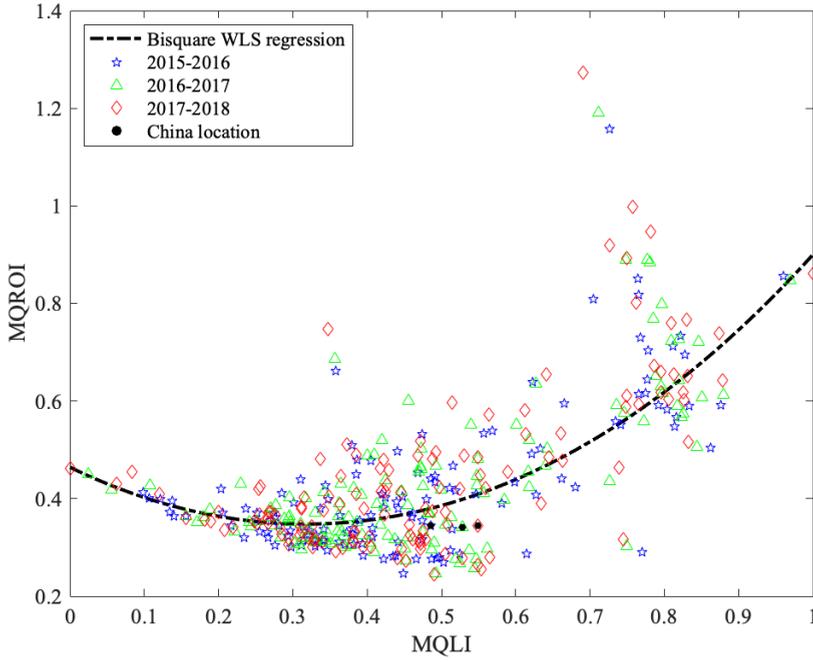
Figure 5   'Bottom-line' OLS regression between MQLI and MQROI (see online version for colours)
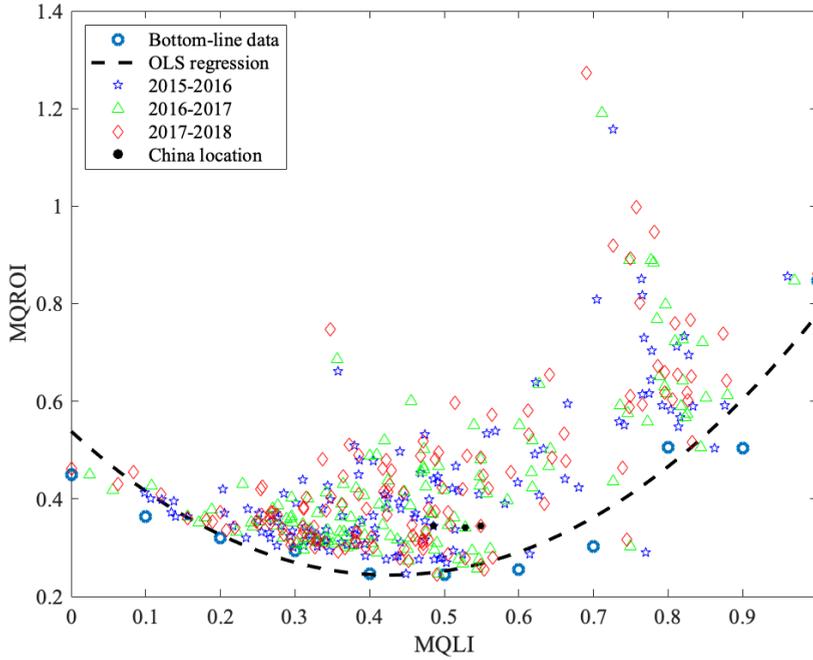
4.3   Ineffective frontier analysis

A total of 393 *MQLI* data are rounded to one decimal place to optimise the 'bottom-line' analysis. Under the same rounded *MQLI* value, the corresponding minimum *MQROI* value is selected. After combination, 11 sets of data are marked with little circle in Figure 5. After applying the OLS regression method, the fitting formula is shown in equation (16). The goodness of fitting is 0.90. The bottom point is located at (0.428, 0.244). Overall, the shape of the graph is 'U-shaped'.

$$MQROI = \frac{1.777 * e^{MQLI}}{e-1} + \frac{1.538 * e^{-MQLI+1}}{e-1} - 2.929 \tag{16}$$

5   Discussion

In this section, the mechanism of the macro-quality canyon phenomenon and suggestions for countries and economies that are trapped in are discussed. The graphic performances of the two models are consistent. They all indicate that countries will encounter the situation of *MQROI* decrease instead of increasing, in the process of improving the quality level. 'Bottom-line' analysis further confirms the existence of a macro-quality canyon, especially for those countries and economies with poor economic performance. Since the results of fitting curves are 'U-shaped', this section takes the analysis of Bisquare WLS fitting results as an example. From the robust fitting results, the country's economic performance is acceptable but has a slightly decrease when the *MQLI* is low. When the quality level reaches around 0.3, the *MQROI* meets its lowest point, which is similar to the process of falling into a trap and hard to get out of it. When the *MQLI* of the country crosses the bottom period, economic performance and investment on a quality level have a positive correlation.

