Abstract

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System Failures Co-Evolution:  
An Empirical Evidence from Taiwan’s Electric Vehicle Sector

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The study explores an evolving sectoral system of Taiwan’s electric vehicle sector which has failed to system failures of vicious cycles, despite its system has strong governmental supports. The empirical investigations were conducted by using a two-stage design of the patent search from a period of 1990-2014 and the use of inductive interview methods. The results reveal that the four time-periods of Taiwan’s electric vehicle systems are demarcated by the four agent-level blocks and present that heterogeneous system failures composed by agent-level blocks are interdependence and interaction in which these underpin how and why such sectoral system imperfection occurs. Institutional failures drive other agent-level system failures to have reciprocal interdependence and contribute to the development of imperfection in the sectoral innovation system. We conclude that the proposed policy framework of agent-level sectoral innovation systems based on strategic-oriented innovation allows legitimizing and insights of system imperfection in the Taiwan’s electric vehicle sector, and such framework offers an critical device for understanding transitional change in the certain sector. Finally, some further policy implications for how to escape the system failures of vicious cycles are discussed.

Keywords: Vicious cycle, Sectoral innovation system, Electric vehicle sector
1. Introduction

The development of the electric vehicle industry is one of the main priorities of Taiwan's industrial policy, as demonstrated in a series of industrial legislation and regulation including the “Smart Electric Vehicle Development Strategies and Action Plan”. Nevertheless, despite a considerable degree of government support, Taiwan’s electric vehicle industry is awarded to the information technology area. This implies the absence of a rationale why the performance of Taiwan's electric vehicle industry is far inferior to that of information communication technology sectors, since these two industries operate in homogenous technological regimes and share a common innovation systems supported by government (Nelson & Winter, 1977, 1982). To challenge legitimizing for the evolving system of Taiwan's electric vehicle, government conducts a goal-oriented sectoral innovation system approach (Malerba, 2002, 2004, 2005a) to aim at understanding sectoral patterns of change and facilitating critical system factors that affect performance and competitiveness of social-economic agents and institutions (Malerba & Mani, 2009). However, crucial emerging problems affecting system performance of the sectoral innovation call for the policy intervention that brings difficulties in a closely coordination of these interactive behaviors since such system depends on performance of its agents' interaction and institutions governing. Indeed, the rationale for government intervention goes beyond market failures (Arrow, 1962) and has to shift from important systems failures (Chaminade & Edquist, 2010; Smith, 2000; Woolthuis, Lankhuizen, & Gilsing, 2005). Many types of system failures are identified in Taiwan’s sectoral system. For example, infrastructure failures, network failures, institutional failures, actor failures and capability as well as competence failures (Carlsson & Jacobsson, 1997; Edquist, 1997; B. Johnson & Gregersen, 1994; Woolthuis et al., 2005), and transition as well as
lock-in failures (Jorgensen, 2012; Smith, 2000). These various system failures are usually connected and mutually interdependent with the success of sectoral innovation systems (Hu & Hung, 2014).

In line with view of strategic niche management and transition management (Elzen, Geels, & Green, 2004; Geels, 2004, 2005; Hoogma, Kemp, Schot, & Truffer, 2002; Schot & Geels, 2008; Schot, Hoogma, & Elzen, 1994), these approaches indeed emphasize transformative activities and a new regime adoption of sustainable development for goal-oriented sectoral innovation systems to handle the system imperfection, however, they are only loosely connected with innovation policies and conceptual framework (Bleda & del Rio, 2013; Weber & Rohracher, 2012; Woolthuis et al., 2005), and thus have not gained empirical evidence for sufficient legitimacy and impact such system performance (Negro, Alkemade, & Hekkert, 2012). Recently, many important arguments based on functional theories in support of transition-oriented policies and alternative regime adoption policies contend use of technological innovation system (TIS) approach with focus on technology-specific innovation policies to deal with such system imperfection problems (Markard & Truffer, 2008; Suurs & Hekkert, 2009; Weber & Rohracher, 2012). Nevertheless, these existing studies with focus on the technology-specific approaches are certainly danger in neglecting interactions with other system environmental elements such as sectoral contexts (Jacobsson & Bergek, 2011) and they only draw attention on specific emerging technologies but lack of fully tackling crucial sustainable problems of existing sectoral systems towards the new competitive regimes (Weber & Rohracher, 2012). From our point of view, we assert that the conceptual foundation and actual implementation of sectoral innovation system by integrating strengths of strategic-oriented innovation policies may significantly improve complicated
heterogeneous system failures having cumulative interdependence in vicious formations. The higher acceptance in vicious formations of these system failures gains better rationales and relationships of understanding sectoral innovation system on imperfection as justification for legitimizing policy intervention.

In this paper, we argue that the proposed framework of agent-level sectoral innovation systems based on strategic-oriented innovation policies indeed deal with heterogeneous system failures formed vicious cycles in the Taiwan's electric vehicle industry. With offering empirical evidence of the study, we analyze the Taiwan's case by introducing insightful debates to present how to escape such vicious cycles and make innovation policies ready to face the grand challenges on the evolving system of Taiwan's electric vehicle. These vicious cycles highly connected by four building blocks of the sectoral innovation systems framework have heterogeneous system failures that emerge the cumulative interdependence (see in Figure 1). In the vicious cycles, these heterogeneous system failures limit and hinder to agent-level interactively technological and organizational learning and capabilities as well as competence accumulation. Such restricted interaction patterns of accumulation at the levels of agents and institutions result failing in success of sectoral innovation systems. The vicious cycle is sketched in Figure 1.

<<INSERT Figure 1 HERE>>

2. Literature Review

2.1 Sectoral Innovation Systems

The original concept of sectoral innovation systems was defined by Malerba (2002). According to the Malerba's definition, the sectoral system focuses on a set of new and established products for specific uses and the set of agents carrying out market and non-market interactions for the creation, production
and sale of those products (Malerba, 2002). This system is an integrated and dynamic view of sectoral compositions which involves the knowledge base, technologies, inputs and an existing, emergent and potential demand. However, such seminal work (Malerba, 2002) presents two important factors driving the sectoral system that undergoes dynamic processes: agents and institutions. Specifically, the agents in the sectoral systems include firms (e.g., users, producers, and input suppliers) and non-firm organizations. The non-firm organizations cover wider agents that include universities, financial institutions, government agencies, trade-unions or other technical associations. These agents are characterized by specific learning processes, competences, objectives, organizational structures and behaviors and interact through processes of communication, exchange and cooperation. Such of interactions among the agents are shared by institutions or regulations and rules.

Malerba (2005a) had identified three main building blocks for the sectoral innovation systems as a composed set of knowledge and technology, actors and networks, and institutions. These compositions can be described as the collective outcome of the co-evolutionary interactions among the building blocks (Malerba, 2002, 2004, 2005b). Empirical evidences have suggested that sectoral patterns of system innovation undergo processes of change through the co-evolution of its various blocks (Malerba & Orsenigo, 1997). In order to clearly demonstrate the evolving system of Taiwan's electric vehicle, we elaborate the agent-level sectoral innovation system in terms of four building blocks: knowledge and technology, actors, networks, and institutions as follows:

2.1.1 Knowledge and technology

Knowledge and technology stand at a center of sectoral innovation systems. The focus on knowledge and technology has an issue of cross sectoral boundaries
that are affected by the knowledge base and process of knowledge accumulation (Dosi, 1997; Malerba, 2005a, 2005b; Metcalfe, 1998). This constitutes constrains on the full range of diversity and taxonomies in the agents’ behaviors (Malerba & Orsenigo, 1990, 1993, 1997) where complementarities and links among different activities define the real boundaries of the sectoral system. Thus knowledge and technology have characterized an important block to affect firm’s innovative behavior and decide firm’s innovative activities, so called technological regimes (Malerba & Orsenigo, 1993, 1997, 2000). The technological regimes describe the set a specific behavior boundary for firms’ innovative activities (Winter, 1984) and also can be seen as the knowledge environmental conditions in which firms learn and create knowledge under different situations (Nelson & Winter, 1982). These conditions are likely to affect the rates of technological progress and the diffusion process (Malerba & Orsenigo, 2000).

