Innovation Analysis for Business Productivity

Inpong Luanglath, J.D.
inpong.l@bu.ac.th
Bangkok University

Abstract

The purpose of this paper is to provide tools for the determination and analysis of innovation through statistical methods. Innovation is defined by the confidence interval of the normal probability distribution density function where $\mu \pm 2\sigma = 0.95$ leaving a room of $\pm\alpha = 0.05$ for innovation analysis. The upper tail of the probability distribution density curve ($+\alpha = 0.025$) and the lower tail of the curve: $-\alpha = -0.025$ are subject of innovation analysis. Innovation is tested by comparing the claimed output change against the industry reference mean. Innovation may also be proven where there is no external reference. Absent such an external reference indicator, the Dixon outliers test may be used.

Keywords: *Benchmarking, Innovation, Confidence Interval Test, Correlation Coefficient, Dixon Outliers Test, Hotelling's T-square, T-test, Z-test.*

บทคัดย่อ

วัตถุประสงค์ของบทความนี้ คือ การนำเสนอวิธีการพิสูจน์และวิเคราะห์นวัตกรรมใหม่โดยการใช้วิธีการวิเคราะห์ทางสถิติเป็นเครื่องมือ นวัตกรรมใหม่ ถูกนิยามโดยใช้ช่วงความเชื่อมั่นของความหนาแน่นของการแจกแจงความน่าจะเป็นแบบปกติในระยะ $\mu \pm 2\sigma = 0.95$ และกำหนดให้ความหนาแน่นของการแจกแจงความน่าจะเป็นนอกระยะ คือ $\pm\alpha = 0.05$ เป็นระยะการวิเคราะห์นวัตกรรมใหม่ ทั้งนี้ ความหนาแน่นของการแจกแจงความน่าจะเป็นช่วงบน คือ $+\alpha = 0.025$ และช่วงล่าง คือ $-\alpha = -0.025$ ของเส้นโค้งรูประฆัง ซึ่งเป็นขอบเขตในการสนับสนุนว่ามีนวัตกรรมใหม่เกิดขึ้น การพิสูจน์นวัตกรรมใหม่สามารถกระทำได้โดยการเปรียบเทียบความแตกต่างจากค่าเฉลี่ยของปริมาณผลิตผลภายในองค์กรโดยใช้ปริมาณผลิตผลของอุตสาหกรรมเป็นตัวเลขอ้างอิง นวัตกรรมใหม่ยังสามารถพิสูจน์ได้เมื่อไม่มีจุดอ้างอิงจากภายนอก โดยใช้วิธีการทดสอบค่าแตกต่างระหว่างตัวแปรน้อยที่สุดกับตัวแปรมากที่สุดของ Dixon

คำสำคัญ: *การวัดเปรียบเทียบสมรรถนะเกณฑ์มาตรฐาน นวัตกรรม ช่วงความเชื่อมั่น สัมประสิทธิ์สหสัมพันธ์ การทดสอบหาค่าผิดปกติ การทดสอบสองกลุ่มตัวอย่าง การทดสอบการแจกแจงแบบปกติ การทดสอบการแจกแจงแบบปกติ*

Introduction

Attempts to define innovation had been confined to qualitative analysis and are not helpful in quantitative examination. In order to prove that innovation occurs, it is necessary to use quantitative analysis. Qualitative analysis of innovation limits the development of knowledge in innovation analytics because most innovation claims involve the claim of "cost reduction" or "increase in productivity". These two facets of claims of innovation are numerical in nature; therefore, a more scientific method to prove and analyze innovation is necessary. Innovation studies must meet these requirements: (i) replication, (ii) external review, and (iii) data recording and sharing. This paper defines innovation as the introduction of new method or procedure for an existing activity to raise productivity. (EuDaly, Schafer, Boyd, Jim, Jessup, McBridge, & Glischinksi, 2009). The two basic elements of innovation are (i) existing procedure and (ii) increased productivity or performance improvement (Salge & Vera, 2012).

Methodology

Innovation has been defined as "something original, new, and important-in whatever field-that breaks in to (or obtains a foothold in) a market or society". (Frankelius, 2009). This definition is inaccurate because it confuses innovation with invention. Invention is the introduction of new things never before existed. Innovation, on the other hand, is the use of existing resources to increase productivity or lower cost. Innovation has also been equated to creativity. Mumford (2003) asserts that creativity involves novelty and usefulness. The definition is an improvement over what had been defined by Frakelius because it mixes innovation with invention. "Novelty" is an element of invention only; while improvement may be applied in both invention and innovation. These terms: invention and inventiveness are indicators of novelty element used to defined invention. Invention is a legal concept; it is defined as a new discovery or improvement on existing discovery (35 USC §101: Title 35 United States Code, Section 101 (United States Code).

Innovation does not involve new discovery. It is the improvement of process, methods or usage of existing invention for the same use or new application. Invention may be an improvement of an existing discovery, such as a portable flash drive is am improvement from a floppy disk. Both may be granted separate patents under patent law. However, the various applications of the drive, such as using it to store audio and video files in addition to data files, are innovation. Creativity involves a thought process that is applicable to both invention and innovation because creativity involves 'novelty' (invention) and usefulness (innovation). Novelty used to define invention is a qualitative concept. Usefulness used to define innovation is a quantitative concept. This utilitarian ideal of innovation does not differentiate innovation in micro or macro-perspective. In measuring innovation, some researchers looked at cost effectiveness as the indicator (Chalkidou et al., 2009). The value-based evaluation of innovation has been claimed to be useful (Roughead, Lopert, & Sansom, 2007). Value-based comparison method is generally used in innovation analysis (Faunce & Nguyen, 2010; Faunce, 2007; Faunce, 2006).

