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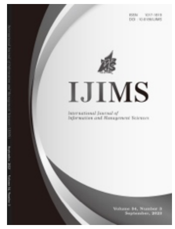

# The Penrose Effect in a Global Semiconductor Industry: The Piecewise Linear Growth Models

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**Keywords**

Penrose Effect; Hierarchical Linear Model; Complementarity.

**Abstract**

This study builds upon existing literature regarding firm growth theory. It explores three main research questions: (1) Does the Penrose curve exist? (2) If so, do firms make different choices between submarkets in different periods? Furthermore, (3) Does the degree of complementarity between submarkets affect firm performance? Analysis of 163 semiconductor firms across 52 submarkets reveals several key findings. Firstly, firms experiencing rapid expansion in one period may encounter managerial experience challenges, leading to stagnation in growth in subsequent periods. Secondly, rapid growth in one period may be achieved by strengthening the position of the top two submarkets, but further expansion may not be sustainable in subsequent periods. These findings align with prior research. Lastly, firms can sustain growth by strengthening the positions of the first and second submarkets in one period and then focusing on one relatively unfamiliar submarket in the next period.

## 1. Introduction

Even though researching a company's growth is essential for both scholars and professionals (Mahoney & Pandian, 1992), previous studies on multiple-market interactions failed to consider how managerial expertise could affect the impact of mutual restraint on company performance (Pilloff, 1999; Gimeno, 1999; Haveman & Nonnemaker, 2000; Greve, 2008). Additionally, research on company growth has neglected to explore how market selection behavior might influence the effect of complementarity among submarkets on company performance.

In the behavioral theory of the firm, the foundation lies in understanding how economic actors navigate through highly uncertain and noisy aggregate data (Simon, 1982). Managers are expected to make more accurate decisions than relying solely on historical experiences when dealing with the behavior of firms in various markets. Thus, exploring how two key assumptions—bounded rationality and managerial capabilities—affect firm performance within bounded rationality is essential.

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When managers make decisions such as investments or selecting segments or submarkets for growth, their managerial capabilities may limit their choices (Hay & Morris, 1991). Firm growth does not happen automatically, so managerial experience can help decision-makers allocate resources more effectively to the segments or submarkets with the most profit potential. In bounded rationality, when deciding on firm growth strategies, one option could be to focus on the top three segments or submarkets that align with managers' incentives to enhance firm performance.

In this study, we leverage the insights from the theory of firm growth under the historical context assumption (Penrose, 1959) to explore how the choice behavior regarding the top three submarkets, within the framework of bounded rationality theory (Simon, 1982), influences firm performance across various growth trajectories.

We aim to compare growth rates across two distinct period trajectories. Possible research questions include: (1) "Does the Penrose curve exist?"; (2) "If the Penrose curve does exist, do firms make different choices between submarkets for growth in the two periods?"; (3) "Does the degree of complementarity between submarkets influence firm performance?"

Our analysis of 163 semiconductor firms across 52 submarkets reveals distinct growth trajectories. We found that the average market share growth is positively correlated with the expansion of the firm's share in the top three submarkets during the first period but negatively correlated during the second period. Additionally, our analysis indicates that the complementarity among the shares of the top three submarkets is negatively correlated with the firm's performance.

## 2. Theoretical Background and Hypotheses

The growth of firms' market share can lead to enhanced profit margins, influencing managers' decisions across markets within a firm (Arrfelt et al., 2013). However, firms striving to innovate quickly enough to gain time-based advantages may face deterrent effects, such as faster market share growth (Polidoro, 2012). Despite this, it incentivizes further expansion as managers seek to utilize their growing experience and resources.

The theoretical foundation of the resource-based view can be traced back to Penrose's work on the firm's growth (1959). She argued that firms organize their resources and externally acquired resources to produce and sell each segment profitably. This theory of firm growth focuses on examining how firms' productive opportunities change over time. However, these opportunities are limited by the extent to which a firm identifies expansion opportunities, is willing to pursue them, or can respond to them (Penrose, 1959).

As a result, a firm that experiences rapid expansion in one period is likely to encounter managerial challenges, potentially leading to stagnation in growth during subsequent periods. This phenomenon has been referred to as the "Penrose effect" in the literature (Hay & Morris, 1991; Shen, 1970) and has been investigated in numerous studies (Boynton, 2024; Chen et al., 2019; Gander, 1991; Johnson et al., 2000; Orser et al., 2000; Shane, 1996; Shen, 1970; Thompson, 1994).

