

In Search of An Alternative Technological Diversification Measure to the HHI-based Index

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1. Introduction

Technological diversification has recently received scholarly attention in the field of technological innovation management. Garcia-Vega (2006) considered cross-fertilization between different technological areas could reduce the lock-in effect in low profitable technologies. Breschi et al(2003) suggested being technologically diversified, i.e. being able to master and use different technologies, may represent a necessary requisite to survive and grow as an innovator. In his empirical examination, Miller(2006) specified the contingencies and demonstrated how technological diversity could positively relate to firm performance.

As more studies emerge in further discussing the antecedents and consequences of technological diversification, it becomes vital that we have a reliable measure in gauging the degree of technological diversification. While HHI-based index has conventionally been adopted in the current stream of literature (Jaffe 1986; Watanabe et. Al., 2004; Jaffe 2005; Garcia-Vega 2006; Jang et. al, 2008; Chen and Chang, 2009), some concerns over HHI-based index has also been raised. Hall (2005) first pointed out the index will generally be biased downward when the number of counts is small, and suggested a simple correction for the bias. Chen, Jang and Wen, 2010 further elaborated and empirically tested such scale bias against small-and medium-sized firms.

In this study, we propose an alternative measure that could account for the potential bias of HHI-based index due to its statistical properties. A few notable features of our proposed measure, Variance-Mean Ratio (VMR) in the present study include: 1) it is more sensitive than HHI-based index in capturing the differences in diversity level, 2) it distinguishes the conflated effects of scale, scope and dispersion, and 3) it could account for the effect of total amount of technology, and thereby measure out the type or the variety of technology.

In the following session of this paper, we illustrate in session 2 the underpinning and economics implication of the HHI-index, in comparison to its extended application to management studies. In session 3 we decompose our proposed VMR index into three conceptually independent yet quantitatively related factors, followed by session 4, where we show partial effects of these factors and provide hypothetical examples to empirically examine how VMR measure would apply comparing to HHI-index. Our finding that VMR is a more sensitive and intuitive measure is further supported in session 5 by the patent data of two technology driven companies. Concluding remarks in session 6 point out the utilities of VMR for future studies.

2. Measuring Market Concentration vs Technological Diversification

HHI was first derived to measure market concentration at the industry level, and subsequently applied to measure technological diversification at firm level. We briefly discuss in the following sections these different usages in the literature, and the potential application constraints we noted.

2.1 HHI as a measure for market concentration

Herfindahl-Hirschman Index, or HHI, is a commonly used measure to capture the market concentration of a particular industry. After its introduction by economist Herfindal (1950) and Hirschman(1945), researchers have considered such index, by computing the specific market shares of individual firms and aggregating to a composite figure, could well assess the structure of a concerned industry (Cowling & Waterson, 1976; Clarke & Davies, 1982). Because of its explicit nature, bounded properties, ease of understanding and intuitive appeal, earlier researchers gave the edge to HHI in comparing to other similar measures, such as Concentration Ratio (CR) and entropy (Jacquemin and Berry, 1979; Stigler, 1983). Since 1980, HHI-based index has been more widely applied among economists. For example, in assessing whether an enterprise has violated anti-trust provisions, governmental agencies such as the U.S. Department of Justice and the Federal Trade Commission, set up benchmark scales using HHI¹; Thoening and Verdier (2003) took HHI to reflect industrial concentration when discussing globalization issues. It could be rightfully claimed that HHI is still one of the important indicators² to portray concentration level of different markets and industries.

2.2 HHI as a measure for technological diversification

In addition to being used to assess industry concentration, its application has been widen to other areas. Jaffe (1986) first utilized HHI to examine firms' technology related issues, by using the root of HHI as a proxy to gauge technological spillover effect. Following, other researchers applied HHI to measure technological concentration, and based on the measure, discussed how technological

¹ U.S. Department of Justice (1997) › Chapter 1.14 depicts that 1) when $HHI < 0.1$, the industry is considered not-concentrated, 2) when the value is ranged between $0.10-0.18$, the industry is considered semi-concentrated, 3) when $HHI > 0.18$, the industry is considered highly concentrated.