2.1.2 Actors and Networks

The sectoral innovation system is mainly composed of heterogeneous agents that involve the organizational and individual actors (e.g., users, entrepreneurs), essentially describing the sectoral structure. The organizational actors include firms (e.g., users, producers, and suppliers) and non-firm organizations (e.g., universities, financial institutions, government, trade-unions, and technical association). These also cover sub-units of larger organizations (e.g., R&D center or other departments) and groups of organizations (e.g., industrial associations). The individual actors include users, producers, and suppliers. These different agents are characterized by learning processes, competencies, beliefs, goals, organizational structures and behaviors (Malerba, 2005b). They interact through the different process of communication, exchange, cooperation, competition and command (Malerba, 2005a). Within a sectoral system, the heterogeneous actors
are connected in various ways through market and non-market relationships. These connections between actors described as networks offer clues to integrate complementarities in the knowledge, capabilities and specialization (Edquist, 1997; Lundvall, 1993; Nelson, 1995), and conduct sectoral structures that differ from sectoral systems (Malerba, 2005a, 2005b). According to suggestions by Malerba (2005b), the two types of network relationships are often identified. First, the vertical integration as a main mechanism connects industrial actors who involve in the process of knowledge exchange, competition, and command (Streb, 2003). This type serves as an internal way of knowledge learning, transfer and integration. Second, the formal cooperation and informal interaction among actors or non-firm organizations are examined. Such type of network covers a wider range of interaction such as R&D cooperation, and university industrial collaboration (Malerba, 2002, 2005a, 2005b). These diversity networks between the firms and non-firm organizations become an important source of innovation and dynamic change in the sector over time (Nelson & Rosenberg, 1993).

2.1.3 Institution

Institutions play a major role in affecting rates of technological change and organization of innovative activities of sectoral system. Actors’ actions, behaviors and interactions are shaped by the institutions which include norms, standard, routines, habits, rules, law and common practices (Malerba, 2002, 2004). These are grouped by formal and informal institution settings that emerge either as a result of deliberated planned decision by firms or as unpredicted consequence of agents’ interaction. Specifically, the formal institutions refer to formal regulations of game that include laws and standards delineating an evolving sectoral system. For example, in 1990, California Air Resources Board (CARB) proposed a formal regulation of California Zero Emission Vehicle Mandate (The California ZEV
mandate) (Calef & Goble, 2007) to reduce motor vehicle emissions in California since they convinced of the inadequacy of existing air quality standards. This proposal forced the sectoral agents to introduce a new phase of low-emission vehicles and launched clear fuels to meet the standards. The informal institutions, on the other side, describe the rules that offer legitimacy to individual practices referred by values, shared conception, obligations and common practices (Scott, 1995). Such informal institutional settings are often tentatively assessed in terms of shared visions and patterns of thinking (Faber & Hoppe, 2013). Cowan & Hulten (1996) suggested that transition to electric vehicle regime not only has to focus on regulations but also draws attention on informal institutional settings, such as user’s taste as well as habit.

2.2 System Failures

Innovation system approaches (e.g., national, sectoral or technological) have been instrumental for legitimizing for scientific, technology and innovation (STI) policy (Edquist, 1997; Lundvall, 1992; Nelson, 1993). These innovation systems put an emphasis on interactive process and non-linear learning in which actors, e.g., firms interact with a manifold agencies and organizations (e.g., universities, research institutes, customers, government agencies) and institutions (e.g., IPR regime, regulations). This complex process, reciprocity and feedback determine and support their success of innovative activities and capabilities in the specific system contexts (Edquist, 1997; Lundvall, 1992; Nelson, 1993). However, when system imperfections take place, interactive actors within the system focus on difficult in institutions and institutional settings which affect their capacities, learning styles and other actors to innovate (Carlsson & Jacobsson, 1997). These system imperfections may often include knowledge infrastructures (Smith, 2000), inability of structural transition for knowledge adoption (Smith, 2000; Woolthuis,
et al., 2005), insufficient uses and link of research organization and education
(Carlsson & Jacobsson, 1997), ineffective learning (Smith, 2000), flawed
characteristics and contexts of legislation and regulation (Smith, 2000; Woolthuis
et al., 2005). Innovation policies aim at intervening to eliminate these
imperfections and bottlenecks and then creating an institutional environment for
actors who are more conductive to their innovative capacities and synergies and
provide spillover effects (Bleda & del Rio, 2013; Dodgson, Hughes, Foster, &

The basic rationale for policy intervention in innovation systems is based on
the market failure argued by Arrow (1962). The market failure argument focuses
on an innovative environment which leads to under-investment in research and
development. Such rationale of policy intervention aims to provide a sub-optimal
level of investment in technology development and create a potential knowledge
spillover by justifying innovation instruments such as general R&D subsidies, tax
refund and credits incentive (Hauknes & Nordgren, 1999; Jaffe, 1986). However,
other common rationales are often intervened when heading of system failures
arises because such type emphasizes to create mechanisms in contributing weak
system performance (Freeman & Soete, 1997). Categorization of system failures
may differ, but we refer several previous studies (Carlsson & Jacobsson, 1997;
Smith, 2000; Woolthuis et al., 2005) to distinguish four types of failure followed
by agent-level sectoral innovation systems categorization.

2.2.1 Knowledge and Technology Failure

The knowledge and technology failures refer to the absence of the necessary
competences and capabilities to adopt new paradigm and changing circumstance
(Smith, 2000; Woolthuis et al., 2005). This type of failure is compatible with the
capability or lock-in failures. The former refers to firms lack abilities (e.g., human,
organizational, technological and so forth) to make the leap from an old to new regime (Woolthuis et al., 2005), whereas the latter relates to the insufficient abilities to adapt to new technological paradigm due to from social-technological inertia derived and path-dependency constraint (Chaminade & Edquist, 2010). The knowledge and technology failures may lead to the phenomenon that firms lack the capabilities to learn effectively and result in transition problems to the extent that excessive focus on existing technologies to prevent foresee the emergence of new opportunities. The policy intervention for such failures has to support scaffolding assistances for the targeted groups of firms to acquire the qualified capabilities as well as resources and adopt the managerial techniques (Smith, 2000). Moreover, many previous studies have identified that lack of appropriate knowledge and technologies are found among most actors within electric vehicle systems (Masiero, Ogasavara, Jussani, & Risso, 2017; Yilmaz, 2015). For example, (1) lack of technological knowledge of electric vehicle power supply; (2) lack of ability of entrepreneur to pack together and lobby for electric vehicle. (3) lack of ability for users’ purchase to facilitate electric vehicle market demand.