At a macro-level, innovation is measured and compared country-by-country through various indicators, such as the number of patent applications approved. One study found that the number of U.S. Patent grants peaked in 1873, and declined thereafter (Huebner, 2005). However, patent issuance is concerned with invention, not innovation. Huebner was contradicted by another study which claims that innovation increased not decreased (Smart, 2005). The confusion between invention and innovation continues. This confusion was made clear by the more recent reaffirmation by Strumsky that patent grant is an indicator of innovation (Strumsky, Lobo, & Tainter, 2010). This paper clarifies the confusion by defining innovation on the basis of creative use of the existing invention for purposes of optimizing utility either via cost reduction or increase productivity. Although there are attempts to measure innovation at the macro-level by looking at the number of patent applications. This approach at innovation analytics is misplaced.

Current literature does not focus on the empirical studies of innovation. This paper intends to fill this gap. These empirical models introduced in this paper have practical implication for the measurement of innovation and proving that innovation is a source of improvement in productivity: cost reduction or performance increase. Macro-analysis of innovation, such as country-to-country comparison study, may be accomplished through other indicators: factors utilization, and workers productivity measurement. At a firm level, similar approach may also be undertaken by looking at procedures that leads to cost reduction or productivity increase. This paper introduces empirical methodologies for innovation measurement which can be applied at firm and national levels. The implication of the research is the practical application of innovation measurement methods discussed in this paper. These methods are useful in the measurement of organizational productivity.

The methodology employed in this paper is inferential statistics. There are four types of inferential statistics: frequentist, likelihood, fiducial and Beysian (Geisser & John, 2006). Frequestist statistical inference is used in this paper. Economic data from the Bank of Thailand is used to illustrate how innovation is measured. The following statistical tests were used as tools for measurement: Hotelling T-square test and Dixon test for outliers. Inferential error is controlled by the use of relevant test statistic with confidence interval set at 95%. Company or industry specific observation is subject to t-test; sector or national estimate is subject to the Z-test. The lower tail of the probability distribution density function is used to determine innovation in resource utilization and the upper tail is used to determine innovation in productivity (Ord, 1972).

Use Existing Procedure as a Point of Reference for Innovation Analysis

The use of existing procedure as a point of reference helps to differentiate innovation from invention. Invention is defined as the introduction of new idea that is not yet in existence. Entrepreneurs usually look for new ways to improve business process through strategies and technologies (Heyne, Boettke, & Prychitko, 2010). Innovation is the area that lies outside of the confidence interval under the probability distribution density function:

$$f(x) = \frac{1}{\sqrt{2\pi}\sigma} \exp\left[-\frac{(x-\mu)^2}{2\sigma^2}\right] \qquad (1)$$

The mean output from the use of existing procedures may be used as a reference point. This approach is applicable for innovation analysis at firm, industry benchmarking, and national contexts. The point estimate used is the mean. From this mean of past performance, a confidence interval may be constructed. For instance, the confidence interval may be defined as $\mu \pm 2\sigma$ or $1 - \alpha = 0.95$. Thus, the observed data or claim that lies outside of this confidence interval region may be classified as statistically significant and, therefore, is evidence of innovation.

Raised Production or Cost Reduction as the Basis for Innovation

The rationale for the second element: raised productivity, is the test statistic focusing on the upper tail of alpha ($+\alpha$) of the Gaussian probability distribution density as expressed in equation (1). In words, the productivity raised, after the implementation of the improved procedure, must be more than 2σ. This second requirement differentiates innovation from six sigma which does not speak of raising productivity (quality), but to reduce random error by forcing the confidence interval outward from $\pm 2\sigma$ to $\pm 3\sigma$, thus making the confidence interval equal to 6σ about the mean. Under innovation, increased productivity is a result of 'creative destruction (Schumpeter, 1943). Through technologies and organization strategies, organizations find a new way to create additional value. The test statistic for innovation in a specific case is given by:

$$t = \frac{\bar{x} - \mu_0}{S_x / \sqrt{n}} \qquad (2)$$

Where t is t-critical at $t_{0.95} = 1.96$; $\bar{x}$ is sample mean (subject observation); μ_0 is population mean (reference group); n is number of observations in the subject group. The operational assumption of the confidence interval is 0.95 making the random error equal to α = 0.05; since innovation focuses on the upper tail of the normal distribution curve, the alpha is 0.50α = 0.025 with the t-critical $t_{0.95}$ = 1.96. The confidence interval is defined thus: $t = (\bar{x} - \mu_0)/S_x/\sqrt{n}$, multiplying both sides of the equation by $\left(S_x/\sqrt{n}\right)$: $t\left(S_x/\sqrt{n}\right) = \bar{x} - \mu_0$, add μ_0 to both sides of the equation:

$$t\left(S_x/\sqrt{n}\right) + \mu_0 = \bar{x} \quad (3)$$

In order to express the equality as an interval, the equation must be written as an inequality in terms of the sample mean bounded by the upper and lower limits; thus, the confidence interval for innovation under the t-test is given by:

$$\mu_0 - \left(S_x/\sqrt{n}\right) \le \bar{x} \le \mu_0 + \left(S_x/\sqrt{n}\right) \quad (4)$$

From equation (4), the formal definition of innovation is:

$$\mu_0 \pm \left(S_x/\sqrt{n}\right) + I_i \quad (5)$$

The following hypothesis test applies:

$$H_0 : \mu_0 + \left(S_x/\sqrt{n}\right) + I_i < t_{0.95}$$
$$H_A : \mu_0 + \left(S_x/\sqrt{n}\right) + I_i > t_{0.95}$$