² Other concentration measures commonly adopted in different disciplines include: Blau index in sociology, Shannon index in ecology, and Entropy in physics.

concentration of a firm would affect productivity, spillover and various other economic variables (Trajtenberg, Henderson, & Jaffe, 1997; Hall, Jaffe, & Trajtenber, 2001; Jaffe & Lerner, 2001 ; Hu & Jaffe, 2003).

Further application has been extended to the area of Technological Innovation Management (TIM). Management scholars have been keen to the concept of technology diversification, and they took the inverse form of HHI to obtain an operational measure on the degree of diversification level, such that

$$\text{Diversification} = 1\text{-HHI}$$

Watanabe, Matsumoto & Hur (2004) used HHI to measure firms' technological performance, and related that to financial performance and the strategic issues. In analyzing how technology specialization might affect innovation performance, Garcia-Vega (2006) used HHI to capture the range of specialization-diversification. Chen & Chang (2009) in analyzing patent performance of pharmaceutical firms and its relation to firms' market values, used HHI to distinguish the patterns of technology ranges as shown from patents applied. Chen, Jang & Wen (2010) suggested that in using HHI to measure firms' technology diversification, researchers should pay attention to effect of patent scale and patent scope.

In this paper, we use HHI to represent the measure for concentration and diversification (1-HHI) interchangeably. Since the extant management stream of research works is patent-based, we also use take patent and technology interchangeably.

2.3 The potential application constraint in adopting HHI

The general form of HHI-index could be expressed as followed:

$$\text{HHI}_i = \sum_{n=1}^N s_{in}^2 \quad (1)$$

It reaches a value of unity when the state is highly concentrated.

To measure market concentration, N stands for the number range of firms within the industry, while S_{in} is the market share of each individual firm in the industry. On the other hand, to measure technology concentration, N represents the range of technological areas of the focal firm, while S_{in} is a ratio, patent count in technological area n to the entire patent set owned by the focal firm. Table 1 shows the

comparison.

Table 1 : HHI in measuring market concentration vs technology concentration

	Market Concentration	Technology Concentration
i	Industry	Firm
N	# of firm	# of technology area
S_{in}	Market share of firm n in the industry.	Ratio of patent count in area n to the entire patent stock of the firm.

Researchers have noticed application constraints in adopting HHI. With mathematical models, Cowling & Waterson (1976) and also Clarke & Davies (1982) noticed when examining market concentrations across different industries, there would be bias in directly using HHI, if the supply elasticity of these industries differs.

Therefore, it's more often for HHI to be used to analyze a single industry, to assess the state of being. For examples, Forcarelli & Panetta (2003) used HHI to examine the change of market concentration in the banking industry before and after merger and acquisition events. Mayer & Sinai (2003) also used HHI to evaluate market concentration in the airline industry and its effect on service quality.

When HHI is adopted for measuring technology diversification (the inverse form of concentration), researchers most likely use the index for cross-firm analysis. To control for firm heterogeneity, researchers have taken different external variables, for examples, Watanabe, et al.(2004) incorporated economic condition, time trend and scale factor when using HHI to analyze Japanese firms' technology diversification strategy. Similarly, in comparing firms' diversification as depicted by HHI, Garcia-Vega (2006) took country and sector variables for control.

However, researchers have not accounted for individual firm's technology stock (i.e. patent count) which could ultimately affect the range of its technology areas (i.e. technology class count). In the conventional market concentration calculation, there is no such complication in parallel. The current use of HHI-based index in assessing a firm's technology diversification is based on the relative weight of different technology areas. We feel this approach would overlook some essential elements in making cross-firm comparison. We propose the following alternative ratio in an attempt to modify the current HHI to enhance measurement effectiveness in capturing technology diversification.