2.2.2 Actor Failure

The actor failures focus on the absence of players (e.g., incumbents, entrants) within the innovation systems who constrain innovative activities (Jacobsson & Johnson, 2000). This type of failure occurs while the market failure is defined as the organization of current market and criteria used to select targeted technology. A new technology may suffer competing incumbent substitutes that have been able to undergo a process of lack of groups of actors. This tends to associate the new competing actors with weak abilities (lack of capability and experience) or low utility (poor performance, network externalities and infrastructure) (Arthur,
If the gap with insufficient groups of firms and strong actors exist, a new technology may not have the chance to rectify such initial disadvantages. In the case of electric vehicle sectors, it has a hard time to break through in the market dominated by traditional internal combustion engine regime which reaps the benefits from large groups of firms and economies of scale. This makes the traditional regime provide cheap and efficient in the large scales of quantities aligned to old institutional setting and users’ preference. However, in search for alternative regime of electric vehicle systems, the policy intervention needs to formulate groups of firms and powerful actors (e.g., universities, research institutes) to involve such competition and has an interference that encourages their heuristics (Negro et al., 2012).

### 2.2.3 Network Failure

The network failure refers to the lack of links, interactions and cooperative relationships between the actors in innovation systems that limit insufficient use of complementarities, interactive learning and opportunities creation (Woolthuis et al., 2005). Carlsson & Jacobsson (1997) distinguished two network failures as weak and strong types that arise in situations where interaction is too weak or too strong. Both of two types of network failures hinder innovations. The former refers to the lack of linkages between actors that result in inhibiting learning and innovations whereas the latter arises when its interactions are too dense to allow for novel insights or new inspirations to emerge (Chaminade & Edquist, 2010). Following the network theory perspective, the weak network failures take place if insufficient use of technological impulses and knowledge structure holes exists (Burt, 1987; Granovetter, 1983), on the other hand, the strong one fail the wrong direction and investment because they are too intensive cooperation to be the blindness resulting from the limited information exchange with outside actors.
(Carlsson & Jacobsson, 1997). In the previous works (Johnson & Jacobsson, 2000), they identified weak and strong network failures as blocking mechanisms in the field of renewable energy technologies (RETs) in Dutch context. Too strong connectivity and intensive network resulted in RETs strategic conformity with respect to homogeneous market position and technological choices may lead to increased vulnerability. However, the weak network relations between industrial providers and universities as well as capital goods suppliers and potential users not only fail to interactively learn but make it difficult to handle technological and market uncertainty.

2.2.4 Institution Failure

The institution failures refer to insufficient sets of formal and informal rules and regulations to limit relations and interactions between the actors and groups of firms within the innovation systems (Edquist & Johnson, 1997; Smith, 2000; Woolthuis et al., 2005). Johnson & Gregersen (1994) had distinguished two institution failures as formal and informal types that play significant roles in the production and dissemination of innovations. The formal institution failures refer to the framework of regulation and general legal system (e.g., rules, law and standards) to constrain innovations whereas the informal ones relate to matters of political and social cultures, social norms and values that shape public policy objectives and macroeconomic environment to hinder innovations (Smith, 2000). Moreover, the institution failures also influence the fundamental establishment of infrastructure that actors need to function (e.g., IT, telecom) and science and technology infrastructure (e.g., laboratory and accommodation, transport, energy supply, science parks) (Smith, 2000). For example, electric vehicle technologies infrastructure are needed than the current internal combustion engine such as charging station and battery swap station (Liu, 2012). These electric vehicle
technologies demonstrate slow diffusion when the refueling infrastructures are not developing quickly enough (Suurs & Hekkert, 2009). Locking of availability of knowledge flows and skills from the academia and research institutes suffer from high risks of renewable technologies and business opportunities (Foxon et al., 2005).

2.3 System Failures of Vicious Cycles

Myrdal (1971) proposed the economic principles of interlocking, causation cycle of inter-dependence within a cumulative process and development circular. This causation cycle nowadays works innovation system approaches either in a vicious or a virtuous circular which may be influenced by the endogenous factors of the local system (e.g., sectoral) (Myrdal, 1971). In the ideal circumstance, the sequence of the sectoral system forms a virtuous cycle and triggers a positive loop. Conversely, a sectoral sequence has conflicts and standstills resulted in the vicious cycle. Now note that in our study of vicious cycles in Figure 1, there are heterogeneous system failures hampering innovative activities and driving toward a negative circular among the innovation systems. Figure 1 identifies the vicious cycles that have exerted heterogeneous types of systems failure influence on the sectoral innovation systems and highlights the strong interdependence between heterogeneous system failures in the vicious cycles of Taiwan's electric vehicle systems. The system failures of vicious cycles in Taiwan's electric vehicle sectors are closely alignment with the agent-level of sectoral innovation systems: knowledge and technology, actor, network, and institution. The vicious cycles of Taiwan's electric vehicle about how to interdepend are presented as follows.

The independence between different system failures of agent-level sectoral innovation systems is an important characteristic for such vicious cycles. While the notion of independence between heterogeneous system failures has been
characterized in a variety of ways, the reciprocal independence mainly identified appear to be particularly relevant to the system failures (Thompson, 1967). It suggests that the output of initiative system failure is penetrated by the other. The output of failure A is the input of failure B, whose output also subsequently becomes the new input of failure A. This distinctive characteristic of reciprocity between two system failures constitutes a contingency for the other failures and its outputs serve as inputs to others and vice versa. In case of Taiwan’s electric vehicle system, for example, an initiative institution failure such as Smart Electric Vehicle Development Strategies and Action Plan (2010) whose intervention has focused on increase in overall subsidies and R&D expenses especially on battery technology development, but these policy interventions fail to catch knowledge advancement on power supply efficiency, battery developed industrialization and domestic content rate [institution failures → knowledge and technology failures]. Since the restrictive knowledge and technology advancement does not achieve policy objectives (e.g., battery efficiency and use, local content ration), this subsequently fails to sectoral policy coherence that shuts down or adjusts the current policy [knowledge and technology failures → institution failures]. The reciprocal failures are likely to be consistently happened in the relations between institution and actors as well as institution and networks. Such initiative institution failures with limited electric vehicle regime vision and narrow share value produce the reduction of active players who involve the game [institution failures → actor failures] and reduction of limited cooperation of R&D alliances and universities and industries collaboration [institution failures → network failures]. Due to lacking of active actors or large established actors involving and limited networks of interaction, subsequently these two reciprocally produce the reduction of sectoral policy facilitation [actor failures → institution failures;
network failures → institution failures]. Moreover, reciprocal independences are likely to found in failure relationships among knowledge and technology failures, actor failures and network failures. Due to apparently failing of knowledge and technology development, this failure produces the limited incentive to attract the actors involving and confined R&D consortia and alliances to faster interactive learning [knowledge and technology failures → actor failures; knowledge and technology failures → network failures]. Also these two failures are no doubt not only generally independent each other (e.g., few actors influence the formation of network; a small network is resulted in few actors involving), but also reflect reciprocity on the knowledge and technology failures. Such limited actors and networks fail to the development of electric vehicle relevant technologies [actor failures → knowledge and technology failures; network failures → knowledge and technology failures] (see Figure 2).