**H1: The average market share growth is an increment to the initial status in the first period and decrement in the second period.**

As managers allocate resources across various submarkets, more managerial resources are required, such as coordinating the integration of design and manufacturing, which increases diversity. For instance, Intel's growth in the two submarkets of wafer manufacturing and chip design has been constrained, leading to the Penrose effect. To address such submarket growth limitations and the Penrose effect, scholar Lazonick (2024) advocates for fixed-cost investments in the productive capacity of company employees to promote organizational learning. Scholar Joffe (2024) believes that this learning, driven by dynamism and managerial capabilities, will lead to more success, as success breeds success. This involves managers proactively taking action and successfully implementing manager-specific capabilities, such as creativity in fundraising (Penrose, 1959, p. 34), with these actions being influenced by path dependence (Penrose, 1959, pp. 173-174), gradually expanding the company's market share or extending its geographical reach in foreign markets (Kano, 2023).

Such matching capabilities and governance abilities (von Nitzsch et al., 2024) should help Intel overcome the growth limitations in the two submarkets of wafer manufacturing and chip design, leading to increases in sales, market share, employment, and productivity (Belitski, et al., 2023).

Leveraging various resources is closely tied to developing managers' and entrepreneurs' thoughts, experiences, and knowledge (Penrose, 1959). Varadarajan (2023) found that to protect and capitalize on their advantageous resources, companies with heterogeneous resources tend to take more action and respond more quickly after a competitor's move. However, when companies expand rapidly to respond swiftly to competitors over a certain period, this aggressive expansion could harm operations (Fu, et al., 2024). Therefore, this paper suggests that Intel's growth in the wafer manufacturing and chip design submarkets could be influenced by the successful experiences of its managers, who may focus on executing market share growth strategies through expansion, while neglecting investment in human capital development (Han & Dong, 2023), or resource misallocation (Helfat & Maritan, 2023). As a result, growth in the top three markets has been limited, leading to the Penrose effect. Thus, hypothesis 2 is proposed:

**H2: The average growth of market share is positively correlated with the expansion of the top three submarket shares of the firm in the first period and negatively in the second period.**

Hypothesis 1 and 2 focused on the so-called "Penrose curve," a firm that expands rapidly in one time period is likely to incur managerial experience problems. Consequently, the firm's growth may stagnate in the subsequent period. However, a firm's submarket complementarity of the pair of market segments enables firms to exploit each other in complementary areas (Lee et al., 2010; Burgelman et al., 2022; Kim & Finkelstein, 2009). Thus, the complementarity among the top three submarket shares positively correlates with the firm's performance.

However, from a competitive perspective, firms with a more significant influence in similar submarkets may face heightened economic conflicts, providing opportunities for competitors to exploit. Under competitive pressures, divestitures allow struggling firms and high performers to free up financial and managerial resources for reinvestment in more productive uses, leading to what is referred to as a complementary Penrose effect (Vidal & Mitchell, 2018). Therefore, the complementarity among the top three submarket shares negatively correlates with firm performance.

**H3a: The complementarity of the top three submarket shares positively correlates with the firm's performance.**

**H3b: The complementarity of the top three submarket shares negatively correlates with the firm's performance.**

## 3. Methods

### 3.1. Sample

In the semiconductor industry, characterized by intense competition and diverse market segments (Chuang et al., 2018), a prime opportunity exists to study firms' decisions regarding product launches and abandonment. This industry confronts challenges such as shrinking product lifecycles, a growing array of individual applications utilizing semiconductor components, and increasing specialization horizontally and vertically within value chains. Since the late 1990s, the industry has experienced the emergence of new semiconductor applications alongside a gradual decline in demand within the personal computer market, resulting in industry fragmentation (Macher et al., 2008).

The sample used to test our hypotheses was sourced from the Dataquest database maintained by Gartner, a leading market research agency specializing in the global semiconductor industry. This database has been utilized in previous studies focusing on technological innovation within the semiconductor sector (Podolny et al., 1996; Stuart, 2000). Gartner collects data on semiconductor firms' sales across various market segments.

While Gartner's database does not encompass sales data for all firms within the industry, the firms included in Dataquest represent approximately 90 percent of the market share in the semiconductor industry. As Gartner reclassified market segments in Dataquest in 2000, we selected 2000 as the initial observation year and included all firms present in the database between 2000 and 2009. Firms with fewer than three submarket segments were excluded from the analysis. In total, the sample comprised 163 firms competing across 52 market segments.

In response to the uncertainty within the semiconductor industry, certain firms like Qualcomm, Texas Instruments, and NVidia have opted to leverage their core competencies to diversify into various product-market segments while outsourcing production. On the other hand, companies like Intel and Samsung Electronics have chosen to diversify into different product-market segments while retaining their in-house production capabilities. Consequently, around 60 percent of firms within the industry operate across multiple product-market segments.