3. An Alternative to HHI: Variance-Mean Ratio

Variance-Mean Ratio (VMR) is a measure of dispersion showing the amount of variation or spread in the values of a variable. In statistics, it is also called the Fano Factor, used to measure the noise-to-signal in a random process (Fano, 1947). VMR has been used to characterize the distribution of events or objects whether in time or space, and its application has for example been used in biology to measure the dispersion of how organisms cluster (Bottomly et al, 2005; Magurran and Henderson, 2003). Statisticians adopt the fundamental property of the Poisson distribution that the distribution is random with the variance and the mean are equal, and compare VMR values of different distributions to VMR of Poisson distribution ($\text{VMR}_{\text{poisson}}=1$) to assess the levels of dispersion in different distributions. Under the Poisson distribution, the VMR is about 1.0; larger values ($\text{VMR} > 1.0$) correspond to the existence of over-dispersed pattern, while smaller values ($\text{VMR} < 1.0$) correspond to a more-uniform or even distribution.

3.1 Equation for VMR

VMR could be expressed as followed :

$$\text{VMR}_i = \frac{\sum_{n=1}^{N_i} \left(A_{in} - \frac{A_i}{N_i} \right)^2}{\frac{A_i}{N_i}}, \quad (2)$$

A_i is the total patent count of firm i ; N_i is the total patent technology area count of firm i ; A_{in} is the patent count of technology n of firm i ; A_i / N_i is the average patent count of each area.

In this paper, VMR conceptualizes the level of technology concentration by capturing the dispersion of average patent count of each patent class. VMR always has a positive sign. The higher magnitude VMR is, the more concentrated the firm's patent portfolio, i.e. technology is concentrated in particular areas. In contrast, when the ratio is closed to zero, it applies the firm is more widely diversified as shown in the spread across different patent classes.

If we separate out total patent count A_i from the above equation 2, and reduce the fraction for both the numerator and the denominator, we would obtain the following:

$$VMR_i = A_i \times \sum_{n=1}^{N_i} \left(\frac{A_{in}}{A_i} - \frac{1}{N_i} \right)^2 \quad (3)$$

We further define $s_{in} = \frac{A_{in}}{MA_i}$ (jc note: M should be deleted) which represents the patent count in area n in proportion to total patent count of firm i . Bring S_{in} into equation 3, we have the following:

$$VMR_i = A_i \times \sum_{n=1}^{N_i} \left(s_{in} - \frac{1}{N_i} \right)^2 \quad (4)$$

3.2 Decomposition for VMR

Variance provides a quantitative depiction for the degree of dispersion of a distribution. We could measure the variance of a firm's relative weight in different technology areas that could lead us to understand the dispersion of patent portfolio in the technology space. With that in mind, we further define:

$$D_i = \frac{\sum_{n=1}^{N_i} (s_{in} - \frac{1}{N_i})^2}{N_i}$$

D_i represents variance of patent shares of different technology classes, in other words, the degree of dispersion of S_i . Bring this $D_i \times N_i = \sum_{n=1}^{N_i} \left(s_{in} - \frac{1}{N_i} \right)^2$ into equation 4, we have the following:

$$VMR_i = A_i N_i D_i \quad (5)$$

where , $A_i > 0$, $N_i > 0$, $D_i \geq 0$.

After the above substitution, from equation 5 we identify that VMR of a firm could be decomposed to three elements: total patent count (A), total technology class count (N), and the variance of patent proportion pertaining to different technology areas (D). Each element is further elaborated as followed:

Total Patent Count (A): It is the aggregate amount of patent owned by a firm, representing the technology scale, or the cumulative results of firm's R&D efforts.

Firms with different technology scale levels might differ significantly in whether to concentrate or diversify in their technology landscape.

Technology Class Count (N): It is the number of patent classes owned by a firm. In general, the more technology classes a firm possess, the wider its technology scope, and researchers has taken directly the patent class count as a measure for diversification (Patel & Pavitt, 1997). While patent classes count illustrates the range of technology, it does not capture the extent; in other words, each class is not necessarily equally weighted in the patent portfolio. Therefore, aside from the class count, how it is distributed is also relevant in understanding the scope coverage.

