

## **From Acting What's next to Speeding Trap: Co-Evolutionary Dynamics of an Emerging Technology-Leader**

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**Abstract:** How does technological innovation emerge and evolve? We approach such an inquiry by synthesizing the perspectives of dynamic capabilities and co-evolutionary dynamics to portray organizational routines and multi-phase strategic renewals of an emerging technology-leader. To untangle the emergence of technological innovation, we conducted a longitudinal case study on the first and the largest dedicated semiconductor foundry, TSMC, located in the emerging economy of Taiwan. The firm-case of TSMC illustrates two unique co-evolutionary paths, that is, transforming from industry-latecomer to technology-leader and from process innovation to product innovation. We found multi-motor co-evolutionary dynamics between TSMC and the semiconductor industry, where its co-evolutionary mechanism of managed selection in its creating phase of mature process-innovation (1987-1998) has migrated to hierarchical renewal in its extending phase of advanced process-innovation (1999-2001), and then to holistic renewal in its modifying phase of product-innovation (2002-2007). During such paths, our research discovered a unique type of organizational routines, acting *what's next* because TSMC has proactively searched for potential problems sooner than its competitors. However, such routines, although driving technological innovation, also lead to a unique type of success-trap, that is, *speeding trap*. When an emerging technology-leader fundamentally changes the industrial structures to over-specs, the growth driven by technology speeding may trap such a leader in a loop of over-exploration.

**JEL Classifications:** O33, O53, L63

**Keywords:** dynamic capabilities, emerging economies, organizational routine, strategic renewal, technological innovation

### **1. Introduction**

The objective of this study was to untangle the inquiry, how technological innovation emerges and evolves. Although Schumpeter's argument that the prime driver of economic development is technological innovation instead of perfect competition is seldom disputed (Schumpeter, 1942; Van de Ven, 1996), most organizations encounter barriers that defeat their attempts at innovation. In particular, organizations must change when they innovate (Tushman & Anderson, 2004). Therefore, we conducted a longitudinal case study on an emerging leader to investigate how an organization co-evolve with its industry, when actively adapting to macro and micro changes and consequently reshaping the industrial landscape by multi-phase technological innovation.

Based on the assertion that strategy is crucial during times of change, the theorists of dynamic capabilities posit that organizations must actively adapt to and exploit changes in their business environment, and proactively seek opportunities to create changes through technological, organizational, or strategic innovation (Helfat, Finkelstein, Mitchell, Peteraf, Singh, Teece, & Winter, 2007). Following this argument from the perspective of dynamic capabilities, we analyzed the emerging and evolving processes of technological innovation of a semiconductor leader located in an emerging economy, which transferred its core competence from, and then out-performed, its co-founder located in an advanced economy.

Three aspects of exploring the emergence and evolution of innovation have not been fully addressed in the related literature, which strongly motivated our research. In brief, the literature regarding dynamic capabilities and technological innovation has relatively emphasized outcomes, contents, and purposeful changes. By contrast, this study demonstrated the antecedents, processes, and co-evolutionary emergence of technological innovation with an emphasis on organizational routines. However, it remains challenging to choose an appropriate research methodology, particularly on the emergence of innovation. Such a challenge lies in the attempt to make the implicit organization-specific mechanisms explicit by emphasizing the emerging antecedents and co-evolutionary processes. Moreover, the forming processes and transformation mechanisms are relatively less observed and analyzed than the components and outcomes of technological innovation. Therefore, we used the qualitative approach to examine an in-depth case of an emerging technology-leader.

In short, we attempt to explain, rather than to predict, the emergence and evolution of technological innovation from the analytical view of co-evolutionary dynamic capabilities. Based on a longitudinal case study of an innovative organization, our research specified the organization-specific mechanisms of sequential strategic renewals induced from the macro co-evolutionary dynamics of a technology-latecomer transforming to industry-leader, as well as the micro co-evolutionary dynamics of organizational routines transforming from process-innovation to product-innovation. Consequently, this study offers practical contributions in reducing the barriers to imitate, innovate, and change. The following sections tell a story about the macro and micro co-evolutionary dynamics of a semiconductor firm and its industrial environment. Our research journey has inaugurated from literature review, methodology, analysis and discussion, and then concluded with research contributions and managerial implications.

## 2. Literature Review

Highlighting our research motivation, we conducted reviews on the literature of the dynamic capabilities, co-evolutionary dynamics, and the organizational routines for technological innovation.

### 2.1 Dynamic Capabilities

Our first research motivation was to redirect research attention from outcomes to the antecedents of dynamic capabilities. The perspective of dynamic capabilities (Teece, Pisano, & Shuen, 1997) combines the resource-based view (Barney, 1991) and the evolutionary theory (Nelson & Winter, 1982). In principle, our research follows the mainstream definition of a dynamic capability as the capacity of an organization to purposefully create, extend, or modify its resource base (Helfat *et al.*, 2007). However, the organizational mechanisms to transform its resource base to a dynamic capability remain unclear. Since the article by Teece, Pisano, & Shuen (1997), the literature on dynamic capabilities has focused on their implications to organizational performance, such as the strategy-content school (Helfat *et al.*, 2007).

By contrast, our search for the emergence of technological innovation attempted to turn the focus backward to the formation and transformation of dynamic capabilities. We argue that dynamic capabilities are crucial when an organization is adapting to a complex system, instead of a rational equilibrium. Sharing the assumption of bounded rationality as behavior economists (Cyert & March, 1963), some scholars from the perspective of dynamic capabilities indicated the effects of “bounded predictability” (Witt, 2005) on the development of dynamic capabilities. For example, Eisenhardt and Martin (2000) contrasted the nature of dynamic capabilities in moderately dynamic markets and high-velocity markets as detailed, analytic, and stable routines with predictable outcomes versus experiential and fragile processes with unpredictable outcomes. Sharing the assertion of bounded predictability in high-velocity markets, we argue that an organization may proactively develop its innovation routines to cope with unpredictable outcomes.

## 2.2 Co-Evolutionary Dynamics

Our second motivation was to expand the definition of dynamic capability driven by purposeful changes into evolutionary emergence with an emphasis on routines. Astley and Van de Ven (1983) classified the diverse schools of organizational thoughts as micro versus macro levels of organizational analysis, and as deterministic versus voluntaristic assumptions of human nature to yield four basis perspectives, as follows: system-structure, strategic choice, natural selection, and collective-action views of organizations. Among these four perspectives, we argue that the perspective of dynamic capabilities aligns with the voluntaristic orientation at micro level, and is accordingly classified as strategic choice view, which is attributed as autonomous behavior and proactive management. However, when incorporating the macro level of organization population, the literature has not fully examined whether micro proactive and reactive changes co-evolve with macro structures.