For instance, companies like STMicroelectronics, Fairchild Semiconductor, Samsung Electronics, Atmel, and Intel have competed in markets such as static random-access memory, embedded microprocessor units, and flash memory devices. Moreover, STMicroelectronics and SanDisk have ventured into markets for NOR-based and NAND-flash memory devices and application-specific standard products (ASSP).

### 3.1.1. Dependent variables and analysis

Our theoretical focus is understanding a firm's performance within specific markets, with market share as our performance measure. To calculate the market share for each firm in a given market segment, we utilized sales data obtained from Dataquest across the 52 submarket segments.

The term "submarket" in this paper is primarily based on Penrose's (1959) recognition that "firms are modeled as a portfolio of products," and these product markets are considered submarkets. For example, Samsung Electronics operates in the smartphone, laptop, television, and semiconductors markets, so Samsung has four submarkets. According to Penrose, individual firms' performance differences or uniqueness stem from the different purposes or methods in which managers allocate resources, leading to uniqueness in firm performance (Penrose, 1959, p. 24). For instance, TSMC focuses on semiconductor foundry services, while Intel combines design and manufacturing, resulting in performance differences between the two companies. As managers allocate resources across various submarkets, more management resources, such as coordinating design and manufacturing, are required. This diversity limits the growth of the two submarkets—semiconductor manufacturing and chip design—resulting in the so-called Penrose effect.

On the other hand, according to Gibrat's Law (1931), after a certain period, firms should have equal probabilities of changes in growth rates, regardless of their initial size. Even after multiple periods, this randomness will lead to firm size exhibiting an asymmetric lognormal distribution, meaning that industry concentration will increase over time. Based on this and drawing from previous literature (Peneder, 2012; Levinthal & Wu, 2009; Penrose, 1959), this paper defines submarkets as the top three markets within a firm that require significant managerial resources. The term "period" is based on the two-stage linear model from prior literature (Raudenbush & Bryk, 2002, p.179) and is summarized in Table 1.

For our analysis, we employed Hierarchical Linear Models (HLM) to test our hypotheses. The development of HLM has provided a robust set of techniques for studying changes in firm market share. Typically, studies investigating changes over time utilize HLM, designed to differentiate among firms at a fixed point and uncover patterns of change across multiple time points (Raudenbush & Bryk, 2002).

To aggregate a multi-market firm's market share across its submarket segments, we followed the approach used in prior research (Tanriverdi & Lee, 2008). We aggregated a multi-market firm's market share of the submarkets where it operated by measure below:

$$\text{Firm } i\text{'s } Market\ Share_{ti} = \sum_{m=1}^{52} \left( P_{im} \frac{Total\ sales_{im}}{Total\ sales_{m}} \right) \quad (1)$$

where P_im is the proportion of firm i's sales from submarket m in a given year, Total sales are the size of submarket m. The total sale is the firm's sales from submarket m. Accordingly, this measure presents the firm's sales-weighted shares of all markets in which it competed.

In our study, the unit of analysis is a firm within a specific market. To analyze multi-market firms, we aggregated yearly observations of each multi-market firm across all markets where it operated. This approach allows us to estimate the effects of theoretical variables on the firm's market share. However, this analysis is susceptible to potential non-independent biases due to repeated observations of each firm at each point. To address this issue, we adopted the approach employed in prior studies, which includes incorporating firm fixed effects and controlling for firm characteristics (Gimeno, 1999). These control variables help mitigate non-independent biases and provide a more robust analysis of the relationship between theoretical variables and firm market share.

We assume that Market Share ti, the market share for the firm i in a given year t, is a function of nonlinearity trajectories or a two-piece growth curve plus random error. The level-1 model was of the form:

$$Market\ Share_{t+1,i} = \pi_{0i} + \pi_{1i} * (A1_{ti}) + \pi_{2i} * (A2_{ti}) + e_{ti} \quad (2)$$

where A1ti and A2ti are coded variables, as defined in Table 1, to represent piecewise linear growth regression through the software in the HLM program.