5.1   Low hanging fruit theory

When the value of *MQROI* decreases, it means that quality improvement does not always bring benefits, which shows a downward trend at the left side of the 'U-shaped' curve in Figure 4. When *MQLI* rises from 0, developing countries have already enjoyed the economic gains brought by the 'low hanging fruit' (Narain and van't Veld, 2008). For example, countries with low labour costs become the world's foundries. When these low-and-middle-income countries master manufacturing and production technologies, how to make good use of the benefits of foreign investment becomes a challenge. They may need a lot of resources to improve the level of IP protection, creating more sustainable cradles for high-quality products or services. If the cost of counterfeiting products in the country is low, enterprises that concentrate on R&D or improvements of product quality will lose price advantage or even competitiveness in both domestic and foreign markets. If these countries only maintain the status of foundry and do not want to develop local high-value, high-quality manufacturing, economic growth will undoubtedly slowdown, which is also the main reason for the appearance of the quality canyon.

5.2   *Sunk cost and time lag effect*

Countries try to build and improve infrastructure to meet the needs of current scientific and technological production. This will lead to some 'sunk costs', with a time lag effect between investments and returns, which shows a downward trend at the left side of the 'U-shaped' curve in Figure 4. It takes relatively a long time for a principle to be found in basic research, proved to be effective and superior, derived to application, and finally accepted by the industry. Countries and enterprises that have low-quality level must make a lot of efforts in basic requirements and efficiency improvement, at the same time gain little. For example, introducing employee continuous learning mechanism (Murugesan, 2014) and implementing anti-monopoly policy, pave the way for the whole industry innovation both internally and externally. However, the effect is not immediate (Vany and Saving, 1983). Achieving progress from zero to some extent is difficult, which share the same methodology with technology development. Once the time gap between investment and return is eliminated, it will be possible for countries to make efficient use of the complementarity of basic and efficiency indicators, producing a relatively low cost 'scale effect' (Yoshikawa et al., 2018).

5.3   *GCR's innovation-driven category*

Before 2018, GCR's calculation logic divided countries into five categories according to GDP per capita. A country is considered as an innovation-driven country only when GDP per capita reached $17,000 (Schwab, 2018). It can be concluded that the economic base is the major premise of national development and innovation. It does not mean that developing countries do not have the capacity to develop innovation, especially macro-quality. It is just that the investment in the innovation field in developing countries cannot achieve the ideal return in the short term, which shows the bottom side of the 'U-shaped' curve in Figure 4. The macro market needs to gradually discover and absorb the improvement of these elements. Due to the slow response of the market, there is no need to doubt the implementation of quality improvement. Before country-level quality reaches the bottom of quality canyon, it is normal for courtiers to achieve a negative rate of *MQROI*.

5.4   *Learning effect and continuous improvement*

The upward trend on the right side of the 'U-shaped' curve in Figure 4 can be attributed to the positive benefits of the learning effect and continuous improvement (Surange et al., 2013). When the country enters the stage of medium-high quality level, a country's investment in quality begins to bear fruit. In this period, the basic requirements and efficiency elements are developed to a certain level, through which, a country can gradually provide high-quality infrastructure, high-quality staff training, stable market order, the latest available technologies, senior talents, patents at the forefront of the world (Kang, 2016) and other conditions. Capital investment aiming at innovation and complexity will penetrate all aspects of national competitiveness to obtain more comprehensive benefits. For example, the implementation of 'industry 4.0' and other manufacturing plans aims to strengthen innovation in various fields and promote industrial quality upgrading (Yin et al., 2018). The existing industrial base, commodity market and labour market efficiency are crucial to this revolution. Compared with

countries with lower *MQLI*, the more quality-developed countries will obtain a higher investment return rate. With the improvement of the overall quality level, the chain reaction of joint innovation in various industries in high-income countries reversely promotes the development of quality growth in the education system, math and science, management school, enterprises, local suppliers, and scientific research institutions, finally making the *MQROI* curve show 'U-shaped' upward growth.

6 Conclusions

This study summarises the causes of the quality canyon in the existing literature and builds a quantitative model for the quality canyon based on the Kano model. Through the modelling of the *MQLI* and the *MQROI*, this study uses selected GCR data to prove that quality canyon does exist in the process of national development. It also means that all the countries and economies need to face the challenges posed by quality canyon.

Several suggestions are put forward for macro-quality management:

1 Since the general trend of curve fitting shows the existence of quality canyon, macro-quality improvement needs to be implemented in a planned way. The quantitative model of this research can clarify the position of the object on the 'U-shaped' curve and provide decision support for the quality improvement strategies

2 In view of how to cross quality canyon, as well as middle income trap, a transformational development strategy needs to be implemented. Countries need to understand the decline in returns brought about by sunk cost and time lag effects, then shift from relying on resources and efficiency to relying on innovation.

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