Variance of the Patent Ratio Pertaining to Different Technology Areas (D): It takes the ratios of the patent count of a particular technology area to the total patent count, and computes the variance among the ratios. This factor is to capture technology dispersion, by measuring variance of patent share pertaining to different technology classes³. Because D is derived by ratios, it is a unit-free number that would not affected by technology scale. In statistics, variance represents the degree of dispersion of observations; therefore, when D value is high, technology dispersion is big, implying the differences among patent ratios of various technology categories are big. Conversely, when D value is small, it represents the differences among different technology categories are small, and consequently the technology dispersion is small. This factor would provide researchers a holistic picture on how patents are distributed within the portfolio, and therefore, yield an important aspect of technology diversification.

3.3 Linkage between VMR and HHI

If we expand the elements in equation 5, we could obtain the following:

$$VMR_i = A_i \left(\sum_{n=1}^N s_{in}^2 - \frac{1}{N_i} \right) \quad (6)$$

Following $HHI_i = \sum_{n=1}^N s_{in}^2$ from formula 1, we could re-arrange equation 6 as followed:

³Theoretically, as long as N is positive, VMR could be defined. However, there is a special case when $N=1$, in that situation, $D=0$, $VMR=0$ which indicates technology is evenly distributed, as all the patents are equally located in one technology area. We suggest to require $N>2$, when using VMR.

$$VMR_i = A_i \left(HHI_i - \frac{1}{N_i} \right) \quad (7)$$

From the above equation 7, we connect VMR and HHI. VMR could be regarded as HHI with adjustments, particularly being amplified by the count of patents (A).

Furthermore, according to the decomposition provided by Brown, Warren-Boulton (1988) and Warren-Boulton (1990), HHI could be decomposed as:

$$HHI_i = \frac{1}{N_i} + N_i D_i, \quad (8)$$

where N_i is the count of different categories, and $D_i = \text{Var}(S_{in}) D_i = \frac{\sum_{n=1}^{N_i} (S_{in} - \frac{1}{N_i})^2}{N_i}$,

same definition as that in formula 5.

VMR and HHI differ in two ways:

- (1) VMR specifically accounts for technology stock into the consideration of diversification measurement. The amount of total patent counts reflects the scale and evidently the technological positioning of the firm, and with the inclusion of this factor, VMR could provide a more fine-tuned measuring than HHI.
- (2) The functional form of HHI could not clearly distinguish the effect of technology scope and technology dispersion. In comparison, VMR reveals three embedded elements that separately and jointly contribute to a firm's diversification level. These decomposed elements: technology scale, scope and dispersion, could provide us an intuitive insight in interpreting the computed figure, while researchers often have difficult times in finding any implication from HHI asides from the reading of its composite magnitude.

4. Partial Effect of VMR Index

To understand how VMR would behavior with the change of each composing elements, we took partial derivative on patent scale (A) and patent scope (N) to observe how they would affect technology concentration (VMR).

To simplify discussion⁴, we assume there is an interactive effect between A and N, namely, $N=N(A)$ and $A=A(N)$, and D will simultaneously be affected by A and N, i.e., $D=D(A,N)$. In other words, scale and scope could potentially affect each other, and dispersion is subsequently affected by both scale and scope.

4.1 The effect of Technology Scale

When the scale increases, it could lead concentration level either increase or decrease. If the increase of patents whose technology content fall upon few selected areas, then it would lead to an uneven distribution, increasing concentration level; in the contrast, if the increase of patent is related to those areas with very small prior count (or to brand new area), this would reduce the “unevenness” between areas, and thus reduce the concentration level.

Take formula 5 and formula 8 with partial effect on A, we have :

$$\frac{\partial VMR}{\partial A} = ND + AD \frac{\partial N}{\partial A} + AN \frac{\partial D}{\partial A} + AN \frac{\partial D}{\partial N} \frac{\partial N}{\partial A} \quad (9)$$

$$\frac{\partial HHI}{\partial A} = -\frac{1}{N^2} \frac{\partial N}{\partial A} + D \frac{\partial N}{\partial A} + N \frac{\partial D}{\partial A} + N \frac{\partial D}{\partial N} \frac{\partial N}{\partial A} \quad (10)$$