**Table 1.** *Coding Schemes for a Two-piece Linear Model*

| | 1<br>2000 | 2<br>2001 | 3<br>2002 | 4<br>2003 | 5<br>2004 | 6<br>2005 | 7<br>2006 | 8<br>2007 | 9<br>2008 | Interpretation of $\pi_S$ |
|---|---|---|---|---|---|---|---|---|---|---|
| A1t | -2 | -1 | 0 | 1 | 2 | 3 | 4 | 5 | 6 | $\pi_1$ base growth rate |
| A2t | 0 | 0 | 0 | 1 | 2 | 3 | 4 | 5 | 6 | $\pi_2$ increment(decrement) to growth in period 2<br>$\pi_0$ status year 2002 |

Based on the Equation (3)~(5) and an unconditional level-2 with π0i , π1i , and π2i random. At level-2, it is the simplest firm-level model by using the following formula:

$$\pi_{0i} = \beta_{00} + r_{0i} \quad (3)$$

$$\pi_{1i} = \beta_{10} + r_{1i} \quad (4)$$

$$\pi_{2i} = \beta_{20} + r_{2i} \quad (5)$$

**3.1.2. Independent variables and analysis**

We constructed our theoretical variables according to the level of interest. Hypotheses 1 and 2 examined the Penrose effect on the average market share growth. Specifically, Hypothesis 1 looked at the average market share growth as an increment to the initial status in the first period and decrement in the second period. To test the hypothesis, we first identified 2002 year as the status, and two-piece growth coded variables, A1ti and A2ti, are coded variables at time one and time 2 for firm i.

Next, the level-1 model remains as in Equation (2). We now introduce three predictors into the level-2 model: 1st Market Seg (the market share of the max submarket segment); and 2nd Market Seg (the market share of the second submarket segment); and 3rd Market Seg (the market share of the third submarket segement). That is,

$$\pi_{0i} = \beta_{00} + \beta_{01} * (1^{st} MARKET\ SEG_i) + \beta_{02} * (2^{nd}\ MARKET\ SEG_i) + \beta_{03} * (3^{rd}\ MARKET\ SEG_i) + r_{0i} \quad (6)$$

$$\pi_{1i} = \beta_{10} + \beta_{11} * (1^{st}\ MARKET\ SEG_i) + \beta_{12} * (2^{nd}\ MARKET\ SEG_i) + \beta_{13} * (3^{rd}\ MARKET\ SEG_i) + r_{1i} \quad (7)$$

$$\pi_{2i} = \beta_{20} + \beta_{21} * (1^{st}\ MARKET\ SEG_i) + \beta_{22} * (2^{nd}\ MARKET\ SEG_i) + \beta_{23} * (3^{rd}\ MARKET\ SEG_i) + r_{2i} \quad (8)$$

In addition, the hypotheses 3a and 3b examined the effect of complementarity on firm performance. Following prior research (Wang & Zajac, 2007), the method to calculate the variable complementarity between submarket segments is adapted from the survivor measure of relatedness where it operated by using the measure below (for more detailed description, see Wang and Zajac (2007)):

$$Comp_{xy} = (J_{xy} - \mu_{xy})/\delta_{xy} \quad (9)$$

where $J_{xy}$ = number of firms that the two , x and y, submarket segement appear in one firm; $\mu_{xy}$ = $(Nx * Ny) / K$ ($Nx$ = the number of firms in submarket segement $x$ ; $Ny$ = the number of firms in submarket segement $y$ ; $K$ = total number of firms);

$$\delta_{xy} = \sqrt{\mu_{xy} * \left(1 - \frac{N_x}{K}\right) * \left(\frac{K}{K-1}\right) * \left(1 - \frac{N_y}{K}\right)} \quad (10)$$

## 4. Results

Descriptive statistics are given in Table 2. We began with an unconditional model in that there were no level-2 predictors. This model provides valuable empirical evidence for determining a proper specification of the firm's market share piecewise linear growth model. Table 3 presents the results of this analysis.

**Table 2**. *Descriptive Statistics*

| LEVEL-1 DESCRIPTIVE STATISTICS | | | | | |
|---|---|---|---|---|---|
| VARIABLE NAME | N | MEAN | SD | MINIMUM | MAXIMUM |
| A1 | 905 | 1.09 | 2.83 | -2 | 6 |
| A2 | 905 | 1.85 | 1.87 | 0 | 6 |
| Market Share | 905 | 0.06 | 0.09 | 0 | 0.77 |
| Comp_1st2nd | 905 | 1.89 | 0.59 | -1.69 | 2.84 |
| Comp_2nd3rd | 905 | 1.85 | 0.58 | -2.27 | 2.81 |

| LEVEL-2 DESCRIPTIVE STATISTICS | | | | | |
|---|---|---|---|---|---|
| VARIABLE NAME | N | MEAN | SD | MINIMUM | MAXIMUM |
| 1st MARKET SEG | 163 | 0.04 | 0.06 | 0 | 0.56 |
| 2nd MARKET SEG | 163 | 0.01 | 0.01 | 0 | 0.09 |
| 3rd MARKET SEG | 163 | 0 | 0.01 | 0 | 0.04 |