The decision rule is to "accept the *null hypothesis* if $t_{obs} < t_{0.95}$, otherwise reject the null hypothesis". Note that in equation (5), the term I_i is introduced as an incremental change that pushes the productivity beyond the boundary of $\pm 2\sigma$ under the normal curve. That boundary is defined as: $\mu_0 + t\left(S_x/\sqrt{n}\right)$ which is equal to $\pm 2\sigma$. In short, innovation is:

$$i = \mu \pm 2\sigma + I_i \quad (6)$$

In a simple experimental design, innovation may be determined by input-output analysis through the use of linear regression analysis: $Y = \alpha + \beta X + c$. (where α is the Y-intercept, β is the slope of the linear regression line and c is the forecast error or standard error of the estimate) Assuming that there are two series of data, the independent variable is represented by the series $\{x_1, x_2, \ldots x_n\}$ and the dependent variable represented by the series $\{y_1, y_2, \ldots y_n\}$. These two series may be plotted in the Cartesian xy-space plane. The hypothesis formulation follows: $H_0 : \beta = 0; H_A : \beta \neq 0$, and to "accept the *null hypothesis* if $\beta = 0$, otherwise reject".

Assuming that there appears to be a relationship where $\beta \neq 0$, thus H_0 is rejected. The next step is to determine the strength of that relationship through correlation coefficient which is given by Pearson's Correlation Coefficient (Rodgers & Nicewander, 1988):

$$r = \frac{1}{n-1}\sum_{i=1}^{n}\left(\frac{x_i - \bar{x}}{S_x}\right)\left(\frac{y_i - \bar{y}}{S_y}\right) \quad (7)$$

The short hand calculation for the correlation coefficient is:

$$r = \beta\left(\frac{S_x}{S_y}\right) \quad (8)$$

The range of r is between -1.00 and +1.00. The value of r must pass the confidence interval test. The test statistic for r is given by:

$$t_r = \frac{r\left(\sqrt{n-2}\right)}{\sqrt{1-r^2}} \quad (9)$$

At this stage of the analysis, a new hypothesis formulation must be made, thus, $H_0 : t_{obs} < t_{0.95}$; $H_A : t_{obs} > t_{0.95}$ Or to "accept the *null hypothesis* if $t_{obs} < t_{0.95}$, otherwise reject". The data of Thailand's export volume at various exchange rates is used to determine whether maintaining strong currency contributes to the growth in export. The dependent variable (Y) is the export volume, and the independent variable (X) is the exchange rate. The objective is to determine whether there is a relationship between x and y.

Table 1 Exchange Rate of Thai Baht

	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011
X	43.00	41.53	40.27	40.27	37.93	34.56	33.36	34.34	31.73	30.49
Y	66.10	78.10	94.90	109.40	127.90	151.30	175.20	150.70	191.60	219.10

Source: Bangkok of Thailand (2012)

The descriptive statistic of the two series follows:

$$n_x = 10 \qquad n_y = 10$$
$$\bar{x} = 36.75 \qquad \bar{y} = 136.43 \qquad Y = 549.58 - 11.24X + 8.78$$
$$S_x = 4.40 \qquad S_y = 50.20$$

There appears to be a negative relationship between the export volume and the exchange rate. This relationship is peculiar because it appears to go against the teaching of economics which posits that 'the weaker the currency, the higher the volume of export'. However, in the present case, it is the opposite. The chart below shows that the weaker the currency (Thai Baht), the lower the export volume.

The strength of the relationship in $Y = 549.58 - 11.24X + 8.78$ may be examined through correlation coefficient calculation. The calculation for the correlation coefficient is following as:

$$r = \beta\left(\frac{S_x}{S_y}\right) = -11.24\left(\frac{4.40}{50.20}\right) = -11.24(0.087) = -0.9852$$

The scale for the correlation coefficient is between -1.00 and +1.00. From the calculation above, the relationship between exchange rate and export volume for Thailand is strongly negatively correlated. The next step is to determine whether the correlation coefficient r lies within the confidence interval. The one-sided alpha with the degree of freedom (df = 10 – 1 = 9) is $\alpha = 1.83 \Rightarrow \frac{1}{2}\alpha = 0.92$. Therefore, the test hypothesis is: $H_0 : t_{obs} < t_{0.95}$; $H_A : t_{obs} > t_{0.95}$, or to "accept the *null hypothesis* if $t_{obs} < t_{0.95}$, otherwise reject". The calculation for the test statistics is as following:

$$t_r = \frac{r\left(\sqrt{n-2}\right)}{\sqrt{1-r^2}} = \frac{-0.9852\left(\sqrt{10-2}\right)}{\sqrt{1-(-0.9852)^2}} = \frac{-0.9852\left(\sqrt{8}\right)}{\sqrt{1-0.9706}} = \frac{-0.9852(2.8284)}{\sqrt{0.0294}} = \frac{-2.7865}{0.1715}$$
$$t_r = 16.2478$$

The result shows that t_{obs} = 16.2478 which is larger than $t_{0.95}$ = 0.92. The strength of the relation of -0.9852 is real because it lies beyond the 0.95 confidence interval. The negative relationship between the exchange rate and the volume of export for Thailand is statistically significant. The implication of this test shows that the conventional foreign exchange policy doctrine to maintain weak currency to stimulate export is questionable. In the case of Thailand, strong currency positively correlates with the increase of export. For purposes of innovation analysis, the question presented is ‘whether the strong currency from FY2002 to FY2011 producing an apparent increase in export volume is *due* to random error or is the result an innovation in policy’. The result of the calculation shows that the increase of export volume in face of strong currency is not due to randomness. The currency regime engaged by Thailand is antithetical to the general advocacy for weak currency. Since the relationship is tested for correlation and the correlation is confirmed through confidence interval test statistic, it may be said that the shift in Thailand’s currency management policy, from pro-weak to pro-strong Baht, is *innovative*.