We could further take equation 9 and revise δVMR 、 δN 、 δD 、 δA to percentage change such as, $\delta VMR/VMR$, we have:

$$\frac{\delta VMR/VMR}{\delta A/A} = 1 + \frac{\delta N/N}{\delta A/A} + \frac{\delta D/D}{\delta A/A} + \frac{\delta D/D}{\delta N/N} \frac{\delta N/N}{\delta A/A} \quad (9.1)$$

$$\frac{\delta HHI/HHI}{\delta A/A} = -\frac{1}{N^2 D} \frac{\delta N/N}{\delta A/A} + \frac{\delta N/N}{\delta A/A} + \frac{\delta D/D}{\delta A/A} + \frac{\delta D/D}{\delta N/N} \frac{\delta N/N}{\delta A/A} \quad (10.1)$$

Because $\frac{\delta VMR/VMR}{\delta A/A}$ could be regarded as the change rate between different variables, and could be expressed as elasticity, which we would replace by variable ϵ_{VMR_A} , and similarly, ϵ_{NA} 、 ϵ_{DN} 、 ϵ_{DA} . We could interpret ϵ_{VMR_A} as the elasticity between Concentration (VMR) and Scale (A) ; ϵ_{NA} as the elasticity between scope (N)

⁴ Mathematically, $A \cdot N \cdot D$ could affect each other, so the complete assumption should be : $A=A(N, D)$, $N = N(A, D)$, $D = D(A, N)$. In this paper, we simplify the situation.

and scale (A); ϵ_{DN} as the elasticity between scope (N) and dispersion (D) ; ϵ_{DA} as the elasticity between dispersion (D) and scale (A). The variable replacement leads to the following:

$$\epsilon_{VMR_A} = 1 + \epsilon_{NA} + \epsilon_{DA} + \epsilon_{DN}\epsilon_{NA} \quad (9.2)$$

From formula (9.2), we could observe, whether scale A increase or decrease VMR depending on the size of ϵ_{NA} , ϵ_{DN} , ϵ_{DA} . If the aggregate of ϵ_{NA} , ϵ_{DN} , ϵ_{DA} leads the right side of equation (9.2) less than zero, then VMR will decrease with increase of patent count (A); with the aggregate elasticity a positive count on the ride of equation, the reverse holds, that VMR will increase with the increase of patent count.

If total patent count (A) increases, but technology area count (N) does not, this would indicate $\epsilon_{NA} = 0$. In such case, the change of VMR depends on the magnitude of $1+\epsilon_{DA}$, while in the same case the change of HHI (see appendix for partial effect analysis on HHI) would only be ϵ_{DA} . This would illustrate that when $\epsilon_{DA} > 0$, VMR would be more sensitive than HHI.

There are also other differences between VMR and HHI. From equation (9.2), it appears for increasing patent count (A) with a VMR decrease, the sum on the right hand side should be less than zero, or $\epsilon_{NA} + \epsilon_{DA} + \epsilon_{DN}\epsilon_{NA} < -1$. In comparison, to achieve effect, HHI would require $\epsilon_{NA} + \epsilon_{DA} + \epsilon_{DN}\epsilon_{NA} < \frac{1}{N^2D}\epsilon_{NA}$ (refer to equation 10.2 in appendix). Although with the increase of technology scope (N) , the bar of HHI in reflecting changes would be higher, it is in general, less strict than VMR.

Scale and scope would more likely to have a positive relation, i.e., in most cases,

$\epsilon_{NA} > 0$. When $\epsilon_{NA} > 0$, $\frac{1}{N^2D}\epsilon_{NA} > 0 > -1 > \epsilon_{NA} + \epsilon_{DA} + \epsilon_{DN}\epsilon_{NA}$. This further illustrates that in the case of scale change, or patent count (A) increases, HHI is more easy linear than VMR in recognizing the change in the level of concentration / diversification.

4.2 The effect of Technology Scope

A good diversification index should well capture the change in scope. In general,

with the increase of technology area (N), the concentration level would decrease. With mathematical rationale, let's see below how the logic works.