**Table 3**. *Model 1: The Linear Model of Growth in Market Share (Unconditional Model)*

| Fixed Effect | Coefficient | Standard Error | *t*-ratio | Approx. *d.f.* | *p*-value |
|---|---|---|---|---|---|
| | | For INTRCPT1, $\pi_0$ | | | |
| INTRCPT2, $\beta_{00}$ | 0.065 | 0.008 | 7.798 | 162 | <0.001 |
| | | For A1 slope, $\pi_1$ | | | |
| INTRCPT2, $\beta_{10}$ | 0.008 | 0.001 | 6.261 | 162 | <0.001 |
| | | For A2 slope, $\pi_2$ | | | |
| INTRCPT2, $\beta_{20}$ | -0.009 | 0.001 | -5.416 | 162 | <0.001 |

| | $\tau_{0i}$ | $\tau_{1i}$ | $\tau_{2i}$ |
|---|---|---|---|
| INTRCPT1, $\tau_{0i}$ | 1.000 | | |
| A1 slope, $\tau_{1i}$ | 0.642 | 1.000 | |
| A2 slope, $\tau_{2i}$ | 0.895 | -0.924 | 1.000 |

| Random Effect | Standard Deviation | Variance Component | *d.f.* | $\chi^2$ | *p*-value |
|---|---|---|---|---|---|
| INTRCPT1, $r_0$ | 0.104 | 0.011 | 71 | 7777.006 | <0.001 |
| A1 slope, $r_1$ | 0.014 | 0.000 | 71 | 882.088 | <0.001 |
| A2 slope, $r_2$ | 0.017 | 0.000 | 71 | 604.527 | <0.001 |
| level-1, $e$ | 0.017 | 0.000 | | | |

| Random level-1 coefficient | Reliability estimate |
|---|---|
| INTRCPT1,$\pi_0$ | 0.986 |
| A1,$\pi_1$ | 0.836 |
| A2,$\pi_2$ | 0.742 |

The estimated mean intercept, $\beta_{00}$, and mean growth rate in period 1, $\beta_{10}$ , and mean growth rate in period 2, $\beta_{20}$ , for the market share were 0.065 , 0.008 , and -0.009 respectively. This means that the average market share at the initial status was estimated to be 0.065, and the market share increased by an average of 0.008 per year in period 1, and decreased by an average of 0.009 per year in period 2. It suggests that the average growth trajectories are incremental to the initial status in period 1 by an average of 0.86% per year and decremental in period 2 by an average of 0.98%, consistent with the implications from prior studies (Penrose, 1959; Tan & Mahoney, 2005).

The corresponding $\chi^2$ test statistic were 882.088 and 604.527, which leads us to conclude that there are significant variations in firm market share growth in different periods. Moreover, according the study (Chuang et al., 2018, p1566; Raudenbush & Bryk, 2002, p172), the market share in period 1 expected to grow at a rate of 0.008+0.014=0.022 per year is higher than in period 2 (-0.009+0.017=0.008 per year i.e., mean + 1 standard deviation). This is, each firm's market share growth rate slowed down in period 2. Moreover, the estimated correlation between periods 1 and 2 was -0.924/(2^0.5)=-0.653†. This means that the correlation of growth is different in the two periods. Thus, Hypothesis 1 is supported.

The estimated reliabilities for initial status and growth rates for the two periods were 0.986, 0.836, and 0.742, respectively. These results indicate a substantial signal in these data in terms of different market shares of the firm in both initial status and two periods.

**Table 4**. Model 2: The Linear Model of Growth in Market Share
(Effects of First, 2nd, and 3rd Market Seg Model)

| Fixed Effect | Coefficient | Standard error | *t*-ratio | Approx. *d.f.* | *p*-value |
|---|---|---|---|---|---|
| | | For INTRCPT1, $\pi_0$ | | | |
| INTRCPT2, $\beta_{00}$ | 0.063 | 0.001 | 44.855 | 159 | <0.001 |
| *1st MARKET SEG*, $\beta_{01}$ | 1.149 | 0.036 | 31.321 | 159 | <0.001 |
| *2nd MARKET SEG*, $\beta_{02}$ | 1.408 | 0.210 | 6.702 | 159 | <0.001 |
| *3rd MARKET SEG*, $\beta_{03}$ | 3.790 | 0.658 | 5.752 | 159 | <0.001 |
| | | For A1 slope, $\pi_1$ | | | |
| INTRCPT2, $\beta_{10}$ | 0.008 | 0.001 | 10.076 | 159 | <0.001 |
| *1st MARKET SEG*, $\beta_{11}$ | 0.161 | 0.013 | 11.829 | 159 | <0.001 |
| *2nd MARKET SEG*, $\beta_{12}$ | 0.553 | 0.146 | 3.780 | 159 | <0.001 |
| *3rd MARKET SEG*, $\beta_{13}$ | -1.288 | 0.698 | -1.845 | 159 | 0.067 |
| | | For A2 slope, $\pi_2$ | | | |
| INTRCPT2, $\beta_{20}$ | -0.010 | 0.001 | -9.493 | 159 | <0.001 |
| *1st MARKET SEG*, $\beta_{21}$ | -0.181 | 0.018 | -9.934 | 159 | <0.001 |
| *2nd MARKET SEG*, $\beta_{22}$ | -0.689 | 0.182 | -3.790 | 159 | <0.001 |
| *3rd MARKET SEG*, $\beta_{23}$ | 1.158 | 0.747 | 1.551 | 159 | 0.123 |