Components of Innovation

From equation (6), innovation is the variable I_i. In order to achieve this parameter, other subcomponents are required. The components of I_i are defined thus:

$$I_i = \sum_{i=1}^{n} ipo_i \tag{10}$$

Where i is input; p is procedure; and o is operating environment.

Innovation is a result of multivariate explanatory factors. Therefore, equation (10) requires multivariate test by using the Hotelling T-square test (Hotelling, 1931). The purpose of the Hotelling’s T-square test is to compare the results of two experiments, each of which yields a multivariate result---meaning that the explanatory factors are many. The objective is to determine if the mean pattern obtained from the first experiment agrees with the mean pattern obtained from the second (Kanji, 1995).

The two experiments are marked A and B. Assuming that the multivariate factors are three factors: x, y, and z, the number of observations is denoted by n_A and n_B for the two experiments. It is necessary to solve for parameter a, b and c. The linear expression for these three factors is as follows:

$$a\left[(xx)_A + (xx)_B\right] + b\left[(xy)_A + (xy)_B\right] + c\left[(xz)_A + (xz)_B\right] = (n_A + n_B - 2)(\overline{x}_A + \overline{x}_B) \tag{11a}$$

$$a\left[(xy)_A + (xy)_B\right] + b\left[(yy)_A + (yy)_B\right] + c\left[(yz)_A + (yz)_B\right] = (n_A + n_B - 2)(\overline{y}_A + \overline{y}_B) \tag{11b}$$

$$a\left[(xz)_A + (xz)_B\right] + b\left[(yz)_A + (yz)_B\right] + c\left[(zz)_A + (zz)_B\right] = (n_A + n_B - 2)(\overline{z}_A + \overline{z}_B) \tag{11c}$$

Where ...

$$(xx)_A = \sum (x_A - \overline{x}_A)^2$$

$$(xy)_A = \sum (x_A - \overline{x}_A)(y_A - \overline{y}_A)$$

$$(xz)_A = \sum (x_A - \overline{x}_A)(z_A - \overline{z}_A)$$

Following the same notation for other terms, the Hotelling’s T^2 is defined as;

$$T^2 = \frac{n_A \cdot n_B}{n_A + n_B} \bullet \left\{a(\overline{x}_A + \overline{x}_B) + b(\overline{y}_A + \overline{y}_B) + c(\overline{z}_A + \overline{z}_B)\right\} \tag{12}$$

The test statistic is:

$$F = \frac{n_A + n_B - p - 1}{p(n_A + n_B - 2)} \bullet T^2 \quad (13)$$

The test statistic follows the F-distribution with p and $(n_A + n_B - p - 1)$ degrees of freedom, and p is the number of variables.

For purpose of equation (11), substitute x, y and z by i, p and o. Thus the multifactor analysis becomes:

$$a\left[(xi)_A + (xi)_B\right] + b\left[(xp)_A + (xp)_B\right] + c\left[(xo)_A + (xo)_B\right] = (n_A + n_B - 2)(\bar{i}_A + \bar{i}_B)$$
$$a\left[(xp)_A + (xp)_B\right] + b\left[(yp)_A + (yp)_B\right] + c\left[(yo)_A + (yo)_B\right] = (n_A + n_B - 2)(\bar{p}_A + \bar{p}_B)$$
$$a\left[(xo)_A + (xo)_B\right] + b\left[(yo)_A + (yo)_B\right] + c\left[(zo)_A + (zo)_B\right] = (n_A + n_B - 2)(\bar{o}_A + \bar{o}_B)$$

Where ...

$$(xi)_A = \sum (i_A - \bar{i}_A)^2$$
$$(xp)_A = \sum (x_A - \bar{x}_A)(p_A - \bar{p}_A)$$
$$(xo)_A = \sum (x_A - \bar{x}_A)(o_A - \bar{o}_A)$$

Following the same notation for other terms, the test statistic remains the same:

$F = \frac{n_A + n_B - p - 1}{p(n_A + n_B - 2)} \bullet T^2$, but the term for the T^2 changes according to equation (10)'s components, thus:

$$T^2 = \frac{n_A \cdot n_B}{n_A + n_B} \bullet \left\{a(\bar{i}_A + \bar{i}_B) + b(\bar{p}_A + \bar{p}_B) + c(\bar{o}_A + \bar{o}_B)\right\}$$

The input and procedure are combined to produce output. These two components need no further definition. However, the operating environment (Khan, 1989) has embedded components:

$$o_i = \sum_{i=1}^{n} (LFRM)_i \quad (14a)$$

Where L is leaders; F is followers; R is resources; and M is market condition. The same T^2 procedure applies to equation (14a). For purposes of T^2, the terms L and F in equation (14a) may be combined into one: organizational culture (W). (Salge & Vera, 2012). The Hotelling T^2 analysis is as following:

$$a\left[(xw)_A + (xw)_B\right] + b\left[(xr)_A + (xr)_B\right] + c\left[(xm)_A + (xm)_B\right] = (n_A + n_B - 2)(\bar{w}_A + \bar{w}_B)$$
$$a\left[(xr)_A + (xr)_B\right] + b\left[(yr)_A + (yr)_B\right] + c\left[(ym)_A + (ym)_B\right] = (n_A + n_B - 2)(\bar{r}_A + \bar{r}_B)$$
$$a\left[(xm)_A + (xm)_B\right] + b\left[(ym)_A + (ym)_B\right] + c\left[(zm)_A + (zm)_B\right] = (n_A + n_B - 2)(\bar{m}_A + \bar{m}_B)$$