The extensive selection-adaptation literature spans diverse theoretical perspectives; however, is inconclusive on the role of managerial intentionality in organizational adaptation (Volberda & Lewin, 2003). Therefore, recent research has introduced the inter-organizational perspective into evolutionary theory by illustrating the co-evolutionary dynamics of organizational capabilities and industrial competition (Huygens, Baden-Fuller, Van Den Bosch, & Volberda, 2001). Volberda and Lewin (2003) proposed an over-arching framework to expand the evolutionary perspective from organizational-level to multi-levels analysis as co-evolutionary dynamics within and between firms. Based on various levels of managerial intentionality, Volberda and Lewin (2003) identified four co-evolutionary mechanisms to demonstrate the range of evolutionary paths, including naïve selection, managed selection, hierarchical renewal, and holistic renewal. Among these four mechanisms, the managed selection co-evolutionary path requires continuous attention to the reflection and refreshing of routines (Lewin & Volberda, 2003; Volberda & Lewin, 2003). In brief, the co-evolutionary perspective emphasizes proactive managerial intentionality and the role of routines, which is consistent with our research motivations.

Although scholars have applied such co-evolutionary lens to empirical researches, rare studies addressed multi-levels nor multi-motors co-evolutionary paths as our research. Rather than applying the perspective of dynamic capabilities as this study, some multi-level studies have integrated the network and evolutionary perspectives, such as co-evolution of entrepreneurs' social networks and entrepreneurial processes in the Chinese context (Guo & Miller, 2010), as well as the impacts of Japanese horizontal and vertical business networks as underlying interfirm mechanisms on firm innovation (Zhang & Cantwell, 2011). Specifically at the macro level, most studies have discussed co-evolutionary dynamics between firms and national institutions, including keiretsu networks in Japan (Cantwell & Zhang, 2006) and business system in China (Chen, 2007; Krug & Hendrichske, 2008), as well as between technologies and institutions, including hard disk drive and liquid crystal display industries in Taiwan (Hung, 2002).

Specifically at the micro level, some scholars applied both perspectives of evolutionary and dynamic capabilities, in the empirical context of Mexican firms (Dutrénit, 2007) and Korean giant, Samsung (Lee & He, 2009) to describe evolutionary changes of intra-organizational core capabilities. In brief, most empirical studies concentrated on one level or the macro level of national institutions, rather than the co-evolutionary dynamics between the focal organization and its industrial environment as our study.

In view of the shifting focus from evolution to co-evolution, Volberda and Lewin (2003) specifically requested longitudinal research on how an organization and its industry co-evolve by several renewal engines. While focusing on managerial innovations, Damanpour and Aravind highlighted that the importance of both technological and managerial innovations and the need for their coexistence and co-evolution for economic growth (Damanpour & Aravind, 2011). Applying such a view of co-evolutionary dynamic capabilities, we further demonstrated the interactions between proactive changes of managers and their reactions to adapt to environmental changes through sequential strategic renewals of an emerging technology-leader. Strategic renewal refers to crucial strategic changes preceded by internal experimentation and selection (Burgelman, Christensen, & Wheelwright, 2004; Crossan & Berdrow, 2003).

### 2.3 Organizational Routines for Technological Innovation

Our third motivation was to focus more on the process aspect than the content aspect of strategy. Conventionally, the mainstream strategy scholars assumed that strategy is something that organizations have. By contrast, the scholars promoting ‘strategy as practice’ have a different perspective, that is, strategy is something that people undertake, or ‘an activity’ (Johanson, Langley, Melin, & Whittington, 2007). In the article, “*Dynamic Capabilities: What are they?*,” Eisenhardt and Martin (2000) defined dynamic capabilities as a set of specific and identifiable processes. They argued that dynamic capabilities have significant commonalities across firms, which is popularly termed ‘best practice,’ although dynamic capabilities are idiosyncratic in their details and path dependent in their emergence. Based on their argument, however, the reasons why some best practices are relatively easier to imitate, whereas others are more difficult remain unclear, especially when organizations located in emerging economies engaging in unpredictable innovation.

In “*The Theory of Economic Development*,” Schumpeter defined technological innovation as the development of new ideas into marketable products and processes, and separated the technological change process into three sequential stages: invention, innovation, and diffusion (Schumpeter, 1934). Various types of innovation have been identified in the literature, such as incremental versus radical, and product versus process (Burgelman *et al.*, 2004). This study applied Porter’s distinction between product-innovation, product design to enhance quality and features to meet customer requirements, and process-innovation, process development to tune the production and delivery system to improve performance (Porter, 1983).

Our research highlights the role of routines in organizational change (Feldman, 2000) and more specifically the co-evolutionary dynamics of organizational learning versus unlearning (Akgün, Byrne, Lynn, & Keskin, 2007) in technological innovation. Routines are defined as regular and predictable behavioral patterns of organizations by a behavioral theory of the firm (Cyert & March, 1963) and the evolutionary theory of economic change (Nelson & Winter, 1982), which indicate that an organization is a collection of routines for responding and adapting to its environments. Although identifying the critical role of routines in breeding innovation, both theories suggested different concepts of routine change. Whereas Cyert and March (1963) regarded routine change as adaptation, Nelson and Winter (1982) called it mutation, especially evident in the advent of a crisis. Both have not fully addressed how an organization to design its new routines or change its existing routines for adapting proactively. Therefore, whether, or

indeed how, organizational routines themselves may also be developed as outcomes of innovation has not yet been theoretically discussed and empirically examined.

### 3. Method

Methodologically, the inductive method is more common in strategy process research, in which case-based methods have been suggested as a more appropriate approach (Helfat *et al.*, 2007). Specifically, we selected Taiwan Semiconductor Manufacturing Company (TSMC, hereafter), the world's largest semiconductor manufacturing service, as an intentional sample (Eisenhardt, 1989) of one corporate setting (Burgelman, 1994; Burgelman, 2002; Cherry, 2003; Yin, 2002). Our data collection includes not only archival and interview data about TSMC, but also comparisons with its major foundry-competitor, United Microelectronics Corporation (UMC, hereafter) in Taiwan.

#### 3.1 TSMC Case Background

TSMC was founded in 1987 as an international joint venture of ITRI (Industrial Technology Research Institute), a Taiwanese government-sponsored agency, and Philips, the Dutch technology-leader (Wen & Lee, 2012). TSMC is the world's first firm establishing a pure-play foundry, specializing in manufacturing semiconductor products based on designs provided by its up-stream customers, fabless firms. Ever since its establishment, TSMC has successfully maintained its leading position in the foundry sub-industry either in terms of technology or revenues. Although initially as a technology-latecomer, it only took TSMC 15 years to become one the top-ten semiconductor firm, which has surpassed its technology founder, Philips, since 2002. TSMC in Taiwan and Samsung in Korea are the only two semiconductor firms rooted in emerging economies that have achieved the extraordinary transition from a latecomer to a leader (ITIS, 2001-2008; Mathews & Cho, 1999). Moreover, among the top-ten semiconductor firms, TSMC is the only one foundry provider, and the other nine leaders, including Samsung, all adopt the mainstream business-model of IDM (Integrated Device Manufacturer), meaning that they design, manufacture, and sell their own integrated circuit (IC) products to down-stream customers, electronic system-providers.