3. Methodology

In the empirical evidence, following a previous study (Hu & Hung, 2014), we conducted an integrative two-stage methods to clarify heterogeneous system failures of vicious cycles of Taiwan’s evolving system of innovation in its electric vehicle industry. In the first stage of analysis, we applied the concept of sectoral innovation systems to Taiwan’s electric vehicle sector and accessed patent-based indexes to capture four agent-level blocks of such sectoral system during years of 1990-2014 by using patent data. The results at the first stage were validated by considering qualitative approaches in the second stage. At such of second stage of analysis, in-depth interviews, archive documents and secondary data related to Taiwan’s electric vehicle industry are conductively analyzed. Each stages of
analysis are now elaborated as follows.

3.1 Patent Search at the First Stage

We used four agent-level blocks of sectoral innovation systems to observe the evolving system of Taiwan's electric vehicle industry. These basis elements of the sectoral innovation system are composed by four building blocks: knowledge and technology, actors, networks and institutions (Malerba, 2002, 2005a). Since the electric vehicle was characterized by advances in science and technology, and usually conducted by premium level of interaction among multi-disciplinary and technological domains (Kumar & Revankar, 2017; Manzetti & Mariasiu, 2015), it is appropriate to obtain by using knowledge stocks and accumulated knowledge (Pilkington, Dyerson, & Tissier, 2002; Yang, Xu, & Neuhausler, 2013; Zhang, Liang, Yu, & Xie, 2017). These four agent-level blocks of sectoral innovation systems were calculated based on the electric vehicle patent numbers, patent owner, co-owned patents and patents granted by Taiwanese assignees. These specific patent-based indexes capture agent-level sectoral innovation system are shown in Table 1.

<<INSERT Table 1 HERE>>

We extracted electric vehicle patents data from the frequently used Derwent Innovation Index database (DII). To accurately capture electric vehicle patents from Derwent Innovation Index database, we closely followed the International Patent Classification (IPC) codes searching strategy utilized by Pilkington et al. (2002); Yang et al. (2013). Each IPC code consists of a hierarchical symbol coding that has descriptive properties with (1) section, (2) class, (3) sub-class, (4) main group, and (5) sub-group. The IPC codes are updated annually and revised every three years to catch technological changes effectively. As for IPC codes for electric
vehicle technologies, we followed prior studies (Pilkington et al., 2002; Yang et al., 2013) and then invited five knowledgeable experts at electric vehicle domains to revise the IPC codes in order to fully capture electric vehicle technologies. Finally, we used a broad range of IPC codes with five-digit at electric vehicle technologies which include five sub-categories such as battery technology, motor technology, motor controlling technology, battery management technology, and entire vehicle controlling systems. The selected IPC codes of sub-categories are listed in Table 2. For instance, IPC codes “H02K 17/”, “H02K 19/”, “H02K 21/”, “H02K 23/”, “H02K 25/”, “H02K 27/”, “H02K 29 ” and “H02K 41/” representing the “asynchronous induction motors”, “synchronous motors”, “permanent magnets”, “mechanical commutator”, “DC interrupter motors”, “AC commutator motors”, “non-mechanical commutator devices”, and “propulsion systems” are essential for electric vehicle motor technologies and are selected. These selected IPC codes are feed into DII database and to avoid the possible duplication, the application number is used to calculate the quantity of electric vehicle patents.

<<INSERT Table 2 HERE>>

We performed the patent data retrieving process from USPTO in May 2016. To eliminate duplicated electric vehicle patents, we checked the frontpage of each patent. After clearing process, we finally identified 2,365 electric vehicle patents granted by Taiwanese assignees during a time period of 1990-2014 among which there are 328 patents associated with battery technologies, 214 patents related to motor technologies, 410 patents related to motor controlling technologies, 809 patents related to battery management technologies and 604 patents related to entire vehicle controlling systems respectively (see in Table 2).

3.2 Conductive In-Depth Interview at the Second Stage
The results of electric vehicle patents analysis at the first stage were verified and validated by using inductive qualitative approach as continued second stage. Importantly, the second stage was to understand the rationale why institutional policy of Taiwan’s electric vehicle sector was intervened as the building block of sectoral innovation systems. Therefore, this stage of data collection and analytic approach exemplifies the historical process research initiatives (Langley, 1999; Pentland, 1999). Such historical process research focuses on understanding of how and why the discrete institutions evolve over time (Elsbach & Sutton, 1992). This analysis process results in the articulation of practices that remain over time or diachronic changes that emerge chronologically across time (Barley, 1990). To demonstrate how Taiwan’s electric vehicle institution influences four agent-level blocks of sectoral innovation systems, we conducted such historical process to understand the evolution and development of Taiwan’s electric vehicle industry.

By perusing historical overviews of actors and events prior to the action plan “Smart Electric Vehicle Development Strategies” (Executive Yuan, 2010), and holding discussions with experts who had been involved in such electric vehicle policy negotiations during this period, we identified some key actors in the field of Taiwan’s electric vehicle policy: government (Board of Science and Technology at the Executive Yuan; Department of Industrial Technology at the Ministry of Economic Affairs; Industrial Development Bureau at the Ministry of Economic Affairs), universities and research institutes (National Taipei University of Technology; Institute of Materials and Chemical at the Industrial Technology Research Institute; Institute of Electrical and Mechanical Systems at the Industrial Technology Research Institute), and industries and businesses (Hua-Chuang Automobile Information Technical Center Co., Ltd.; TECO Electric and Machinery Co., Ltd., and Chroma ATE Inc.). In 2016, 18 in-depth interviews
were held with 13 representatives of these actors (4 from government, 4 from universities and research institutes, and 5 from industries) who had conducted and observed institutional interventions of evolving system of Taiwan’s electric vehicle over time. These interviews lasted 60 to 90 minutes and produced 150 pages of transcripts. Interviewees were asked to chart the policy intervention in the evolving system of Taiwan's electric vehicle, rationales accounting why the policy intervened, and how the policy produced system failures (see in Table 3).

<<INSERT Table 3 HERE>>

In parallel, we collected secondary data to trace back the policy intervention for Taiwan’s electric vehicle. We gathered reports and articles from government agencies, newspapers, media publications and Web from the period 1970-2016. These publications dealt with the key policies for Taiwan’s electric vehicle system, the unfolding of electric vehicle policy negotiations, the status of electric vehicle agreements, and key knowledge and technologies of electric vehicles. Finally, we created a fairly comprehensive set of data from which to identify and triangulate results about policy intervention logics and frames of Taiwan’s electric vehicle.

3.3 Analytic Strategy of Integrative Two-Stage Methods

In analytic strategic of interactive two-stage methods in our study, four steps were conducted. Firstly, we conducted the chronological identification of major historical events that marked the evolution of the debate in the Taiwan’s electric vehicle systems. We began with scientific attention to oil crisis in 1973 as a global issue (e.g., oil crisis) and ended with the plan of Execution Yuan announcement “Smart Electric Vehicle Development Strategies and Action Plan (Second Phase)” in 2014. This had produced the total of 8 major historical events. Secondly, after demarcating array of key historical events, we examined which of these were
field-configuring events (Hardy & Maguire, 2010). These key events provided impetus for policy interventions within the institutional field in Taiwan's electric vehicle systems. Following these 8 historical events, we charted the frames and underlying logics with our interviewees during the focal period and assessed the extent to which these events shifted their frames before, during or after the historical events to understand rationales why system failures of vicious cycles interdepended. Third, we searched for underlying factors based on agent-level sectoral innovation systems that induced policy intervention in each of 8 events identified. We looked for evidence to indicate how, and why different agent-level blocks (e.g., knowledge and technology, actors, networks) were either driving or driven by field-configuring events (e.g., institution) or by other factors' responses to these events. This required analyzing how policy institution affects these agent-level blocks and how policy produced system failures. Finally, the fourth step are used to look globally at the Taiwan's electric vehicle systems arising from outside forces and institutions over time such as economic forces (e.g., oil crisis) and environmental, innovation, and energy policies (e.g., standard of carbon dioxide emissions) (see in Figure 3 and Figure 4).