| Random Effect | Standard Deviation | Variance Component | *d.f.* | $\chi^2$ | *p*-value |
|---|---|---|---|---|---|
| INTRCPT1, $r_0$ | 0.010 | 0.000 | 68 | 151.314 | <0.001 |
| A1 slope, $r_1$ | 0.008 | 0.000 | 68 | 179.570 | <0.001 |
| A2 slope, $r_2$ | 0.009 | 0.000 | 68 | 209.455 | <0.001 |
| level-1, $e$ | 0.018 | 0.000 | | | |

| Random level-1 coefficient | Reliability Estimate |
|---|---|
| INTRCPT1,$\pi_0$ | 0.429 |
| A1,$\pi_1$ | 0.636 |
| A2,$\pi_2$ | 0.471 |

† Based on the Equation 6.8 (Raudenbush & Bryk, 2002, p167), $\hat{\rho}(\pi_{1i}, \pi_{2i}) = \hat{\tau}_{12}/(\hat{\tau}_{11} + \hat{\tau}_{22})^{1/2}$, the correlation between periods 1 and 2 was -0.653 (=-0.924/(2^0.5)).

Hypothesis 2 proposed that the average growth of market share is positively correlated with the expansion of the top three submarket shares of the firm in the first period and negatively in the second period. Table 4 presents the estimated fixed-effects results for this analysis. The market share for firms with a higher degree of 1st Seg market, on average, at a rate of 0.161 per year, faster than the lower degree of the 1st Seg market in period 1 (i.e.,$\beta_{11}$=0.161). Similarly, each additional degree of 2nd Seg market share per year was associated with a 0.553 increment to the growth rate (i.e.,$\beta_{12} = 0.553$).

According to Table 1, $\pi 1$ represents the base growth rate, while $\pi 2$ represents the gradually increasing or decreasing slope. Based on Table 4, $\beta_{11}$ (0.161) is less than $\beta_{12}$ (0.553), indicating that the slope of the black line (representing the first segment market share) is smaller than that of the blue line (representing the second segment market share). The two colored dashed lines may overlap in the future.

Additionally, $\beta_{21}$ is -0.181, and $\beta_{22}$ is -0.689, where the negative sign indicates an incremental decline in the second phase. Since $\beta_{22}$ (the blue line's 2nd segment market share) has a more significant rate of decline than $\beta_{21}$ (the black line), the gap between the blue dashed line and the solid line is greater than that of the black line. This shows that in the second phase, the average market growth rate of the top three submarkets differs. The statistical results above partly confirm the validity of Hypothesis 2. The illustration of this explanation is shown in Figure 1.