We selected TSMC as an intentional case because of the following three reasons. First, the semiconductor industry is characterized as technology-intensive due to its rapid changes in technology. Scholars define technology-intensive firms as those which require complex coordination of knowledge and activities more generally (Helfat & Raubitschek, 2000). Following Moore's law (Moore, 1965) as a self-fulfilling prophecy, the semiconductor industry has regularly developed next-generational technologies to manufacture larger-sized wafers with increasingly higher circuit resolutions (TSMC, 2000~2006). Second, as a new business-model of pure-play foundry, TSMC enjoys a unique technological scope by specializing in process-innovation, rather than product-innovation, which IDM players are committed to. Such unique evolutionary paths for TSMC transforming from a latecomer to a leader and extending from process-innovation to product-innovation may generate useful lessons for other latecomers who are striving for innovation in emerging economies (Meyer, 2006; Wright, Filatotchev, Hoskisson, & Peng, 2005). Moreover, some scholars specifically highlight that the corporate renewal of technology industries is an increasingly important part of many emerging economies (Bruton, Dess, & Janney, 2007; Bruton & Rubanik, 2002). Third, the interactions between TSMC and the semiconductor industry provide an applicable empirical context for studying the co-evolutionary dynamics. From a macro perspective, TSMC has initiated two critical types of routinized innovation, which have fundamentally changed the landscape of the semiconductor industry. TSMC's pure-foundry model has accelerated the disintegration trend of the semiconductor industry, including fabless firms (IC design), packaging and testing firms in the 1990s, and design-service and SIP (Silicon Intellectual Property) firms in 2000s. Moreover, TSMC's aggressive capacity expansion supported by its



leading position in advanced process-technologies has pushed more IDMs as Intel to outsource their manufacturing to pure-foundry, and some even to convert their business-model from IDM to fabless as AMD. Therefore, TSMC's extension from process to product-innovation manifested another unique co-evolutionary dynamics between intra-organizational and trans-organizational innovation (Millar, Demaid, & Quintas, 1997). As a electronic component-manufacturer, TSMC has to co-develop semiconductor products with its fabless customers; and as a government-initiated enterprise located in the Hsin-chu Industrial Park, it has also collaborated with other on-park firms and universities for knowledge exchange (Chan, Oerlemans, & Pretorius, 2010; Malairaja & Zawdie, 2008).

### 3.2 Fieldwork and Data Collection

Our fieldwork of interviews and analysis was carried out during 2006 and 2008. In addition to archival data, mostly in Chinese (ITIS, 2001-2008; Mathews, 1997; Shih, 2003), two cases on TSMC published by Harvard Business School (Iansiti & Strojwas, 2003) and Stanford Graduate School of Business (Shneorson, Lee, & Whang, 2006) provided the historical background for TSMC's distributed innovation with its partners and for its e-foundry program.

Confined by concerns with confidentiality about innovation activities, we eventually completed 15 interviews sessions. All interviewees requested to remain anonymous. Each interview lasted from one to two hours. The profile of our interviewees included 7 TSMC employees, 3 UMC employees, and 5 TSMC partners. Due to TSMC's practice of cross-functional transfer, 7 TSMC interviewees in fact covered multi-level and multi-functional perspectives, including engineer, director, vice president, and senior vice president of R&D; the quality and reliability engineering function; manager of design service, financial and sales, as well as manager and vice president of marketing. The profile of the UMC interviewees covered executives of R&D, financial as well as IC design functions. Further, the interviewed TSMC partners included executives of an EDA (Electronic Design Automation) supplier, two fabless customers, a venture capitalist, an ex-chairman of ITRI, which is the local founder of TSMC.

## 4. Analyses and Discussion

To provide empirical evidence of the emergence and evolution of technological innovation, our research framework incorporated both macro and micro levels of analysis on co-evolutionary dynamics between the semiconductor industry and TSMC. Based on the macro co-evolutionary paths of TSMC transforming from technology-latecomer to industry-leader of semiconductors, we found three sequential strategic renewals embedded with three co-evolutionary motors. At the micro level, the TSMC case revealed that it proactively renewed its organizational routines to speed its development of next-generation technologies, and modified its dynamic capabilities from process-innovation to product-innovation. Accordingly, we inductively specified a unique type of routine as *acting what's next* and a unique type of success trap as *speeding trap*.

Proposing further research regarding migration from evolution to co-evolution, Volberda and Lewin (2003) proposed a motor for each of the four co-evolutionary mechanisms, as follows: bVcSR (blind variation, competitive selection, retention) driving naïve selection, and dVvSR (deliberate variation, vicarious selection, retention) driving managed selection, administrative motor driving hierarchical renewal, and collective sense making driving holistic renewal. Specifically on the empirical context of emerging economies, some scholars have adopted such co-evolutionary lens to study the state-business relations in Korea (Cherry, 2003) and interfirm networks on the internationalization process of Taiwanese small and medium enterprises (SMEs) (Lin & Chaney, 2007). Based on this perspective of co-evolution, we found unique multi-motor

paths of TSMC through three sequential strategic renewals for technological innovation, as illustrated in Table 1.

**Table 1.** TSMC's multi-phase and multi-motor co-evolutionary dynamics

Strategic Renewal	Creating Phase 1987~1998	Extending Phase 1999~2001	Modifying Phase 2002~2007
Co-evolutionary Path	Managed Selection	Hierarchical Renewal	Holistic Renewal
Co-evolutionary Motor	dVvSR (deliberate variation, vicarious selection, retention)	Administrative	Collective Sense-making
Innovation Strategy	Mature Process-innovation	Advanced Process-innovation	Product-innovation
Innovation Routines **	<ol style="list-style-type: none"> <li>1. To transfer mature technology from its foreign founder – Philips</li> <li>2. To transfer fab-facility and teams from its local founder – ITRI</li> <li>3. To transform its business-model to eFoundry</li> <li>4. To catch up ITRS roadmap* by operational improvements</li> </ol>	<ol style="list-style-type: none"> <li>1. To recruit R&amp;D talents from the technology leaders</li> <li>2. To proactively search for problems for detecting potential defects as early as possible</li> <li>3. To co-develop with customers and suppliers</li> </ol>	<ol style="list-style-type: none"> <li>1. To extend monitoring system in R&amp;D lines</li> <li>2. To timely deliver by end-to-end coordination</li> <li>3. To smoothly hand-over by side-by-side collaboration</li> <li>4. To allocate less resources in operational improvements</li> <li>5. To create problems when process-technology over design-specs</li> <li>6. To convert design service to IP house to cope with the curse of economy of scale (drifting out of foundry)</li> </ol>

**Note\*:** ITRS (International Technology Roadmap for Semiconductors) roadmap is the fifteen-year assessment of the future technology requirements of the semiconductor industry

**Note\*\*:** Please refer to Appendixes 1a, 1b, 2, 3a, 3b for details of innovation routines.

#### 4.1 Sequential Strategic Renewals

Following the definition of a dynamic capability as the capacity to purposefully create, extend, or modify its resource base (Helfat *et al.*, 2007), this study specified the organizational life-cycle as three consecutive phases of creating, extending, and modifying. We found multi-motor co-evolutionary dynamics between TSMC and the semiconductor industry, where its co-evolutionary mechanism of managed selection in its creating phase of mature process-innovation (1987-1998) has migrated to hierarchical renewal in its extending phase of advanced process-innovation (1999-2001), and then to holistic renewal in its modifying phase of product-innovation (2002-2007). Each strategic renewal was initiated at the start of a radical change of technological innovation. The first renewal of TSMC was initiated as creating the first dedicated Semiconductor foundry in the world in 1987. The second started as declining the

technology-transfer of IBM when TSMC extended from a technology-latecomer focusing on mature process-innovation toward industry-leader focusing on advanced process-innovation in 1999. The third started as launching TSMC's first advanced-platform of 0.13-micron platform when modifying its innovation strategy from process-innovation to product-innovation in 2002.