4. Result

The empirical results are structured by the four stages of vicious cycles. The first stage starts with early attention to the battery electric vehicles (TsingHua No.1) by the scientific community and ends with the Asia Pacific 1 (AP-1, BEV) as well as Asia Pacific 2 (AP-2, switch to HEV) in 1996 (Stage 1: Before 1996). The second stage begins with the 1997 and ends with the passage of technology
development programs and university-oriented programs to develop the hybrid electric vehicles in 2008 (Stage 2: 1997-2008). The third stage starts with the initiative R&D consortium for the battery electric vehicles called Taiwan Automotive Research Consortium (TARC) in 2009 and ends with the importance of Smart Electric Vehicle Development Strategies and Action Plan (first phase) in 2013 (Stage 3: 2009-2013). The final follows electric vehicles developments from 2014 to present day, when Smart Electric Vehicle Development Strategies and Action Plan (second phase) was announced by Execution Yuan (Stage 4: After 2014). Table 4 presents major system failures linked by four agent-level blocks. For each state, we demonstrate the results around agent-level sectoral innovation systems emerged in that phase and introduce agent-level explanation associated with these heterogeneous failures, and present how they have the co-evolution and interdependence relations.

**Stage 1 (Before 1996).** Over past century, Taiwanese government agencies and scientific communities have noted that challenges of oil crises (first oil crisis happened in 1973, second oil crisis happened in 1979) and oil prices have risen significantly. These two external forces attributed to an increased release of large attention “energy saving and carbon reduction” are argued to have consequence of following policy intervention in the evolving system of Taiwan's electric vehicle industry. In Taiwan's electric vehicle system, experimental-based battery electric vehicles of TsingHua No.1 in 1974 and TsingHua No.2 in 1975 elevated the legitimacy of the idea coordinated agents had to the potential to approach. These two battery electric vehicles supported by Taiwanese government agencies (e.g., Ministry of Economic Affairs, National Science Council) are launched to be used
in the public domain but they fail to result from regulatory uncertainty and lacking of coordination policies. By late 1996, electric vehicles research from two disparate vehicles as Asia Pacific 1 (AP-1) performed by BEV and Asia Pacific (AP-2) powered by HEV is organized into industrial coordinated agents such as Formosa Plastic Group and OVONIC corporation. These two disparate electric vehicles are finally shut down because of high R&D costs and insufficient battery charging infrastructure.

The first emergent institutional intervention (or policy frame) we identified was the kick off research and development on the electric vehicles by Ministry of Economic Affairs (MOEA) and National Science Council (NSC) because of growing agreement of energy saving and carbon reduction. The six agent-level reciprocal co-evolution shifts, initiated by government policies, can be seen as contributing to the first stage of vicious cycle of system failures. The first institution failures address regulation problems without through bargaining the Taiwanese political processes (e.g., insufficient coordination policies, lacking of battery charging infrastructure, continuous R&D support) that have emerged with knowledge and technology failures [1a] that capture little patenting activities: 9 (2.74%) patents in battery technology, 1 (0.05%) patent in motor technology, 6 (1.46%) patents in motor controlling technology, 12 (1.48%) patents in battery management technology, and 14 (2.32%) patents in entire vehicle controlling system, and that have compromised on few actors and networks who involve the evolving system [2a, 3a] that have captured the fall of sole-patenting relationship throughout the phase, including 9 (100%) patents in battery technology, 1 (100%) patent in motor technology, 5 (83.3%) patents in motor controlling technology, 11 (91.7%) patents in battery management technology and 13 (92.7%) patents in entire vehicle controlling system respectively (see in Table 4). Similarity, the knowledge
and technology, actor and network failures have no doubt reflection of reciprocal interdependence of institution failures. A large portion of constraint knowledge and technology development, few actors and limited networks coordination are likely to be characterized by reciprocity to insufficiently put forward achieving the policy goals [1b, 2b, 3b]. On the other hand, growing consensus of knowledge and technology failures about electric vehicles also reciprocally reflects actors and network failures. Prior to 1996, the limited focus of technological researches on BEV and HEV was confined in the research labs and sole institute [4b, 5b]. These few actors and networks involve a number of reciprocal knowledge and technology failures that restrict within contributing knowledge development on electric vehicle domains [4a, 5a]. The actor failures also convene network failures that stress reciprocal interdependence activities such as in the case of a large of sole patenting and narrow focus on sole research institute development [6a, 6b].

Stage 2 (1997-2008). Spurred by the stage 1, initial policy intervention and general concerns about environment, Taiwanese government agencies worked to construct on the HEV development by using technology development programs (TDP). Military of Economic Affairs (MOEA) represents the second stage effort to regulate the HEV policies and makes a shift from a previous view of scientific research to an industrialized diffusion growth, acknowledging that narrow focus on power-system components of HEV (e.g., IGBT/MOSFET). From 2001 onward, MOEA supported the Industrial Technology Research Institute (ITRI) to develop an 18W parallel-hybrid power system and 100W related power systems. By 2005 and 2006, MOEA also provides technology development programs to encourage private firms (e.g., Formosa Automobile Corporation, HAITEC) to undertake R&D activities in terms of motor controlling technologies (41.7% occupied by total patents) and entire vehicle controlling systems (31% occupied by total patents).
In particular, HAITEC was established by MOEA support to aim to develop vehicle manufacturers and EV system integration and promise to create its owned brand “Luxgen EV” in 2006. In 2008, there are 16 universities with single focus on HEV researches sponsored by National Science Council (NSC) called “intelligent light moving vehicles technology programs”, they mainly emphasizes on hybrid power supply and motor technology components as key technologies of light hybrid electric vehicles.

The second institutional intervention we identified was conducting a policy instrument by using technology development programs to enforce sectoral actors to emphasize hybrid electric vehicles. However, as we noted above, not all actors paid attention on needs of HEV development. In the run-up to government sponsored projects (e.g., technology development programs) intervened, some key actors (ITRI, Formosa Automobile Corporation, HAITEC) began to undertake R&D activities on battery and motor technologies of hybrid electric vehicles. These institutional interventions serve as successful trigger for the six reinforcing agent-level blocks co-evolution shifts but however they have flaws in position on IGBT/MOSFET R&D, as components of power transition which make choices for use electronic power or common-source amplifier. Such failures have contributed to emergence of second vicious cycle of system failures and fail to critical HEV components development [1a]. One of our interviewees stated that:

“In Taiwan's hybrid electric vehicle system, we have difficult in technological position policies to select metal-oxide semiconductor field effect transistors (MOSFET) and insulated-gate bipolar transistors (IGBT) of electronic switch to make key components as extremely important for hybrid electric vehicles”.