If we take prior formula 7 and 8, and perform partial derivative over N, we obtain:

$$\frac{\partial VMR}{\partial N} = ND \frac{\partial A}{\partial N} + AD + AN \frac{\partial D}{\partial N} + AN \frac{\partial D}{\partial A} \frac{\partial A}{\partial N} \quad (11)$$

$$\frac{\partial HHI}{\partial N} = -\frac{1}{N^2} + D + N \frac{\partial D}{\partial N} + N \frac{\partial D}{\partial A} \frac{\partial A}{\partial N} \quad (12)$$

Following the notation change from δVMR 、 δHHI 、 δN 、 δD 、 δA to percentage change of $\delta VMR/VMR$ 、 $\delta HHI/HHI$ 、 $\delta N/N$ 、 $\delta D/D$ 、 $\delta A/A$ ，formula (11.1) 、(12.1) are expressed as followed:

$$\frac{\partial VMR/VMR}{\partial N/N} = \frac{\partial A/A}{\partial N/N} + 1 + \frac{\partial D/D}{\partial N/N} + \frac{\partial D/D}{\partial A/A} \frac{\partial A/A}{\partial N/N} \quad (11.1)$$

$$\frac{\partial HHI/HHI}{\partial N/N} = -\frac{1}{N^2 D} + 1 + \frac{\partial D/D}{\partial N/N} + \frac{\partial D/D}{\partial A/A} \frac{\partial A/A}{\partial N/N} \quad (12.1)$$

Adopting the same rationale that such percentage change could be regarded as elasticity between variables, We replace ϵ_{VMR_N} 、 ϵ_{HHI_N} 、 ϵ_{AN} 、 ϵ_{DN} 、 ϵ_{DA} for

$\frac{\partial VMR/VMR}{\partial N/N}$ 、 $\frac{\partial HHI/HHI}{\partial N/N}$ 、 $\frac{\partial A/A}{\partial N/N}$ 、 $\frac{\partial D/D}{\partial N/N}$ 、 $\frac{\partial D/D}{\partial A/A}$ is the elasticity between VMR and patent scope N while ϵ_{HHI_N} is the elasticity between HHI and patent scope N, and likewise. The replaced notation leads to:

$$\epsilon_{VMR_N} = \epsilon_{AN} + 1 + \epsilon_{DN} + \epsilon_{DA} \epsilon_{AN} \quad (11.2)$$

$$\epsilon_{HHI_N} = -\frac{1}{N^2 D} + 1 + \epsilon_{DN} + \epsilon_{DA} \epsilon_{AN} \quad (12.2)$$

Through formula (11.2) and (12.2), we could examine how the increase of technology scope affects technology concentration as measured by VMR and HHI. It appears to what extent would VMR and HHI decrease with the increase of N would

depend on the elasticity of ϵ_{AN} , ϵ_{DN} , ϵ_{DA} . If their aggregates cause the right side of the equation (11.2) - (12.2) less than zero, then VMR and HHI would decrease with increase of N; otherwise, VMR and HHI would increase with N increase.

Hypothetically, if technology scope (N) increases without the increase of scale (A), this would indicate $\epsilon_{AN} = 0$. In this case, the elasticity of VMR to N, ϵ_{VMR_N} , depends only on elasticity of dispersion D to scope N, ϵ_{DN} ; in comparison, the elasticity of HHI to N, ϵ_{HHI_N} would have an added effect. $-\frac{1}{N^2D}$ Because $-\frac{1}{N^2D}$ is always negative, if technology class count (N) increase, and the variance of patent share of difference class (D) decrease, i.e. ϵ_{DN} is negative, HHI in comparing to VMR would be more prone to show the decrease of concentration level. With the increase of technology scope (N), the difference between VMR and HHI would gradually be smaller. This is to say when firms with bigger technology scope, the resulting VMR and HHI would converge. But, when firms do not have wide enough range of technology areas, HHI tends to be lenient. Therefore, VMR in general is more strict and consistent in reflecting the change of concentration level with the change of technology scope.