The critical event dividing those sequential renewals and multi-motor paths was the decision by TSMC to self-develop its first advanced-technological platform during 1999 and 2001. Our research specifies the technology to manufacture IC on a larger-size wafer as disruptive (Christensen, 1997), because all of the equipment and the process-specs (recipes) must be re-designed to accommodate new wafer-size, which is usually associated with higher circuit resolution, more functionality, lower average cost driven by the economy of scale, and higher selling price per die. The technology platform has migrated from the aluminum-interconnect with the resolution-nodes lower than 0.15 micron on 8-inch wafer to the copper-interconnect and low-K technologies with the resolution-nodes higher than 0.13 micron on 12-inch wafer since 2002.

#### **4.2 Managed Selection in Creating Phase (1987~1998)**

During its creating phase, TSMC co-evolved with the semiconductor industry as the path of managed selection driven by the motor of deliberate variation, vicarious selection, and retention of its founding chairman, Dr. Morris Chang. In 1987, believing that a dedicated foundry was the only opportunity for a latecomer of an emerging economy to substantially grow the semiconductor industry, Dr. Chang persuaded both the government of Taiwan and Philips Semiconductor to realize such a vision. In brief, Dr. Chang's foresight of the foundry business-model has framed the evolutionary paths of TSMC since its inception. In 1997, Dr. Chang foresaw the future trend in the Internet era, that is, a virtual fab called eFoundry. Together with the top management team, he led an organizational renewal initiative to transform TSMC from a manufacturing-oriented to service-oriented organization at the micro level, and modified the foundry business-model into virtual IDM at the macro level. Powered by a collection of Internet-based programs that allowed customers and TSMC to virtually integrated in design, logistics, and engineering, eFoundry functions as an in-house fab for its customers (Shneorson *et al.*, 2006).

As a latecomer, TSMC had to catch up its one-year lag behind the technology leaders and to maintain its cost-advantage. In its creating phase, TSMC co-developed innovation routines with its founders and customers, regarding facility transfer, technology transfer, and design-recipes, for incrementally improving manufacturing yield through mature process-technology.

#### **4.3 Hierarchical Renewal in Extending Phase (1999~2001)**

We specified the extending phase of TSMC as hierarchical renewal driven by the administrative motor during 1999-2001. In 1999, the technology leader of IBM Microelectronics offered the latecomers of TSMC and subsequently UMC an opportunity to transfer its proprietary next-generational technologies via silk material to manufacture 12-inch wafer. Facing such a dilemma of co-developing as a follower versus self-developing as a leader, these two competing latecomers made contrasting decisions, the consequences of which were critical turning points for their future competitiveness. After a one-year evaluation, TSMC declined the offer from IBM and then successfully developed multiple platforms with its equipment supplier, Applied Materials. Aiming to overthrow the leading position of TSMC, UMC paid IBM a licensing fee of USD 100 million, and relocated approximately 50 R&D engineers from Hsin-chu in Taiwan to the IBM Lab in Fishkill in the U.S. in 2000. In such an innovation race, the alliance of IBM and UMC ramped up the production line of 0.13-micron nearly one year later than TSMC.



In this extending phase, TSMC developed four major routines to transform from latecomer to leader in advanced process-technologies. First, to expand its organizational slack (Cyert & March, 1963), TSMC aggressively recruited experienced R&D talents from the industry-leaders to lead a large new Ph.D. crew. For example, its R&D team successfully test-ran a preliminary recipe of copper-interconnect on the 0.18-micron node by the end of 1998. This achievement of independent R&D supported its decision to decline the offer from IBM, and our proposition that the accumulated slack bred capability renewals. Second, by declining the learning opportunity from IBM, TSMC renewed its innovation aspiration from technology transfer to leading development. Third, to exploit matured process-technologies, TSMC mobilized both R&D and other function-units to proactively search for problems, functioning as a wide-range radar screen to detect potential defects as early as possible by exposing the operational teams in diversified design-recipes even during the R&D phase. Fourth, to explore the future recipes, TSMC proactively searched for the emerging customers and suppliers to co-develop the next-generational equipment and design-specs.

#### 4.3.1 Acting What's next

We observed a unique type of routines, *acting what's next*, because TSMC proactively searched for problems by experimenting with future diversified scenarios as exhaustively as operating the next-generational technologies, earlier than its competitors (such as UMC) and even technology-leaders (such as IBM). Although sharing the characteristics of problemistic search highlighted by a behavioral theory of the firm (Cyert & March, 1963), we argued three conceptual differences between proactive search for problems and problemistic search. First, problemistic search is motivated by a particular problem and depressed by a problem-specific solution, whereas search for problems is motivated by making implicit problems explicit, and depressed by avoiding such early-detected symptoms in operation. Second, problemistic search proceeds on the basis of a simple-minded causality until driven to a more complex causality, whereas search for problems proceeds on the basis of complex model for detecting all potential problems in the future environment. Third, problemistic search is biased as reflecting organization-specific experiences and goals, whereas search for problems is biased as proactively scanning organizational blind spots via trans-organizational innovation beyond firm-boundaries.

Because any identified problem may decrease quality or performance considerably, an organization must prepare a bottom-up sensitivity in problem identification and cyclical process for problem resolution at the earlier R&D stage. Using a fab as an example, the early specification of the safe-zone of parameters of new recipes is mission-critical to maintain the target yield for the future design-specs, especially when migrating technology platforms. For illustrating how the routine of *acting what's next* works, the R&D Director of TSMC in charge of copper-interconnect highlighted a thermo-electronic experiment, whose results demonstrating that the low-K performance of silk material decreases substantially under high temperature. Such a simulated recipe was designed base on its previously manufactured IC used in projectors, requiring resistance to high temperature. As a result, TSMC was able to relinquish silk material earlier than IBM, whose silk-material patent for over 20 years became its blind spots to detect such a critical problem in higher resolution platforms. The success of TSMC in developing low-K technology using black-diamond material in 2000 was its critical milestone to transform from latecomer to leader.

The routines characterized as *acting what's next* suggest that it is feasible to benefit from both the low administrative transaction costs powered by competitive selection and trial-and-error learning powered by deliberate variation when macro contingencies align with micro routines. Instead of searching for a confined solution to a specific problem, TSMC proactively designed the organization-wide routines to proactively search for future problems, and subsequently expose

those problems in operation-like R&D labs, which are co-located and frequently interacting with internal operation teams and external alliance-partners. Such unique routines of *acting what's next* also serve as an unlearning mechanism for TSMC to eliminate its organizational memory confined as a technology-follower (Akgün et al., 2007). Therefore, we propose Proposition 1 to explain the transformation of an emerging technology-leader.