(Quote from an interviewee)

These institution failures address a new regulation problem since they have
emerged with increased active actors (e.g., industrial actors’ patenting are highly occupied during the period) but miss-alignment with IGBT/MOSFET study [2a]. The increased actors strongly preferred trigger growth of technological patenting that includes 86 (26.2%) patents in battery technology, 117 (54.7%) patents in motor technology, 171 (41.7%) patents in motor controlling technology, 355 (43.9%) patents in battery management technology, and 187 (31%) patents in entire vehicle controlling system respectively, but weakly capture the co-owned patenting with focus on complementary relationship during the period [3a] such as 3 (3.5%) co-owned patents in battery technology, 9 (7.7%) co-owned patents in motor technology, 6 (3.5%) co-owned patents in motor controlling technology, 26 (7.3%) co-owned patents in battery management technology, and 7 (3.7%) co-owned patents in entire vehicle controlling system respectively (Table 4).

When these active actors do not draw attention on key power components of IGBT/MOSFET related knowledge because of misunderstanding intervention of technological adoption and position, such flaw indeed curtails them to desire collaboration reciprocally [6a, 6b].

Equally, the perceived failure position in IGBT/MOSFET knowledge domains from policy interventions, this flaw has reciprocal interdependence on actor and network failures. Such misunderstanding of knowledge investment has seriously influenced the reduction of actors and networks which are willing to endow [4b, 5b]. Few actors and networks are subsequently incapable of contributing certain domain knowledge and technology [4a, 5a]. Consequently, these heterogeneous failures (e.g., knowledge and technology, actor, network) reflect reciprocity on institution failures due not to achieve policy goals [1b, 2b, 3b]. These reciprocal failures formed a vicious cycle have caused Taiwan to lose its leading edge on targeting HEV development. One of our interviewees stated that:
"In Taiwan's hybrid electric vehicle system, we have had a snapshot chance to stand on leading edge but lose knowledge adoption on MOSFET and IGBT R&D investment especially in high-power components related to HEV motor technology and motor controlling technology". (Quote from an interviewee)

Stage 3 (2009-2013). Stimulated by the stage 2, an important historical event played a role in this shift as in the case of "HAITEC had launched its owned brand vehicle of Luxgen MPV EV+ (BEV) subsidized by MOEA 5-year financial support of technology development programs in 2009. This unfolding previous institutional intervention followed by stage 2 successfully substitutes the prior stage to rather focus on battery electric vehicles then hybrid electric vehicles. In the third stage, Taiwan’s Executive Yuan and Military of Economic Affairs are two key interpretive institutions contribute to growing efforts on the battery electric vehicle researches that purpose being BEV industrialization with emphasis on specific products such as batteries, motors, chasses and controlling systems. In 2009, Military of Economic Affairs called for several industrial actors (e.g., ITRI, ARTC, MIRDC, NCSIST, HAITEC, Yulon, Takisawa Taiwan, TAIGENE, and FUKUTA) to ally an automobile R&D consortium called “Taiwan Automotive Research Consortium (TARC)” and commissioned it to execute an “Electric Vehicle System Modules and Key Technology Development Plan”. Such action plan aims to develop battery electric vehicle chasses, power modules and subsystems, and controlling systems. By 2010, Taiwan's Executive Yuan approved the new “Smart EV Development Strategy and Action Plan (phase 1)”, confirming that future direction of battery electric vehicles with focus on E-cars, E-buses and E-scooters. This plan would expect to achieve a “3-year, 3,000 EV-adoption in public applications. However, it seems to be difficult to approach its policy expectation. According to ARTC dedications, the EV-adoption introduced only 289 vehicles
into operation during 2010-2013, achieving 9.6% of targeted volume.

The third institutional intervention we identified was initiated by a few of technology development programs and a political action plan to facilitate the development of battery electric vehicles in the public domain. Such intervention substitutes a previous focus that has detached hybrid electric vehicles progress and its shift expects flaws in framing knowledge accumulation and technological dependence, which miss-lead to its key players’ understanding of hybrid electric vehicles in the future. For a series of government-sponsored projects intervened, TARC aims to develop key modules and components of battery electric vehicles and another actors (e.g., like FUKUTA, Chroma Corp.) have become key suppliers for Tesla’s manufacturing production and BMW Mini’s corporation, along with the components they supply. In 2009, HAITEC developed the LUXGEN MPV EV+ as the first self-integration battery electric vehicle to boast better performance. Most importantly, by 2010, Taiwan’s government approves the battery electric vehicle plan to extend previous government-sponsored projects throughout Taiwan to 2013 with aim at achieving the 3,000 unit goals. These institutional interventions have successfully promoted six agent-level blocks co-evolution shifts but they have opposed policy mechanisms for being knowledge accumulation uncertainty, in which the industrial actors stray from dichotomy electric vehicle technologies and sidestep the significant knowledge investment for hybrid electric vehicles followed by the previous stage [1a]. Such failures contributed to emergence of third vicious cycle of system failures.

These institution failures regulate a problem since they have emerged with industrial active actors who focus on knowledge development of hybrid electric vehicles influenced by the second stage [2a] and increased networks which have growth of technological patenting in rather fields of hybrid electric vehicles than
fields of battery electric vehicles that misalign with the policy intervention [3a]. Although the technological patenting has increased in the five sub-category that include 176 (53.7%) patents in battery technology, 83 (38.8%) patents in motor technology, 196 (47.8%) patents in motor controlling technology, 361 (37%) patents in battery management technology, and 317 (52.5%) patents in entire vehicle controlling system, these are misalignment with the current policy spot that influences the knowledge accumulation of battery electric vehicles and then has a consequence of potential actors who would like to involve and form associated networks reciprocally [6a, 6b]. Such perceived failure attention on hybrid electric vehicle knowledge and technology, a substitutive BEV focus fails to interdependence on actor and network failures that have a misunderstanding of knowledge accumulation and indecisive technological investment of electric vehicle [4b, 5b]. Then these actors and networks are not willing to contribute the certain knowledge investment due to alternative electric vehicle policy spot [4a, 5a]. Consequently, these heterogeneous failures (e.g., knowledge and technology, actor, network) reflect reciprocal interdependence on institution failures due not to approach the policy goals [1b, 2b, 3b]. One of our interviewees supported our findings to state that:

“In Taiwan's electric vehicle system, we over-emphasize on key performance indicators of electric vehicles (e.g., self-content ration, targeted adoption of volumes) to evaluate whether a current policy intervention is effectiveness or not. These short-term performance may easily damage Taiwan's evolving EV system and result in the failure situation”. (Quote from an interviewee)

Stage 4 (After 2014). After the adoption of prior institutional intervention of Smart EV Development Strategy and Action Plan (phase 1), Taiwan's government has waited for its policy entry into force. This institutional intervention requires
EV-adoption of targeted volume of 3,000 units during the period of 2010-2013. However, when such action plan of phase 1 only obtains 289 EV-adoptions (9.6% of targeted volume) into operation which do not approach the current policy goal, Taiwan’s government substitutes the previous stage frame to refocus on plug-in hybrid electric vehicles (PHEV) rather than battery electric vehicles by approving “Smart EV Development Strategy and Action Plan (phase 2)” from the period of 2014-2016” combined with the “Electric Scooters Development Projects” in 2014. This phase two “Smart EV Development Strategy and Action Plan” related to all government authorities such as Military of Economic Affairs (MOEA), Ministry of Transportation and Communications (MOTC), and Environmental Protection Administration (EPA) jointly attempts to achieve a “10-year, 10,000 EV-adoption” (local-content ration required 50% in 2016), and nourishes the e-scooter supply chain as well as boost the e-scooter of Taiwan-made performance whose running roads of 37,000 volumes by 2017 with a local-content ration of 93%.