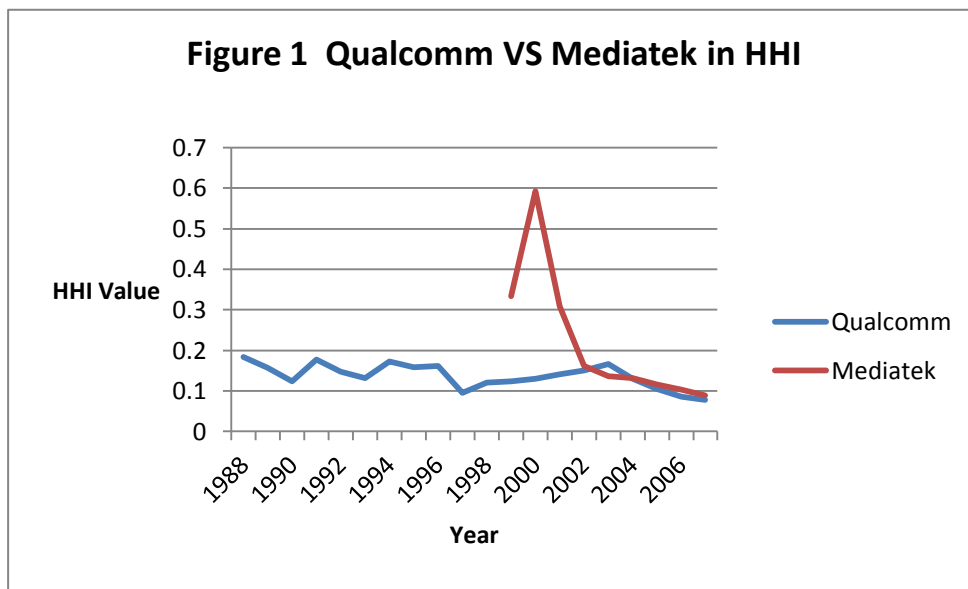
In sum, through the analysis of partial derivatives, we have a glimpse of how technology scale and scope would affect the concentration level. We note that in identifying the magnitude and direction the change drivers, both patent count (A) and class count (N), have over the concerned concentration level, VMR seems to provide a more fine-tuned measure.

5. Case Application of VMR vs HHI

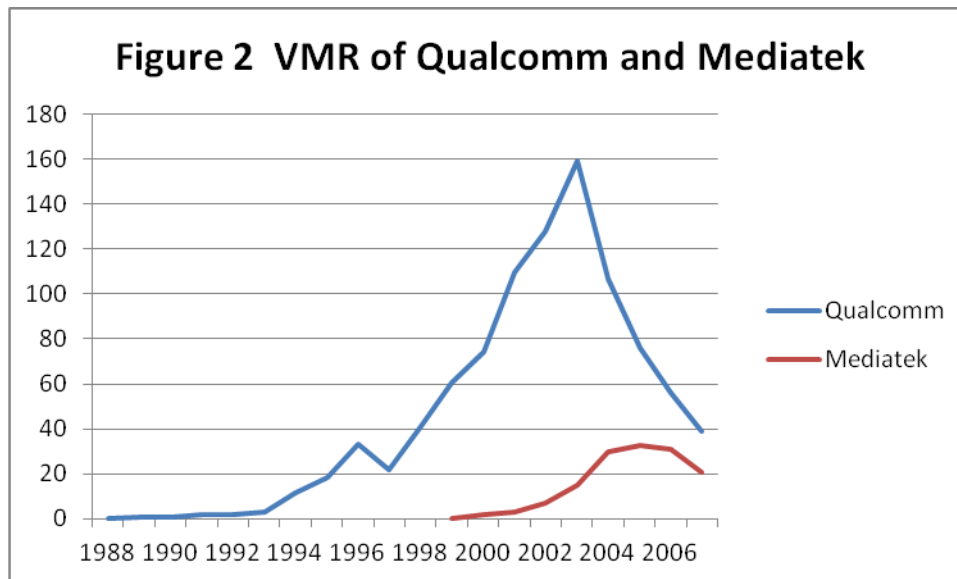
We selected two integrated circuit (IC) design firms as case companies to illustrate how VMR and HHI could be applied. IC design, as a sector within the semiconductor industry, is technology-intensive, and to stand out in this market, firms' repertoire of knowledge (or their intangible R&D capabilities) is the primary competitive advantage. The average RDI (Research and Development Intensity, defined as the ratio between R&D expenses and net revenues) is close to 30%. The levels of R&D investment and patent penetration for IC design firms are significantly higher than those of other industries.