The test statistic is: $F = \frac{n_A + n_B - p - 1}{p(n_A + n_B - 2)} \bullet T^2$

Where: $T^2 = \frac{n_A \cdot n_B}{n_A + n_B} \bullet \left\{a(\bar{w}_A + \bar{w}_B) + b(\bar{r}_A + \bar{r}_B) + c(\bar{m}_A + \bar{m}_B)\right\}$

The two components: L and F are self-explanatory. However, resources have further subcomponents:

$$R_i = \sum_{i=1}^{n} r_i \tag{14b}$$

Where the components of r_i includes: human resource ($r_1 = x$), financial resource ($r_2 = y$), physical infrastructure ($r_3 = z$), and technological resource ($r_4 = v$). The multivariate component analysis for equation (14b) is given by:

$$a\left[(xx)_A + (xx)_B\right] + b\left[(xy)_A + (xy)_B\right] + c\left[(xz)_A + (xz)_B\right] + d\left[(xv)_A + (xv)_B\right] = (n_A + n_B - 2)(\overline{x}_A + \overline{x}_B)$$

$$a\left[(xy)_A + (xy)_B\right] + b\left[(yy)_A + (yy)_B\right] + c\left[(yz)_A + (yz)_B\right] + d\left[(xv)_A + (xv)_B\right] = (n_A + n_B - 2)(\overline{y}_A + \overline{y}_B)$$

$$a\left[(xz)_A + (xz)_B\right] + b\left[(yz)_A + (yz)_B\right] + c\left[(zz)_A + (zz)_B\right] + d\left[(xv)_A + (xv)_B\right] = (n_A + n_B - 2)(\overline{z}_A + \overline{z}_B)$$

$$a\left[(xv)_A + (xv)_B\right] + b\left[(yv)_A + (yv)_B\right] + c\left[(zv)_A + (zv)_B\right] + d\left[(xv)_A + (xv)_B\right] = (n_A + n_B - 2)(\overline{v}_A + \overline{v}_B)$$

As before, the test statistic follows the same format, thus:

$$F = \frac{n_A + n_B - p - 1}{p(n_A + n_B - 2)} \bullet T^2$$

Where $T^2 = \frac{n_A \cdot n_B}{n_A + n_B} \bullet \left\{a(\overline{x}_A + \overline{x}_B) + b(\overline{y}_A + \overline{y}_B) + c(\overline{z}_A + \overline{z}_B) + d(\overline{v}_A + \overline{v}_B)\right\}$

The market condition in equation (14a) also contains subcomponents. These components are defined as:

$$M_i = \sum_{i=1}^{n} m_i \tag{14c}$$

The components of m_i includes (i) competitive intensity (e), (ii) local policy or legal compliance requirement (f), and (iii) regional challenges (g). For many organizations in the ASEAN region, this regional challenge is the AEC-2015. The multivariate component analysis for equation (14c) is given by:

$$a\left[(xe)_A + (xe)_B\right] + b\left[(xf)_A + (xf)_B\right] + c\left[(xg)_A + (xg)_B\right] = (n_A + n_B - 2)(\overline{e}_A + \overline{e}_B)$$

$$a\left[(xf)_A + (xf)_B\right] + b\left[(yf)_A + (yf)_B\right] + c\left[(yg)_A + (yg)_B\right] = (n_A + n_B - 2)(\overline{f}_A + \overline{f}_B)$$

$$a\left[(xg)_A + (xg)_B\right] + b\left[(yg)_A + (yg)_B\right] + c\left[(zg)_A + (zg)_B\right] = (n_A + n_B - 2)(\overline{g}_A + \overline{g}_B)$$

As before, the test statistic follows the same format, thus:

$$F = \frac{n_A + n_B - p - 1}{p(n_A + n_B - 2)} \bullet T^2$$

where $T^2 = \frac{n_A \cdot n_B}{n_A + n_B} \bullet \left\{ a(\overline{e}_A + \overline{e}_B) + b(\overline{f}_A + \overline{f}_B) + c(\overline{g}_A + \overline{g}_B) \right\}$

True innovation must be benchmarked against the industry's average or standard. This requirement militates the organization to know about the productivity beyond its own walls. If the current output is referenced to the past output without any reference to the industry, the observed change in output may not be an increase in productivity. It is an increase in output and nothing more. It signifies a better use of input. However, no innovation has been made. The increased in output is an evidence of inefficient use of input in the past. Therefore, the standard analysis must go beyond the analysis of t-statistic. It is imperative to compare the organization's output to its peers in the industry. It is also necessary to project the output of the organization to the assumed population (industry peers) by using the Z-equation. The Z-equation is given by:

$$Z = \frac{\overline{x} - \mu_0}{\sigma_x / \sqrt{n}} \qquad (15)$$

Where $\overline{x}$ is sample mean (subject organization); μ is population mean (industry reference); σ is standard deviation of the population (industry reference); and n is sample size. The standard of review follows the same procedure hitherto discussed. The confidence interval is confined to $1 - \alpha = 0.95$ and the claimed innovation must be larger than $\mu + 2\sigma$. Therefore, the confidence interval is defined by the test statistic as: $Z = (\overline{x} - \mu_0) / \sigma_x / \sqrt{n}$; multiply both sides of the equation by $\sigma_x / \sqrt{n}; Z\left(\sigma_x / \sqrt{n}\right) = \overline{x} - \mu$. By adding both sides of the equation by the population mean μ, the following equality is obtained: $\mu_0 + Z\left(\sigma_x / \sqrt{n}\right) = \overline{x}$. The confidence interval is set by changing the equality into an inequality with the bound of $Z\left(\sigma_x / \sqrt{n}\right)$ or $\mu + 2\sigma$. The interval is given by:

$$\mu_0 - Z\left(\sigma_x / \sqrt{n}\right) \le \overline{x} \le \mu_0 + Z\left(\sigma_x / \sqrt{n}\right) \qquad (16)$$