The final institutional intervention approved substitutes the previous stage to develop plug-in hybrid electric vehicles by announcing the phase two of Smart EV Development Strategy and Action Plan. This imperative action plan switches the policy focus on plug-in hybrid electric vehicles development that jeopardizes knowledge accumulation on battery electric vehicles followed by the stage 3 [1a]. Such policy intervention regulates the failure problem whereas industrial actors and networks become passive during uncertain period, they do not pay attention on knowledge and technology investment regarding to adoption of substitutional policy [2a, 3a]. Under the situation, industrial actors and networks have limited grow up [4b, 5b] and they may hesitate to call for potential players and leave off associations [6a, 6b] and have a misunderstanding of knowledge investment on the plug-in hybrid electric vehicles [4a, 5a]. However, all set of three agent-level
block failures (knowledge and technology, actors, networks) seriously influence the institutional intervention since they have emerged with limited performance for the targeted use of current policy [1b, 2b, 3b].

5. Discussion and Conclusion

The empirical evidences above have shown that the heterogeneous system failures arguments and practices to legitimize policy intervention are apparently observed and valid, but these are confined to address vicious cycle defects in the evolving sectoral system of Taiwan’s electric vehicles. They also give sufficient justices to broader policy implications from strategic-oriented innovation based on agent-level sectoral innovation systems that have been identified as providing insightful processes of transformative change from traditional regime towards a new one. We further suggest that escaping these vicious cycles in different stages consisted of heterogeneous system failures by using strategic-oriented innovation policy implications in order to take on board the requirements of goal oriented transition changes. We follow a critical literature (Weber & Rohracher, 2012) linked to the strategic-oriented innovation policy to debate how to escape such vicious cycle defects in the Taiwan’s electric vehicle sectoral systems. Two policy implications to move forward a virtuous cycle of Taiwan’s electric vehicle systems are discussed.

First, we suggest that developing an evolving electric vehicle sectoral system is closely linked to policy direction and requires the setting of collective priorities. This means that it is not only necessary to generate sectoral innovation systems as effectively and efficiently as possible but also has to contribute to the specific policy direction of transformative change. Such policy direction is usually defined as societal problems or challenges for which solutions need to be developed with the investment of research and development. As an example, the current debates
about the four stages with different EV focus can be mentioned (e.g., stage 1 as a BEV/HEV focus, stage 2 as a HEV focus, stage 3 as a BEV focus, and stage 4 as PHEV focus). This is widely recognized as a major challenge for which long-term policy direction and solution have to be concentrated and consistent in order to invest knowledge as well as technology development and learning processes around specific technological focus (Weber & Rohracher, 2012). To be consistent of policy direction should not be mixed up with other anticipatory myopia of EV focus that is sometimes mentioned as examples of BEV and HEV at the stage 1 and BEV focus of stage 3 as well as PHEV focus of stage 4 because these frequent EV focus changes are not used to justify more investment in research and development. Therefore, consistent policy directions are needed as an element in the portfolio of policy intervention and instruments to provide targeted impulses while they conduct the diffusion of new competitive technology (Jacobsson & Bergek, 2011). Approaching the consistent policy direction implies one level of translation and intermediation mechanisms: the vision-building of setting collective priorities is a critical mechanism to undertake its consistence (Weber & Rohracher, 2012). The vision-building relates to the issues of how to set priority goals and define the directionality of policy frame. Such matter often involves authorities and powerful agencies who play important roles in enacting policy activities which may be in line or not with the key features of the vision as well as for subsequent policy interventions. For instance, developing indigenous R&D capabilities for private firms based on battery electric vehicles technologies (stage 3, 2009-2013) has been propagated as an alternative vision to prevail ICEs regime chain model. A reconfiguration of developing indigenous R&D capabilities for BEVs would challenge the position of the dominant utility firms and constrain technological supports. One of our interviewees stated that:
“In Taiwan’s battery electric vehicle system, government wants to develop firm’s indigenous R&D capabilities based on the traditional ICE regimes, but it does not consider the dominance of established firms and other support of BEV’s technological complexity”. (Quote from an interviewee)

However, to the extent shift a competitive electric vehicle regime emerged as strategic political negotiations and preferences, the dominant utility firms based on ICES regimes have to increasingly engage in EV regimes especially in battery electric vehicles. This indicates that the participatory processes and assistants to switch EV regimes supported by government agencies may need in this process of creating shared expectations, coordination, and execution.

We suggest that policy coordination as a second policy debate focuses on interaction of different agent-level blocks and four stages of vicious cycles in developing a sectoral electric vehicle system. Though the policy coordination has been used as an example of one kind system failure to intervene knowledge and technological domains, this refers only to debates which facilitate R&D actors and networks. The policy coordination considers the coherence between activities of national-level, sectoral-level and technological-level institutions that facilitate the tasks by using policy instruments. Such multi-level policy coordination addresses an important policy mechanism through opening methods of coordination (Geels, 2004, 2005). In the policy example of regulation of California ZEV mandate (Calef & Goble, 2007), for instance, a better coordination between the state-oriented policy and sectoral-oriented policy was sought in the context of CARB (California Air Resources Board), in order to reduce air pollution in Los Angeles and other metropolitan areas and encourages development of zero emission vehicles (ZEV) (e.g, battery electric vehicles qualified as ZEVs) and commonly defines challenges arising from the air pollution impact of electric vehicle technologies. Specifically,
California ZEV mandate required 2% of all passenger cars and light trucks sold in the state by manufacturers who have to emit zero exhaust, starting with the 1998 California models. The percentages of ZEVs was to increase to 5% in 2001 and to 10% in 2003 (Calef & Goble, 2007). The CARB could fine an automobile maker failing to meet the ZEV requirement up to $5,000 for each violation. According to statistics from ZEV mandate website (ww2.arb.ca.gov), its credit balances reflect ZEV regulatory compliance through a total 20% of zero electric vehicles in 2015, California. Compared to Taiwan’s sectoral electric vehicle policy, it has weakly taken place to date in the settings with policy coordination and respect to electric vehicles developers and purchases. This may fail the attention on developing the electric vehicle technologies.
### Table 1 Building blocks of sectoral innovation system

<table>
<thead>
<tr>
<th>Building blocks</th>
<th>Indexes &amp; Measurement items</th>
</tr>
</thead>
<tbody>
<tr>
<td>Knowledge &amp; Technology</td>
<td>Patent numbers</td>
</tr>
<tr>
<td>Actors</td>
<td>Patent numbers</td>
</tr>
<tr>
<td>Networks</td>
<td>Co-own patents</td>
</tr>
<tr>
<td>Institution</td>
<td>In-depth interview</td>
</tr>
</tbody>
</table>