**Proposition 1:** *The routine of acting what's next facilitates the emergence of technological innovation, especially for an organization proactively co-evolving with its industry.*

#### 4.4 Holistic Renewal in Modifying Phase (2002~2007)

We specified the modifying phase of TSMC as holistic renewal since 2002, because all functions have integrated further with the R&D Team for migrating to next-generational platforms. SMC has modified three routines for strengthening its advanced process-innovation in the leading position. First, functioning as proactive radar screen, TSMC extended its monitoring system from operational lines to R&D lines, including explicit measures by the Quality & Reliability Team, as well as cost-tracking and forecasting by the Accounting Team. Second, functioning as end-to-end project coordinator, the Program-management Team under the commands of the operational executives coordinates cross-functional members participating in the R&D phase. Third, functioning as organization-wide drill, those cross-functional participants contribute to speeding the design of initial recipe (Version 0.1) to the commercialized recipe (Version 1.0), and the learning cycle for incremental improvement after the hand-over.

Furthermore, we observed the routine of rotation among functions to facilitate the speeding up of technology migration. For example, during the hand-over period in R&D, approximately one third of R&D engineers in charge of developing a technological node were assigned to the new production line, as soon as it was converted from the R&D lines. For the top-management team, seven (35 %) of the 20 newly-hired executives during the period 2000-2006 served as VPs of R&D, and subsequently rotated to other functions. The average rotated functions were 1.9 for those 7 VPs of R&D, which was considerably higher than the average of 26 executives, 1.4 functions (TSMC, 2000~2006). Supported by such rotation of R&D experts, those innovative routines of end-to-end monitoring and coordination, as well as side-by-side cross-functional collaboration, facilitated a two-way traffic to speed up both development of next-generational recipes in the R&D phase and improve yields in the operational phase.

In addition, we observed three innovative routines for modifying from process-innovation to product-innovation. First, TSMC gradually modified its routines established in its extending phase by allocating fewer R&D resources in operational process improvements. Second, to maintain its leading position, TSMC faced an innovation dilemma in that its advanced process-technology was ahead of the design-specs of its customers. Consequently, fewer fabless and IDM customers have the capability to design the specs ready for test-run in the R&D phase. Third, to bridge such widening gaps between design-specs and manufacturing platforms, TSMC modified its subsidiary of design service as SIP provider to stimulate the capacity demand of its next-generational platforms. Without those required SIP of higher resolutions ready for simulated recipes, the speeding investments of TSMC in next-generational platforms may delay to harvest its economies of scale, particularly when over-specs are sustained.

##### 4.4.1 Speeding Trap

Therefore, we found that the routines of *acting what's next*, although driving technological innovation, also lead to a unique type of success trap: *speeding trap*. When TSMC accelerated the explicit performance-effect to proactively cope with uncertainty associated with innovation, such speeding also generated implicit side effects of over-specs to trap itself in a loop of over-capacity.

Because the incumbent SIP houses preferred to design the standard SIP in higher resolution for a customer, who pays the design fee, it was more difficult for TSMC to find a development partner to provide a simulated recipe, equipped with all necessary SIP's for test-runs. Therefore, TSMC expanded the design talents by hiring and merging up to 600 design engineers in 2007, to prepare the in-house simulated recipe.

Because TSMC offers free SIP to its customers as a bundled service with manufacturing, fewer SIP houses can expect a positive return from their investment in designing the SIP for next generational platforms. Unlike the pure-foundry that facilitates the burst of fabless firms, TSMC's SIP-foundry bundled service has decreased the survival opportunity of dedicated SIP houses. Serving as a next-generational enabler, the emerging product-innovation of SIP design may cause TSMC to shift out of its organizational frame of foundry business-model, with a core competence in process-innovation. Moreover, unlike advanced process-technologies when TSMC leveraged co-development with its upstream partners of fabless, SIP, and equipment vendors, its speeding to next-generational platforms caused TSMC to rely more on its in-house design talents to prepare the simulated recipes in both R&D and operational phases.

Consequently, the future customer-base of TSMC has shrunk in both the number of customers and the size of orders. As a technology-leader, the routines of TSMC toward disciplinary over-exploration may increase the risk of its excess capacity in the next-generational platforms. As a latecomer, TSMC created and realized the growth opportunity as a new business-model of pure-foundry for itself, its customers, and its emerging economy, Taiwan, by *acting what's next* to proactively specify and expand future demand. Applying the analytical view of inertia (Dobrev, Kim, & Carroll, 2003; Miller & Chen, 1994; Tripsas & Gavetti, 2000), the speeding inertia of TSMC toward next-generational technologies may trap it in a loop of over-exploration for advanced technologies and under-exploitation for mature technologies. As an emerging leader, when speeding innovation in such a highly disintegrated value-net, how to balance over-exploration versus over-exploitation becomes more challenging. Therefore, we propose Proposition 2 to specify a future challenge of an emerging technology-leader.

**Proposition 2:** *The speeding trap intensifies over-exploration of technological innovation, especially for an organization proactively co-evolving with its industry.*

## 5. Implications and Conclusions

Derived from the macro and micro co-evolutionary dynamics of TSMC, the following section presents our managerial implications and conclusion.

Our research offers three lessons for managers, including lowering *barriers to imitate* best practice for technological innovation, lowering *barriers to innovate* by sequential strategic renewals, and watching out a unique type of success trap, *speeding trap*. First, when organizational routines become more explicit to facilitate dynamic capabilities for technological innovation, such as *acting what's next*, organizations may lower their *barriers to imitate* the best practice by developing and improving such routines. Eisenhardt and Martin (2000) used 'best practice' to represent dynamic capabilities, and indicated idiosyncrasies in their details and path dependence in their emergence. Our research findings specify the idiosyncratic paths of TSMC, and its detailed routines to breed innovation, even for a technology latecomer with almost no technological foundations.

Second, the successful transformation of TSMC in developing its dynamic capability through sequential strategic renewals in its creating, extending, and modifying phases may help to lower *barriers to innovate*, especially for technology latecomers located in emerging economies. In each phase, one core innovative strategy was specified as mature process-innovation, advanced

process-innovation, or product-innovation, which was interlinked with multiple supporting organizational routines. Finally, further management attention on *speeding trap* is required, even though such a success trap is not an intentional outcome of the renewing organization. When an emerging leader such as TSMC changes the industry landscape from under-specs to over-specs, the growth driven by routines of *acting what's next* may trap such a company in a loop of over-capacity, because of long-term disciplinary over-exploration. Consequently, the extraordinary success of TSMC manifests the challenges of balancing over-exploration versus over-exploitation when proactively integrating strategies and routines for maintaining its leadership in technological innovation.

This study offers contributions in making implicit transformation mechanisms explicit through a qualitative approach and inductive methods. For untangling the emergence and evolution of technological innovation, our research framework synthesized the perspectives of dynamic capabilities and co-evolutionary dynamics. From the co-evolutionary perspective, the TSMC case demonstrates *multi-motor* and *multi-phase* strategic renewals, evolving from managed selection in its creating phase, hierarchical renewal in its extending phase, to holistic renewal in its modifying phase. The co-evolutionary dynamics of TSMC demonstrates two unique co-evolutionary paths: transforming from industry latecomer to technology leader and modifying process-innovation to product-innovation. We observed a unique type of organizational routines, *acting what's next*, because TSMC proactively searched for problems ahead of its competitors. Nonetheless, we found that such routines, although driving technological innovation, lead to a unique type of success trap, *speeding trap*.