Outliers are Appropriate Indicator of Innovation

There may be a case where an industry reference is lacking; the organization is faced with an output that appears to be an anomaly. In this situation, the observed events show some outliers, i.e. extreme values among the same series of observation. The query is whether these outliers are evidence of innovation. This query may be answered by the Dixon test (Rorabacher, 1991). Assume that the sample size is n wherein the sample series are ranked with extreme values placed in front of the series in an ascending or descending order. The order is determined by whether the suspected value is the largest or the smallest. The ordered series is denoted as: $x_1, x_2, \ldots x_n$ then the test statistic is Q where:

$$Q = (x_2 - x_1) / (x_n - x_1) \quad \text{if} \quad 3 \le n \le 7 \qquad (17a)$$

$$Q = (x_2 - x_1) / (x_{n-1} - x_1) \quad \text{if} \quad 8 \le n \le 10 \qquad (17b)$$

$$Q = (x_3 - x_1) / (x_{n-1} - x_1) \quad \text{if} \quad 11 \le n \le 13 \qquad (17c)$$

$$Q = (x_3 - x_1) / (x_{n-2} - x_1) \quad \text{if} \quad 14 \le n \le 25 \qquad (17d)$$

According to the Dixon test, the *null hypothesis* is that the outlier from the sample is rejected if the observed value Q exceeds the critical value. (Dean & Dixon, 1951; Kanji, 1995). This is to say, according to the outlier analysis, if the outlier is rejected, there is an innovation. It means that the outlier is statistically significant; therefore, it is a result of innovative procedure. The decision used in the Dixon test is counter intuitive. The hypothesis formulation is: $H_0 : Q_{obs} < Q_{0.95}$; $H_A : Q_{obs} > Q_{0.95}$

The objective is to prove that the outlier is a result of innovation. Thus, the null hypothesis states that if the correlation Q is not significant and that the outlier is statistically not significant, it should be accepted and treated as member of the series. However, if the critical value of Q is such that $Q_{obs} > Q_{0.95}$ than the outlier should be rejected from the series and treated as statistically significant, i.e. innovative. Thus, the Dixon test is a useful tool to determine whether innovation had occurred in the situation with absent industry reference and when the observations come from one series of data: x_i. The data in row x in Table 1.0 is arranged and ranked as:

Table 2 Ranking Data Set for Use in Dixon Test

Item	Unranked	Ranked	Outliers
1	66.10	**219.10**	X
2	78.10	**191.60**	
3	94.90	175.20	
4	109.40	151.30	
5	127.90	150.70	
6	151.30	127.90	
7	175.20	109.40	
8	150.70	94.90	
9	191.60	**78.10**	
10	219.10	66.10	

Source: Bangkok of Thailand (2012) (Data extracted from Table 1)

There are ten observations. Therefore, equation (17b) is applicable. The calculation is as following:

$$Q = (x_2 - x_1) / (x_{n-1} - x_1)$$

$$Q = \frac{191.60 - 219.10}{78.10 - 191.60} = \frac{-27.50}{-113.5}$$

$$Q = 0.2422$$

Recall: $H_0 : Q_{obs} < Q_{0.95}$
$H_A : Q_{obs} > Q_{0.95}$

The Q comparison shows that Q_{obs} = 0.2422 and the Q-critical is $Q_{0.95}$ = 0.466. The conclusion is that the selected outlier is not statistically significant. The *null hypothesis* cannot be rejected. The outlier remains in the sample. It appears that the conclusion reached under the Dixon text contradicts prior calculation under correlation coefficient test. However, the approach taken above is a common mistake in Dixon test analysis. The foreign exchange rate runs over ten periods: 2011 to 2002. The factor of analysis should have been the foreign exchange rate, not the export volume. The export volume is the evidence of the extent of the outlier.

The first step is to determine the confidence interval for the mean exchange rate for the period. $\bar{x}$ = 36.75 and the standard deviation S_x = ± 4.40. The classification of the currency strength is: $\bar{x}+2S_x+x_{S+1}$ means weak currency and $\bar{x}-2S_x-x_{S-1}$ means strong currency. In the present case, the strong currency occurs at the next rate that comes just before $\bar{x}-2S_x$ to the left of the lower end of the interval, thus:

$$\bar{x}-2S_x-x_{S-1} \tag{18}$$

Where S_x is sample standard deviation, and $x_{S\text{-}1}$ is one event to the left of the left boundary of $\bar{x}-2S_x$. The calculation follows: $\bar{x}-2S_x-x_{S-1}=36.75-8.80=27.95.$
However, the lowest rate in the 10 years interval under observation is 30.49. This rate has to be used as a referenced rate for the strong currency. The Dixon test is now ready to be applied, thus: $Q = Gap\,/\,Range$, the gap and range are modified according to the definition of strong and weak currency above:

$$Q=\frac{x_1-\left(\bar{x}-2S_x-x_{S-1}\right)}{x_{n-1}-x_1} \tag{19}$$

The calculation follows: $Q=\dfrac{43.00-30.49}{43.00-31.73}=\dfrac{12.51}{11.27}=1.11$