The two companies selected are Qualcomm (based in the U.S.) and Mediatek

(based in Taiwan⁵). We collected patent applied to USPTO by Qualcomm, from 1986 to 2010, and that by Mediatek, from 1997 to 2010. In considering the patent data truncation issue, we utilized in our analysis the data up to year 2007. In addition, because of the properties of technological accumulation and depreciation and the fluctuation of annual patent data (Hall, et al., 2005), we adopted a three-year time period. For example, the index value calculated for Qualcomm in 1999 is based on patent data from 1997 to 1999. The definition of patent technological classes is based on the 4-digit International Patent Classification code. With these procedures, we calculated both HHI and VRM for the two firms on an annual basis over the period 1988-2007. Figure 1 shows HHIs of the two respective companies, while Figure 2 shows their VMR over the same period of time.



⁵ Taiwan has a global market share of 24% in 2007, ranking second only to the United States (ITRI, 2008)



In the case of Qualcomm, the firm had 18 patents in 1990 with HHI at 0.1235, and the patent count reached 986 with HHI at 0.1298. From Figure 1, over the period 1988-2007, HHI was ranged narrowly between 0.1 and 0.2. If we take HHI as the proxy for technology concentration or diversification, it would appear technological strategy has remained relatively steady, that Qualcomm maintained a semi-concentrated portfolio. From Figure 2, however, it is apparent that VMR had changed significantly over the years. It had an upward trend, indicating an increase in the concentration level, and only till 2003, had diversification become more evident.

Mediatek is a smaller firm comparing to Qualcomm, differently significantly in patent scale and patent scope. Take year 2002 as an example, Qualcomm had 994 patents, ranging over 46 technology classes, while Mediatek owned 76 patents pertaining to 15 technology classes. Their computed HHI in 2002 indicate the value of 0.1504 and 0.1616 respectively. Yet, from Figure 2, these two were marked differently: the VMR for Qualcomm is 127 and Mediatek 7.2.

The simplicity of HHI being a bounded number between 0 and 1 also at the same time, limits its extended application to conduct cross firm comparison. From the mathematic deduction in section 3, HHI incorporates a firm's patent class count and variance of patent share over different classes, in other words, technology scope (N) and technology dispersion (D), without the consideration of patent count, or technology scale (A). Therefore, to use it as a base to assess concentration level, further complementary information might be needed to provide a meaningful interpretation. In that aspect, VMR demonstrates a more comprehensive property to firm-wise comparison.

6. Conclusion

Because of the application constraint in the conventional HHI-based measure to assess diversification level across different firms, in this study, we propose an alternative measure, VMR to mitigate the potential bias. We consider there are three factors that contribute conceptually and mathematically to a firm's technological level of diversification (or concentration), namely technology scale (A), technology scope (N), and technology dispersion (D). These three factors are independent in concepts, but could also relate to each other significantly. Via mathematical equations, we could detect how VMR and HHI differ. It appears VMR, besides incorporating an added factor of scale, offers a more strict assessment on the level change. When the scale is big, such difference is less noticeable; however, when scale is small, VMR is more sensitive in capturing how the change in scope would affect the ultimate diversification level. This has a particular strong managerial implication when studying entrepreneurial firms or industry. Management scholars ought to reconsider the appropriate usage of HHI and its orientation raised from the economy discipline. In the previous literature, people often use the following model: $Y = f(\text{HHI}, \dots)$ to discuss how the technological diversification on the impact of firm's performance such as its profitability, revenue etc. In the future application of VMR's, researchers could test the alternative $Y = f(\text{VMR}, \dots)$. Further fine-graining could also incorporate $Y = f(\text{Log } A, \text{Log } N, \text{Log } D, \dots)$ to separate out the individual effect, or the relative rate of diversification component change upon researchers' concerned performance outcome. To conduct cross firm or cross time analysis, conflated factors ought to be peeled out, to come out meaningful readings on subsequent performance outcome.

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