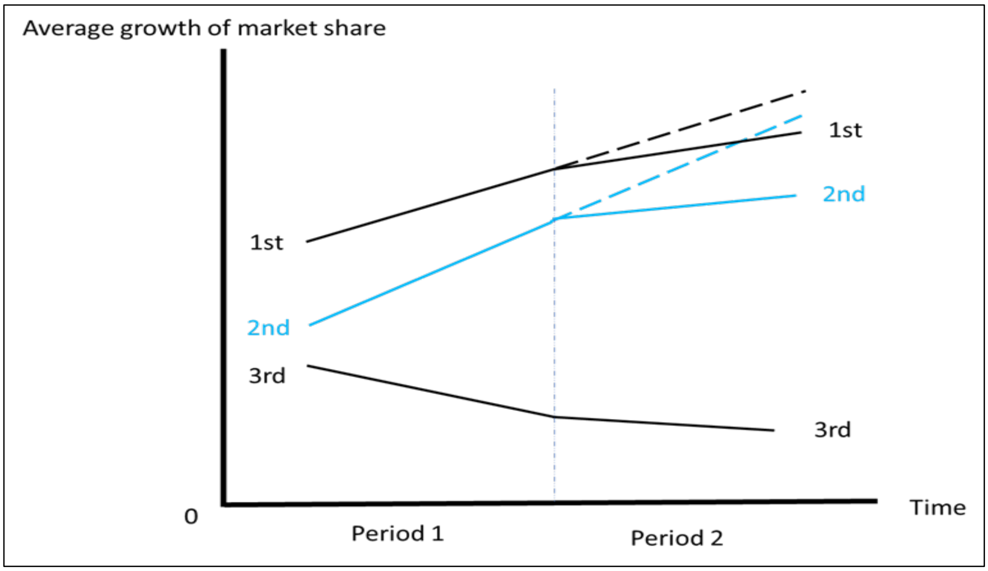


**Fig 1.** *A Sample of The Trajectory of The Average Growth of The Market*

However, the effect of a higher degree of both the 1st and 2nd Seg market share on growth in period 2 was exciting and plausible. On average, the degree of 1st and 2nd Seg market share was negatively related to firm market share growth in period 2 (i.e., $\beta_{21} = -0.181$ and $\beta_{22} = -0.689$). Thus, the growth in period 2 is more variable than period 1. Comparing these results above with the limit to the rate of expansion (Penrose, 1959), it is indicated that the firm existing growing experience provides both an inducement to expand its market share in period one and a limit to the rate of expansion in period 2.

**Table 5**. *Model 3: The Linear Model of Growth in Market Share (Full Two-Piece Linear Model)*

| Fixed Effect | Coefficient | Standard Error | *t*-ratio | Approx. *d.f.* | *p*-value |
|---|---|---|---|---|---|
| | | For INTRCPT1, $\pi_0$ | | | |
| INTRCPT2, $\beta_{00}$ | 0.061 | 0.001 | 48.547 | 159 | <0.001 |
| *1st MARKET SEG*, $\beta_{01}$ | 1.157 | 0.021 | 54.916 | 159 | <0.001 |
| *2nd MARKET SEG*, $\beta_{02}$ | 1.282 | 0.118 | 10.793 | 159 | <0.001 |
| *3rd MARKET SEG*, $\beta_{03}$ | 4.083 | 0.538 | 7.580 | 159 | <0.001 |
| | | For A1 slope, $\pi_1$ | | | |
| INTRCPT2, $\beta_{10}$ | 0.006 | 0.001 | 7.819 | 159 | <0.001 |
| *1st MARKET SEG*, $\beta_{11}$ | 0.178 | 0.011 | 15.191 | 159 | <0.001 |
| *2nd MARKET SEG*, $\beta_{12}$ | 0.456 | 0.109 | 4.162 | 159 | <0.001 |
| *3rd MARKET SEG*, $\beta_{13}$ | -1.016 | 0.642 | -1.582 | 159 | 0.116 |
| | | For A2 slope, $\pi_2$ | | | |
| INTRCPT2, $\beta_{20}$ | -0.008 | 0.001 | -7.648 | 159 | <0.001 |
| *1st MARKET SEG*, $\beta_{21}$ | -0.206 | 0.014 | -14.865 | 159 | <0.001 |
| *2nd MARKET SEG*, $\beta_{22}$ | -0.526 | 0.115 | -4.566 | 159 | <0.001 |
| *3rd MARKET SEG*, $\beta_{23}$ | 0.727 | 0.670 | 1.086 | 159 | 0.279 |
| | | For Comp_1st2nd slope, $\pi_3$ | | | |
| INTRCPT2, $\beta_{30}$ | -0.009 | 0.003 | -2.543 | 162 | 0.012 |
| | | For Comp_2nd3rd slope, $\pi_4$ | | | |
| INTRCPT2, $\beta_{40}$ | -0.005 | 0.002 | -2.102 | 162 | 0.037 |

| Random Effect | Standard Deviation | Variance Component | *d.f.* | $\chi^2$ | *p*-value |
|---|---|---|---|---|---|
| INTRCPT1, $r_0$ | 0.009 | 0.000 | 66 | 135.538 | <0.001 |
| A1 slope, $r_1$ | 0.009 | 0.000 | 66 | 148.573 | <0.001 |
| A2 slope, $r_2$ | 0.010 | 0.000 | 66 | 178.337 | <0.001 |
| Comp_1st2nd slope, $r_3$ | 0.030 | 0.000 | 69 | 173.800 | <0.001 |
| Comp_2nd3rd slope, $r_4$ | 0.019 | 0.000 | 69 | 106.908 | 0.003 |
| level-1, $e$ | 0.014 | 0.000 | | | |

| Random level-1 coefficient | Reliability estimate |
| --- | --- |
| INTRCPT1, $\pi_0$ | 0.361 |
| A1, $\pi_1$ | 0.559 |
| A2, $\pi_2$ | 0.458 |
| Comp_$1^{st}2^{nd}$, $\pi_3$ | 0.408 |
| Comp_$2^{nd}3^{rd}$, $\pi_4$ | 0.298 |