The hypothesis formulation is: "accept H_0 if $Q_{obs} < Q_{0.95}$, otherwise reject H_0". The Q-critical under 0.95 confidence interval is 0.466 and the Q-critical observed is 1.11. The standard of review to accept the *null hypothesis* is $Q_{obs} < Q_{0.95}$. However, in this case, $Q_{obs} > Q_{0.95}$ because $1.11 > 0.466$. Therefore, the null hypothesis is rejected. The outlier 30.49 is statistically significant and should be removed from the group. This removal means that it is a prima facie evidence of *innovative*. It can now be said that the exchange rate at 31.73 (strong Baht) produces an export volume of 191.60 and an exchange rate of 43.00 Baht per dollar (weak Baht) produces an export volume of 66.10 is not due to random chance. This difference is statistically significant. It can be said that strong currency is an innovative policy to move away from the old constriction advocating weak currency to stimulate export. The Dixon test or outlier analysis can be used as a tool to determine whether innovation had occurred. The Dixon test looks for an outlier. Outlier is defined as marked deviation from the group (Grubbs, 1969). Although innovation has been said to be incremental which means that even small amount of change or small increase in value creation is considered adequate, this standard lacks adequate reference point to determine where innovation should have occurred. The point of comparison is the mean plus two units of standard deviation. The Dixon test uses the ratio between the gap and the range of values. This may be an appropriate approach to innovation analysis.

Industry Innovation Indicator: Supper-Q

Hitherto, the Dixon test has been used to calculate innovation in a single series without external reference. Generally, the measurement of innovation requires an external reference. The external reference must be in the same sector and industry. Recall that the Dixon test for outlier follows the general structure: Q = *Gap / Range*. In the case of foreign exchange analysis case study, the Dixon test equation has been modified thus: $Q=[x_1-(\bar{x}-2S_x-x_{S-1})]/x_n-x_1$

In order to construct an industry reference, let Q_I equals industry innovation indicator. The 80/20 rule is used under Pareto optimality principle. Under the 80/20 standard, top-10 companies in the industry may be used as the referenced group: $\sum Q_I$ where $N_I = 10$. industry average then is given by:

$$\mu_Q=\frac{1}{N}\sum_{i=1}^{N}Q_i \quad (20)$$

Recall that $Q=\dfrac{x_1-(\bar{x}-2S_x-x_{S-1})}{x_n-x_1}$; therefore, the long-hand equation for the industry average is:

$$\mu_Q=\frac{1}{N}\sum_{i=1}^{N}\left(\frac{Q_1-(\mu_Q-2\sigma_x-Q_{\sigma-1})}{Q_n-Q_1}\right) \quad (20a)$$

Likewise the standard deviation from the industrial average is:

$$\sigma_Q=\sqrt{\frac{1}{N}(Q_i-\mu_I)^2} \quad (21)$$

The threshold of the confidence interval for the industry is:

$$Q_T=\mu_Q\pm 2\sigma_Q \quad (22)$$

Thus, industry innovation occurs at:

$$Q_I=(\mu_Q\pm 2\sigma_Q)+Q_{2\sigma+1} \quad (23)$$

Recall that Q is the individual firm's claimed innovation, with Q_I as the industry reference. The firm's claim may be compared to the industry's threshold interval which is the confidence interval of the probability density distribution defined as $Q_T=\mu_Q\pm 2\sigma_Q$ and may take the test statistic as: $Z=(\bar{x}-\mu)/\sigma_x/\sqrt{n}$ where $\bar{x}$ is Q (firm's mean), μ is μ_Q (industry mean), S_x is σ_Q (industry standard deviation), and n is number of observation inside the firm. By substitution, the test statistic for industry reference follows:

$$Z_Q=\frac{Q-\mu_Q}{\mu_Q/\sqrt{n}} \quad (24)$$

The test hypothesis follows: $H_0: Z_{obs} < Z_{0.95}$; $H_A: Z_{obs} > Z_{0.95}$. The confidence interval starts with an equality of the firm's mean:

$$Z_Q(\sigma_Q/\sqrt{n})+Q_I=Q \quad (25)$$

Rewrite statement (25) in an interval format:

$$Q_I - Z_Q\left(\sigma_Q / \sqrt{n}\right) \le Q \le Q_I + Z_Q\left(\sigma_Q / \sqrt{n}\right) \quad (26)$$

Innovation will occur if the test statistic has a value larger than the standard interval $Z_{obs} > Z_{0.95}$. The point for the evaluation is the next event that lies outside of the interval defined by mean plus two units of standard deviation about the mean: $Q_I = \left(\mu_Q \pm 2\sigma_Q\right) + Q_{2\sigma+1}$.

According to the Bank of Thailand, the economic indicator of Thailand is made from a composite of 15 industries: one agricultural and 14 non-agricultural industries. In 2011, the mean for the growth among the non-agricultural sector is $\bar{x} = 2.80$ with the standard deviation of $SD_x = 4.575$ (Bank of Thailand, 2012: Table 2). The bound within which innovation analysis requires is $\bar{x} + 2SD_x = 2.80 + 2(4.575) = 2.80 + 7.150 = 9.95$. This is a rough estimate. To be precise, the t-equation (2) must be used to estimate the population mean. The population mean under equation (2) is 2.80. Using equation (24), the population standard deviation is 4.54. The recalculated threshold under the 0.95 confidence interval is $\mu + 2\sigma = 0.80 + 2(4.54) = 0.80 + 9.08 = 9.88$. There is a minor difference: 9.88 vs. 9.95. The number 9.88 is used because it is obtained through the test statistic.