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**Appendix 1a:** Co-evolutionary dynamics of managed-selection path in the creating phase of TSMC for business-model innovation since 1987

Innovation <i>Business Model</i>	Motors of co-evolution <i>dVvSR</i>	Managerial intentionality <i>Limited</i>	Renewal journey <i>Co-evolutionary</i>	Micro co-evolution <i>Facilitative</i>	Macro co-evolution <i>Survival, new unit development</i>
<i>To first commercialize the business model of dedicated foundry</i>	<p><i>Deliberate variation:</i> As ITRI Chairman, Morris Chang foresaw foundry as the optimal option for Taiwan as a semiconductor latecomer.</p> <p><i>Vicarious selection:</i> In 1987, convinced by Dr. Chang's proposal, ITRI and Philips found an international JV, TSMC, as the first dedicated foundry. By contrast, Intel, NEC, and TI did not accept such an IJV proposal.</p>	<i>As top management</i> , TSMC founders created a strategic context for nurturing and selecting promising initiatives, which were confined in manufacturing diversified chip-designs and developing next generational process technology. In late 1980s, TSMC did not receive sufficient orders from local designers because of its over-advanced facility, and from foreign designers because of a lack of confidence in a new foundry.	Both TSMC founders renewed their current routine in forming TSMC. Foundry was selected because of the mixture of <i>market selection</i> , based on Taiwan as latecomer, and <i>managerial adaptation</i> , based on limited growth of the first semiconductor firm in Taiwan, UMC (an IDM span-off from ITRI in 1982), and exploiting Philips' technology assets in emerging economy.	<i>TSMC founders</i> amplified technological variety in foundry by speeding up the delivery cycle-time and the roll-out of multi-generational nodes. Therefore, the bottom-up renewal initiatives focused on shorter cycle-time from industry standard of 12 to 4 weeks, and higher yield in manufacturing.	For a foundry, a fab of a particular technology-platform may serve as unit. Market selects the most efficient fab. TSMC maintained 1 <sup>st</sup> position, even after UMC transformed its business-model from IDM to foundry in 1995, and the technology leader, IBM, span-off its fab as a foundry in 2002. The foundry has changed the industry landscape, where less incumbent fabs invest in excess capacity, and more fabless firms are found or spin-off from downstream chip-users.
<i>To transform its business model to eFoundry (service-oriented firm)*</i>	<p><i>Deliberate variation:</i> TSMC Chairman and CEO, Dr. Chang, foresaw foundry as service-oriented business.</p> <p><i>Vicarious selection:</i> Stepping on technology foundation by learning routines, TSMC re-engineered its manufacturing focus toward service-oriented eFoundry in late 1990s.</p>	<p><i>As top management</i>, Dr. Chang created a strategic context to improve flexibility and transparency for serving diversified customer requirements.</p> <p>As semiconductor mentality against service, most TSMC engineers transformed their manufacturing inertia.</p>	The eFoundry was selected based on the mixture of <i>market selection</i> , because of the higher demand for advanced or complex chips, and <i>managerial adaptation</i> , because of the higher risk of excess capacity if relying only on mature technology.	<i>Top management</i> amplified demand variety in serving customers by a collection of Internet-based programs, such as TSMC On-Line. Therefore, the bottom-up renewal initiatives focused on methods to achieve higher customer satisfaction.	TSMC developed a new unit of virtual fab called eFoundry, allowing customers and TSMC to cooperate in design, logistics, and engineering. Market selected eFoundry because it worked as in-house fab. The eFoundry has changed the industry landscape, because such renewal into customer-oriented culture facilitated TSMC to transform into technology leader.

**Data Source:** The contents are organized based on archival data and field interviews by the framework adopted from Volberda and Lewin (2003).

**Note\*:** Please refer to the TSMC case of Stanford Graduate School of Business for the details of eFoundry (Shneorson *et al.*, 2006).

**Appendix 1b:** Co-evolutionary dynamics of managed-selection path in the creating phase of TSMC for mature process-innovation since 1987

Innovation Mature Process	Motors of co-evolution <i>dVvSR</i>	Managerial intentionality <i>Limited</i>	Renewal journey <i>Co-evolutionary</i>	Micro co-evolution <i>Facilitative</i>	Macro co-evolution <i>Survival, new unit development</i>
<i>To transfer fab-facility and building teams from its local founder -- ITRI</i>	<i>Deliberate variation:</i> As government-sponsored institute, ITRI built the first 4", 6", and 8" fabs in Taiwan for spinning-off to private entity. <i>Vicarious selection:</i> TSMC was selected because it was expected to maximize the semiconductor growth in Taiwan.	<i>As top management,</i> ITRI created a strategic context for TSMC to learn to design and build 6" and 8" fabs. TSMC did not develop the next- generational fab (12") until 1999.	ITRI renewed its fab-transfer routine from leasing its 6" Fab 1 in 1987, to bidding its 8" fab in 1994. ITRI also transferred 150 team- members building 6" fab to TSMC, and 330 of 8" fab to Vanguard, a bidding consortium of 14 firms lead by TSMC.	ITRI amplified variety to upgrade fabs from 6" to 8" wafers for memory IC. Therefore, TSMC's bottom-up renewal initiatives focused on upgrading resolution-nodes from 1.5 to 0.15 micron, and building 2 other fabs of 6" in 1990 & 1992, and 6 fabs of 8" in 1995-2000, for capacity expansion.	The 10 fabs built based on the mature technology transferred from ITRI, offered 11 nodes, ranging from 1.5 to 0.15 micron. Fab 1 was decommissioned in 2002 when the lease expired, and Fab 7 in 2006, replaced with 12" capacity.
<i>To transfer mature technology from its foreign founder – Philips</i>	<i>Deliberate variation:</i> Philips transferred its volume technology to TSMC, and paid a loyalty fee. TSMC also entered the technical cooperation agreement with ITRI, free of charge. <i>Vicarious selection:</i> To protect its technology assets, Philips licensed mature technology to TSMC under certain equity criteria.	<i>As top management,</i> Philips created a strategic context to protect its latecomer JV by granting its patents and cross-licensing with others for free if its equity remained at a certain level.	As technology leader, Philips renewed its growth-routine to license to its latecomer JV based on the mixture of <i>market selection</i> , driven by sharing costs of capacity expansion, and <i>managerial adaptation</i> , driven by exploiting its technology assets.	Philips amplified variety for TSMC to reduce its dependence on licensed-technology when paying royalty. In 1997, Philips agreed to reduce the royalty term and deduct any license fees and defense costs that TSMC paid to any third parties from such royalty payment, starting from 2002.	In 1999, Philips and TSMC found a JV in Singapore, Systems on Silicon fab, based on the successful alliance as TSMC.
<i>To catch up ITRS roadmap* by operational improvements</i>	<i>Deliberate variation:</i> TSMC focused on exact-copying the mature technology by 1999. <i>Vicarious selection:</i> As latecomer, TSMC had to catch up to a two to one generational gap behind ITRS roadmap.	<i>Top management</i> of TSMC created a strategic context to focus on incremental improvements mainly on yield, led by the operation function.	TSMC renewed its learning routines based on the mixture of <i>market selection</i> , driven by lower average costs of next- generational nodes, and <i>managerial adaptation</i> , driven by exploiting its capacity.	<i>Top management</i> amplified variety among technology nodes. Therefore, its bottom-up initiatives focused on learning by undertaking more advanced recipes provided from equipment-suppliers and design-customers.	This catching-up foundry changed the industry landscape. More fabless firms advanced their design competence closer to IDM. A number of IDM's also outsourced advanced design when their capacity was constrained.