Source: the study

### Table 2 Electric vehicle subcategories and corresponding IPC codes

<table>
<thead>
<tr>
<th>No</th>
<th>Sub-category</th>
<th>IPC</th>
<th>Issued</th>
<th>Duplicated</th>
<th>Valid</th>
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</thead>
<tbody>
<tr>
<td>1</td>
<td>Battery technology</td>
<td>H01M-002, H01M-004, <strong>H01M-004/13</strong>, H01M-008, H01M-010, H01M-010/05, H01M-006/14, H01M-006/16, H01M-004/14, H01M-004/50, H01M-004/58, <strong>H01M-004/82</strong>, H01M-010/48</td>
<td>490</td>
<td>162</td>
<td>328</td>
</tr>
<tr>
<td>2</td>
<td>Motor technology</td>
<td>H02K-017, H02K-019, H02K-021, H02K-023, H02K-025, H02K-027, H02K-029, H02K-041</td>
<td>237</td>
<td>23</td>
<td>214</td>
</tr>
<tr>
<td>3</td>
<td>Motor controlling technology</td>
<td>H02P-001, H02P-003, H02P-005, H02P-006, H02P-007, H02P-009, H02P-021, H02P-023, H02P-025, H02P-027, H02P-029, H02P-031</td>
<td>427</td>
<td>17</td>
<td>410</td>
</tr>
<tr>
<td>4</td>
<td>Battery management technology</td>
<td>H02J-001, H02J-003, H02J-004, H02J-005, H02J-007, H02J-009, H02J-011, H02J-013, H02J-015, H02J-050, B60L-003, G01R-019, G01R-031/02, G01R-031/04, G01R-031/06, G01R-031/07, G01R-031/36</td>
<td>1,318</td>
<td>509</td>
<td>809</td>
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<tr>
<td>5</td>
<td>Entire vehicle controlling systems</td>
<td>B60L-015, B60L-007, B60L-008/17, B60W-010/18, B60W-010/24, B60W-010/26, H02J-007, <strong>H01M-010/44</strong>, <strong>H01M-016/46</strong>, <strong>B60L-011</strong>, B60W-020, B60K-006</td>
<td>612</td>
<td>8</td>
<td>604</td>
</tr>
</tbody>
</table>

Source: The list was referred by Pilkington et al. (2002) and Yang et al. (2013), and revised by five industrial experts.

Note: the bold fonts were new added IPC codes by industrial experts.
<table>
<thead>
<tr>
<th>Institutes</th>
<th>Positions</th>
<th>Domain</th>
<th>Times</th>
<th>Time Length</th>
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<td>Electric vehicle policy</td>
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<td>180 mins</td>
</tr>
<tr>
<td>Department of Industrial Technology, Ministry of Economic Affairs</td>
<td>Senior researcher</td>
<td>Electric vehicle policy</td>
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<td>60 mins</td>
</tr>
<tr>
<td>Department of Industrial Technology, Ministry of Economic Affairs</td>
<td>Senior researcher</td>
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<td>70 mins</td>
</tr>
<tr>
<td>Industrial Development Bureau, Ministry of Economic Affairs</td>
<td>Senior consultant</td>
<td>Electric vehicle technology and policy</td>
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<td>70 mins</td>
</tr>
<tr>
<td>Department of Vehicle Engineer, National Taipei University of Technology</td>
<td>Professor</td>
<td>Battery &amp; motor technology</td>
<td>2</td>
<td>120 mins</td>
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<tr>
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<td>Motor controlling technology</td>
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<td>65 mins</td>
</tr>
<tr>
<td>Institute of Electrical and Mechanical Systems, Industrial Technology Research Institute</td>
<td>Director</td>
<td>Entire vehicle controlling systems</td>
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<td>140 mins</td>
</tr>
<tr>
<td>Institute of Materials and Chemical, Industrial Technology Research Institute</td>
<td>Project leader</td>
<td>Battery technology</td>
<td>1</td>
<td>60 mins</td>
</tr>
<tr>
<td>Hua-Chuang Automobile Information Technical Center Co., Ltd.</td>
<td>Director</td>
<td>Battery management technology</td>
<td>2</td>
<td>120 mins</td>
</tr>
<tr>
<td>Hua-Chuang Automobile Information Technical Center Co., Ltd.</td>
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<td>1</td>
<td>80 mins</td>
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<tr>
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<td>Intellectual property rights management</td>
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<td>90 mins</td>
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<td>2</td>
<td>140 mins</td>
</tr>
<tr>
<td>Chroma ATE Inc.</td>
<td>Special assistant</td>
<td>Motor controlling technology</td>
<td>1</td>
<td>70 mins</td>
</tr>
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</table>

Source: the study
Table 4 Summary empirical results of four stage of vicious cycles

<table>
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<tr>
<th>Years/ Types of failures</th>
<th>Focus</th>
<th>Battery technology (N=328)</th>
<th>Motor technology (N=214)</th>
<th>Motor controlling technology (N=410)</th>
<th>Battery management technology (N=809)</th>
<th>Entire vehicle controlling system (N=604)</th>
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<td><strong>Before 1996</strong> BEV/HEV</td>
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<td>Institution failures</td>
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<td>Know &amp; Tech failures</td>
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<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
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<tr>
<td>Actor failures</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Government</td>
<td>2 (22.2%)</td>
<td>0 (0.00%)</td>
<td>0 (0.00%)</td>
<td>1 (8.33%)</td>
<td>1 (7.14%)</td>
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<tr>
<td>Research institute</td>
<td>3 (33.3%)</td>
<td>1 (100%)</td>
<td>4 (66.7%)</td>
<td>1 (8.33%)</td>
<td>1 (7.14%)</td>
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<tr>
<td>University</td>
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<td>0 (0.00%)</td>
<td>0 (0.00%)</td>
<td>0 (0.00%)</td>
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<td>Industry</td>
<td>4 (44.4%)</td>
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<td>9 (64.3%)</td>
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<td>Individual</td>
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<td>1 (16.7%)</td>
<td>1 (8.33%)</td>
<td>3 (21.4%)</td>
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<td>Network failures</td>
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<td>Co-owned</td>
<td>0 (0.00%)</td>
<td>0 (0.00%)</td>
<td>1 (16.7%)</td>
<td>1 (8.33%)</td>
<td>1 (7.14%)</td>
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<tr>
<td>Sole</td>
<td>9 (100%)</td>
<td>1 (100%)</td>
<td>5 (83.3%)</td>
<td>11 (91.7%)</td>
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<tr>
<td><strong>1997-2008</strong> HEV</td>
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<td>Institution failures</td>
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<tr>
<td>Know &amp; Tech failures</td>
<td></td>
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<tr>
<td>Actor failures</td>
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<td>21 (5.92%)</td>
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<td>6 (3.51%)</td>
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<td>165 (96.5%)</td>
<td>329 (92.7%)</td>
<td>180 (96.3%)</td>
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EV policies fail to influence the system due to lacking of coordination policies and infrastructure.

EV policies fail to position on key components study of power switch (e.g., IGBT/MOSFET).
### Table 4 Summary empirical results of four stage of vicious cycles (Continued)

<table>
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<tr>
<th>Years/Types of failures</th>
<th>Focus</th>
<th>Institution failures</th>
<th>Know &amp; Tech failures</th>
<th>Actor failures</th>
<th>Network failures</th>
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<td>79 (95.2%)</td>
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<td>34 (91.9%)</td>
<td>67 (82.7%)</td>
<td>75 (87.2%)</td>
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</table>
Figure 1: The vicious cycles of system failures

K&T: Knowledge & Technology failure
In: Institution failure
Ne: Network failure
Ac: Actor failure

Figure 2: The analysis vicious cycles of system failures

K&T: Knowledge & Technology failure
In: Institution failure
Ne: Network failure
Ac: Actor failure

System failures co-evolution
1a: In → K&T  4a: Ac → K&T
1b: K&T → In  4b: K&T → Ac
2a: In → Ac  5a: Ne → K&T
2b: Ac → In  5b: K&T → Ne
3a: In → Ne  6a: Ne → Ac
3b: Ne → In  6b: Ac → Ne
Figure 3 The sectoral innovation system of Taiwan’s electric vehicle industry
Figure 4 Historical forces and institutions in the Taiwan electric vehicle industry

Source: the study
References