In order to be classified as an innovative industry, the growth rate of the industry must be more than 9.88. Among the 14 non-agricultural industries, there is one industry which posted a growth in 2011 higher than 9.88: *financial intermediation* which grew at 13.40% per year. Similarly, an industry that posted an annual growth rate lower than the lower bound of the confidence interval is considered not competitive. The lower bound is $\bar{x} - 2SD_x = 2.80 - 2(4.575) = 2 - 7.15 = -5.15$. An industry that came close to this number in 2011 was the construction industry which posted an annual growth rate of -5.10% that year. Manufacturing's growth rate was -4.30% in the year 2011.

Certain industry is considered a mature market; domestic growth in these industries is difficult. In 2011, education industry had a growth rate of -0.10, followed by mining (-1.80%) and manufacturing (-4.30%). Education in Thailand is a mature industry. The sluggishness in education industry will continue until the introduction of the ASEAN Economic Community (AEC) in 2015 where Thailand will have access to the regional market for its education market expansion (Louangrath, 2013a & 2013b). Success in the education sector in the AEC depends on Thailand's education industry to implement internationalization policy. Between 2003 and 2011, the average growth of Thailand's education industry was $\bar{x} = 3.17$ and the standard deviation is $SD_x = 1.83$. In order to have a competitive advantage, i.e. innovative, in the education industry, the firm (school or university) must show an annual growth rate of more than two units of standard deviation in equation (24). Firstly, use equation (2) to determine the national mean. Under 0.95 confidence rule, the critical value is 1.64. Where the number of industries in the non-agricultural sector is 14, a mean of 3.18 and a standard deviation of 1.83, the estimated population (national) mean is $\mu = 2.22$. Secondly, use equation (24) to determine the threshold point beyond which innovation lies in the national market. Use equation (24) to solve for the population (national) standard deviation; the calculation yields that $\sigma = 2.58$. The threshold point is $\mu + 2\sigma = 2.22 + 2(2.58) = 2.22 + 5.16 = 7.36$. This means that in order to be competitive, a school must show an annual growth of more than 7.36%.

Table 3 Growth rate of Domestic Production in Major Non-Agricultural Sectors in Thailand: FY 2003-2011

Sectors	2003	2004	2005	2006	2007	2008	2009	2010	2011
A	9.10	2.70	12.10	5.70	4.00	4.50	0.10	5.40	**-1.80**
B	10.20	7.50	4.20	5.60	7.20	2.02	**-2.90**	11.70	**-4.30**
C	4.30	7.50	5.00	3.70	5.50	5.30	3.80	7.00	0.40
D	3.00	8.10	10.00	1.20	3.90	**-5.50**	3.70	9.60	**-5.10**
E	4.80	5.00	2.00	5.20	7.00	**-0.20**	**-4.80**	12.00	1.80
F	**-0.80**	8.50	0.70	9.50	3.80	4.00	**-1.40**	8.40	7.40
G	2.00	11.20	4.80	8.70	8.50	1.40	**-0.20**	5.90	2.70
H	11.50	6.40	5.50	**-0.50**	3.10	1.20	6.60	3.60	13.40
I	11.20	10.70	7.40	8.00	3.10	0.90	**-4.40**	7.70	3.50
J	2.70	0.20	5.10	2.90	7.60	3.20	5.00	2.60	0.10
K	3.80	5.20	4.50	3.30	4.40	0.60	2.70	4.20	**-0.10**
L	1.40	9.30	5.00	4.40	4.60	1.50	0.60	**-0.10**	1.20
M	6.90	12.10	4.50	**-2.70**	**-9.50**	**-0.20**	**-3.70**	7.40	8.60
N	2.90	3.60	0.20	**-2.30**	2.60	1.80	1.90	**-1.20**	1.20

A (mining); B (manufacturing); C (electricity, gas and water supply); D (construction); E (construction); F (wholesale and retail trade, repair of vehicles and personal and household trade); G (hotels and restaurants); H (transport, storage and communication); I (financial intermediation); J (real estate, renting and business activities); K (public administration and defense, compulsory security); L (education); M (other community, social and personal service activities); and N (private households with employed persons).

Source: Bank of Thailand (2012)

This research has several implications: (i) in innovation analysis has both qualitative and quantitative domain. (ii) There is a distinction between invention and innovation. Invention involves the introduction of new knowledge. Innovation involves the new application of existing knowledge. This distinction helps the public to avoid confusion. (iii) As a quantitative research, this paper provides quantitative tools for verifying the presence of innovation. As an analytical tool to aid management decisions, the quantitative approach introduced by this paper may be helpful to researcher and practitioners in the field.

Conclusion

Innovation is a quantitative analysis and is mathematically defined. In order to conclude that innovation exists, there are series of hypothesis testing that the claimant must overcome. These tests are grounded in confidence interval analysis and test statistic. Quantitative analysis of innovation is beneficial because it allows managers and researchers to measure the changes and improvement of the firm's productivity level. This quantitative approach is a tool for obtaining empirical data to verify whether innovation has been achieved. The term "incremental change" is often misused in innovation discussion because the term is used outside of its quantitative context. Incremental change refers to the point estimate from which the change is referenced is two units of standard deviation from the mean. Innovation may not be confined to an intra-organizational analysis. An increase in output within the organization may be attributed to the better use of resources, not a true innovation. In order to verify that the change in output is due to innovation, the output must be benchmarked to that of the industry peers. If the output exceeds the industry's average, and that difference is statistically significant, then it may be said that *a prima facie* innovation exists. This paper uses $\pm\alpha$ under the probability distribution density curve as the reference point to determine whether innovation exists. This paper also points out the difference between innovation and invention. Invention refers to the new or improved discovery. Innovation is a subset of invention. There cannot be innovation without invention. When innovation works to improve the existing discovery to a point that the existing discovery changes completely and no longer resembles its original state, the change ceases to be innovation and is classified as a new invention.

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