**Data Source:** The contents are organized based on archival data and field interviews by the framework adopted from Volberda and Lewin (2003).

**Note\*:** ITRS (International Technology Roadmap for Semiconductors) roadmap is the fifteen-year assessment of the future technology requirements of the semiconductor industry. These future-needs drive present-day strategies and development among manufacturers' research facilities, universities, and national labs.

**Appendix 2:** Co-evolutionary dynamics of hierarchical-renewal path in the extending phase of TSMC for advanced process-innovation since 1999

Innovation <i>Advanced Process</i>	Motors of co-evolution <i>Administrative</i>	Managerial intentionality <i>Concentrated in top management</i>	Renewal journey <i>Teleological</i>	Micro co-evolution <i>Autocratic</i>	Macro co-evolution <i>Local change</i>
<i>To recruit R&amp;D talents from the technology leaders (unlearning by expanding organizational slack)</i>	TSMC expanded its base of employees from 5908 in 1998 to 15880 in 2000 (App. B). In the top-management team, 20 (77 %) of 26 executives were hired after 1996; 15 (75 %) of the newly-hired staff worked for technology-leaders. TSMC offered competitive bonus scheme and decision empowerment to attract the “top-guns” of both experienced and young talents.	<i>Routine of expanding slack, spreading out from R&amp;D talents:</i> Among the 20 newly-hired executives, 7 (35 %) served as VP of R&D, and subsequently rotated to other functions. The average rotated functions were 1.9 for those VP's of R&D, considerably higher than that of all 26 executives who only rotated 1.4 functions.	<i>Experimenting mixed generational slack:</i> The R&D talents from technology leaders hired and trained young talents for building an independent R&D team, instead of learning from the founders. As a comparison, Intel requires an engineer to have a minimal of 15-years experience before joining R&D; whereas the majority of TSMC's R&D entrants are new Ph.D graduates.	TSMC started to invest in developing next-generational technology since 1993. The current routine emerged from the combinations of senior experts' experiences in diversified technology leaders and juniors' fast experiments of diversified practice.	Following ITRS roadmap, most semiconductor players invested in the development of 0.13-node on 12” wafer with two major technology migrations to copper-interconnect and low-K. Those who built the new capacity producing 12” wafer were expected to enjoy the cost-down benefits associated with such migration. Using a memory product of DRAM as an example, the average cost of 6” wafer was 180 % that of an 8” wafer.
<i>To decline IBM's offer of technology transfer (unlearning by giving up learning opportunity)</i>	As the world leader in copper-interconnect, IBM offered TSMC to transfer its technology in 1999, at a fee of USD 100 million. During one-year evaluation period, the majority non-R&D executives of TSMC supported the acceptance of this offer because of a lack of proven records of self-development. The major concern to accept IBM's offer was competitive timing. TSMC estimated one-year lag behind IBM when R&D lines at IBM needed to transfer to operation lines at TSMC.	<i>Routine of transforming to technology leader, spreading out from independent R&amp;D:</i> TSMC counter-offered to IBM to allow two developmental sites, to ensure that the emerging R&D routine did not change twice (from Hsin-chu to Fishkill, and back). As expected, IBM rejected this counter-offer.	<i>Experimenting independent R&amp;D without technology transfer:</i> Although the majority preferred acceptance, and internal debates lasted for one year, TSMC rejected IBM's offer. The top- management of TSMC was committed to establishing an independent R&D for long-term competitive advantage. TSMC rejected IBM's offer	TSMC started to invest in developing next-generational technology since 1993. The size of R&D team grew from approximately 300 in 1999 to 1000 in 2006. The R&D routine emerged from the combinations of senior experts' experiences in various technology leaders and juniors' fast experiments of diversified recipes.	Upon TSMC's rejection, IBM turned to TSMC's main competitor, UMC, which ranked as 2 <sup>nd</sup> foundry with a capacity of 82 % of that of TSMC in 1999. Without lengthy discussion, UMC accepted this offer with a mandate to beat TSMC in next generation, and sent 50 young R&D employees to Fishkill to learn from IBM. However, UMC discontinued this alliance because of a crucial flaw in IBM's low-K technology of silk, and re-built another R&D team in Hsin-chu to develop 0.13-node.

(To be continued on the page 19th)



**Appendix 2: Co-evolutionary dynamics of hierarchical-renewal path in the extending phase of TSMC for advanced process-innovation since 1999****(To continue)**

<i>To proactively search for problems for detecting potential defects as early as possible (unlearning existing operation)</i>	Unlike the R&D of operation team focusing on incremental improvements, the mission of R&D was the early detection of all possible problems of future recipe after migrating to next-generational node. When a problem was identified, the whole organization worked together to develop the solution (future recipe), as early as R&D phase.	<i>Routine of search-for-problems spreading out from R&amp;D:</i> When migrating from a specific resolution-node to the next, the parameters of each 300~500 steps required adjustment to balance performance and defect. Moreover, a dedicated foundry such as TSMC must accommodate wider design diversity than most leaders, such as Intel.	To save the experimental costs and speed the developmental process from the version 0.1 recipes of R&D lines to version 1.0 of first operation line, the R&D team designed minimal runs of parameter-sets targeting to expose all potential problems when manufacturing the recipes of next-generational node.	TSMC maintained a speeding path as a migration to the next resolution-node every two years. Such a path required unlearning the operational recipes accumulated from the previous technologies. During the period of 1987 to 2005, TSMC migrated from initial 1.5-node to another 10 nodes, up to 0.09 micron.	When launching 0.35-node in 1997, TSMC lagged 1 year behind the advanced leaders. It caught-up to 6 months for 0.25-node in 1998, and up to no lag for 0.18-node in 1999. After the unlearning period, TSMC maintained a position of at least 3~6 months ahead of ITRS roadmap, which attests to its successful transformation from technology latecomer to technology leader.
<i>To co-develop with customers and suppliers (unlearning existing designs and equipment)</i>	Unlike the creating phase, when TSMC learned from its customers and suppliers, it started to form co-development partnership for the advanced process technologies of 0.13 node on 12" wafer. Using the leading equipment vendor as an example, Applied Materials (AM) co-developed with technology leaders and subsequently sold the equipment with proven recipes to TSMC. The co-development model was formed through the joint-project with TSMC for developing low-K technology by black-diamond material in 1998.	<i>Routine of search-for-problems spreading out to partners:</i> TSMC's selected co-development partners also participated in the search for future problems. When IBM focused on low-K technology by silk, which provides the lowest K in lab, TSMC simultaneously tested the recipes by silk and alternative materials.	<i>Joint-experiments for future recipes with partner:</i> Based on the parameters from the design for projector IC, TSMC conducted the thermoelectricity-test on all alternatives, and found the substantial problem of leading material, silk, earlier than IBM. IBM failed to discover such over-heat problem of silk before it was able to change to alternative materials.	Without taking any technology for granted, TSMC extended such proactive search for problems beyond its firm-boundaries to its upstream partners of equipment suppliers and downstream partners of fabless designers. TSMC maintained such co-development routine until the gaps of IP in next-generation were excessively large to bridge.	Since TSMC co-developed the recipes of 0.13-node and built the fab-capacity earlier than others in 2001, 8 IDM's, including Intel, AT&T, & TI, adopted a new outsourcing approach, called "phase-in." They outsourced their new recipes to TSMC, which did not volume-produce in their own fabs. The success of phase-in not only secured TSMC's future orders, but also changed the industry landscape. A number of IDM's stopped upgrading their fabs for advanced technology. Moreover, TSMC started to serve as the certification-site of advanced process technologies for semiconductor industry.