The level-2 model remains in Equation (6)~(8). Nest, we now introduce two predictors into the level-1 model:

$$\text{Market Share}_{t+1,i} = \pi_{0i} + \pi_{1i} * (A1_{ti}) + \pi_{2i} * (A2_{ti}) + \pi_{3i} * (\text{Comp } 1^{st}2^{nd}{}_{ti}) + \pi_{4i} * (\text{Comp } 2^{nd}3^{rd}{}_{ti}) \quad (11)$$

where the complementarity score, Comp_1st2nd, between the pair of firm market share of 1st Seg market and 2nd Seg market; Comp_2st3rd, between the pair of firm market share of 2nd Seg market and 3rd Seg market.

Table 5 presents the estimated fixed-effects results for the complementarity between the submarket segment analyses. The average complementarity between 1st and 2nd , $\beta_{30}$ , was -0.009. This means that the level of complementarity between the first and second submarkets was negatively related to firm market share. Similarly, the firm's market share is highly complementary between the second and third segments behind the firm with experience of non-complementary submarket expansion (i.e.,$\beta_{40}$ = -0.005). The pessimistic coefficient estimates of Comp_1st 2nd and Comp_1st 2nd in Model 3 in Table 5 provide support for the hypothesis 3b ($\beta_{30}$= -0.009, $p=.012<.05$; $\beta 40$ = -0.005, $p=.037<.05$ respectively).

## 5. Discussion and Conclusion

We tested hypotheses using a sample comprising 163 semiconductor firms operating across 52 submarkets. Building on previous research (Johnson et al., 2000), we investigated the Penrose effect, which suggests that the average market share growth increases initially but decreases in the subsequent period. The negative correlation coefficient estimated between period one and period 2 serves as evidence supporting the existence of the Penrose effect.

If the Penrose effect indeed exists, the following strategic decision concerning growth among the top three segments to enhance firm performance will be influenced by managerial incentives. The positive estimated coefficients observed between the first segment and the average market share growth in period 1 suggest that managers can improve firm performance by strengthening the dominance of the first and second submarkets. However, in period 2, the dominance of the top two submarkets is negatively associated with firm performance. This indicates that while a rapidly growing firm can grow by expanding the dominance of the top two submarkets in period 1, this expansion does not necessarily lead to further growth in the subsequent period. These findings align with the implications drawn from previous studies (Penrose, 1959; Tan & Mahoney, 2005).

If the relationship between the dominance of the top two submarkets and firm performance indeed exists, then the level of complementarity between these submarkets becomes a crucial concern for managers. The pessimistic coefficient estimates of Comp_1st2nd and Comp_2nd3rd in Model 3 suggest that a rapidly growing firm can enhance its growth by strategically allocating the degree of complementarity between the top two submarkets before one becomes dominant. For instance, a firm can grow by strengthening the dominance of the first and second submarkets in period 1. Then, in the subsequent period, it can focus on one submarket, even if it is relatively unfamiliar compared to the other top two submarkets.

The outcome suggests that a company can attain sustained growth if the manager can introduce relatively unfamiliar or new products into the market in subsequent periods. This capability can facilitate the development of new managerial resources, thereby contributing to the firm's growth trajectory.

Our empirical findings align with a critical tenet of the firm's resource-based theory. According to this theory, firms aim to leverage managerial capabilities rather than merely their tangible resources to achieve growth. Specifically, the ability to explore unfamiliar and valuable product markets represents a crucial resource that can confer a sustained competitive advantage.

Finally, this study offers two suggestions for future research. First, a comparative analysis of the differences in the Penrose effect across various countries could be conducted. Since the semiconductor industry spans multiple countries, and based on the literature on national competitive advantage, the semiconductor industries in different countries will exhibit varying competitiveness due to differences in industrial value. For example, an analysis and comparison of the discrepancies between the United States, Japan, Taiwan, South Korea, and mainland China could be undertaken. Second, regarding the Penrose effect, many studies have highlighted those investments in knowledge and the accumulation of experience can moderate firms' growth limitations. Future research could focus on comparing and analyzing the differences in how firms pursue growth through knowledge investment, experience accumulation, and scaling up.

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