**Appendix 3a:** Co-evolutionary dynamics of holistic-renewal path in the modifying phase of TSMC for advanced process-innovation since 2002

Innovation	Motors of co-evolution	Managerial intentionality	Renewal journey	Micro co-evolution	Macro co-evolution
<i>Advanced Process</i>	<i>Collective sense-making</i>	<i>Organization wide</i>	<i>Cyclical</i>	<i>Transformational</i>	<i>Core change</i>
<i>To extend monitoring system in R&amp;D lines (as radar screen)</i>	The detection of potential problems (disease) requires widespread organizational awareness. For a foundry business, consistent high die yield is not only a high quality indicator, but also a low cost driver.	<i>Routine of early-detection:</i> As early-signals, TSMC extended monitoring system on operations into R&D lines, including explicit measures by Quality & Reliability team, and cost-tracking and forecasting by Accounting team.	The whole organization of TSMC was exposed to experiments of advanced process technologies. Such early involvement of non-R&D teams allowed them to discover potential problems that may be neglected by R&D engineers.	The same system independently monitored the end-to-end process from early development, hand-over from R&D to operational lines, to operational improvement.	Since launching a 0.13-node in 2002, TSMC emerged as the leader in advanced process technology to maintain a leading edge of 3 to 6 months ahead of its competitors. Serving as a certification site, TSMC's co-development team specified the safe-zones of each manufacturing process.
<i>To timely deliver by end-to-end coordination (Operation-lead)</i>	The development of future recipes required disciplinarily coordination of end-to-end participation. Filling new capacity (immunity) requires timely delivery of volume production ahead of its competitors.	<i>Routine of timely-delivery:</i> TSMC set up a new matrix team, called program management, under operation VP and subsequently upgraded it to CEO for next-generation development and major operational improvement. Its main mission was to push all project members to follow the targeted time-line.	The routine of program management emerged from weekly lunch-meetings when developing 0.13-node. The founding staff of program management was transferred from Marketing, R&D, and Operation functions. The rotation of managers and engineers among these three and other roles is a common practice in TSMC.	The timely delivery of the next-generation operation not only influenced TSMC's profits, but also directly influenced its team and individual bonuses. Therefore, all the project members prioritize the target time-line.	Because the source of defects differ from one-node to another, and from one combination of design-specs to another, TSMC's co-development team experimented with all existing combinations and simulated sets as early as possible, even before the equipment was produced.
<i>To smoothly hand-over by side-by-side collaboration (organizational wide drill)</i>	The application of future recipes in volume operation requires widespread organizational collaboration. Because of the cost-down benefits, the profit margin of next- generational node is higher.	<i>Routine of smooth hand-over:</i> In addition to early involvement of non-R&D teams in development stage, approximately 1/3 of R&D engineers were assigned to support the operation lines during hand-over period, and formed projects for improvement after hand-over.	<i>The job-rotation is two-way traffic.</i> The emerging trend in which a number of operational managers and engineers rotate to R&D team further blurred the boundaries between current and next-generation technologies. Such two-way rotation also facilitates cross-functional communication and coordination.	The future recipe co-developed by end-to-end involvement of TSMC with its upstream and downstream partners can be smoothly applied to the operation lines that are ready for improvement.	TSMC's role as certification site has changed the industry landscape. First, the equipment suppliers rely on TSMC's specs to produce equipment for advanced process technologies. Second, the advanced fabless firms have no alternative but to follow TSMC's design-recipes by sharing R&D costs.

**Appendix 3b:** Co-evolutionary dynamics of holistic-renewal path in the modifying phase of TSMC for product-innovation since 2002

Innovation <i>Product</i>	Motors of co-evolution <i>Collective sense-making</i>	Managerial intentionality <i>Organization wide</i>	Renewal journey <i>Cyclical</i>	Micro co-evolution <i>Transformational</i>	Macro co-evolution <i>Core change</i>
<i>To allocate less resources in operational improvements</i>	The sales team proposed technological improvement plan based on the current customers' pending demand for mature technology, such as aluminum-interconnect.  The competitors, such as UMC and Charters, which were behind TSMC in advanced nodes, focused their customization efforts on mature technology.	The sales team required three years to convince the top-management to allocate R&D resources in customization of mature technology. During this period, a number of customers switched their orders to competitors of TSMC.	TSMC allocated more R&D resources to advanced rather than mature technology, to confine the scope of experiments in future specs.	The business opportunities embedded in mature technology may be under-exploited when the whole organization invests insufficient resources and, more important, pays more attention to future demand than the pending demand of current customer base.	Fewer fabless designers were able to catch up with TSMC's speeding in advanced process technology. Conversely, more low-end customers emerged who may not be satisfied with TSMC's service in regard to cost and quality.
<i>To create problems when process technology over design-specs (Innovator's Dilemma)</i>	The further ahead TSMC's advanced process technology, the wider the gap of the semiconductor value net, which facilitated the IC-design on next-generational node.  The cost to design on next-generational node was higher than the cost-down benefits, which justified migration.	When TSMC became the dominating leader in prototyping and verification, time-to-market was driven more by TSMC's new capacity rather than the demand of its customer for next generational technology.	<i>Experimenting with a new competence:</i> Since 1991, TSMC's design service has focused on standard cell solution for the mature technology. Currently, it switches to next- generational nodes.	To enable the next-generational nodes, TSMC tripled its design service team up to 600 in 2007. It is in-charge of designing the future recipes, instead of consolidating from its design partners.	Market selects the timeliest efficient firm. Similar to the founding condition of TSMC, offering more advanced technology than its local designers could afford, TSMC currently offers more advanced technology than all the designers could afford.
<i>To convert design service to IP house to cope with the curse of economy of scale (drifting out of foundry)</i>	TSMC's customer, SONY, postponed its orders on next-generational nodes because standard IP was not available.  The current IP houses did not invest resources in those IP's because more time was required for the IP market to make such an investment profitable.	Because of speeding the capacity building on next-generational platform, TSMC faced a dilemma to delay the time-line of capacity ramp-up or speed up the design competence by proactively designing the advanced IP in house.	<i>Experimenting a detour from foundry:</i> Serving as a capacity enabler, TSMC's design service designed future recipes and associated IPs, such as input/output and MP3.	The expansion of design service extended TSMC's core competence from process technology to IP-design, which is a necessary complementary competence to fill the new capacity of next-generational nodes.	Fewer IP houses can survive when the standard cells in advanced technology are provided by TSMC to its customers free of charge. The disintegrated value-net, enabled by TSMC since 1987, may virtually converge in advanced nodes in the future.