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Innovation Investment under Policy Uncertainty: Exploring Factors Influencing Firms? Technological Investment Decisions

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Abstract

Despite the rising expectation on the renewable energy technologies, the alternative energy sources still heavily rely on government support policies. However, constant changes in government incentive programs and policies have created high level of uncertainty. As the renewable energy sector is striving to achieve grid parity through technology advancement and adoption, how to boost the technological innovation investments has been a major issue in the renewable energy industry sector. Most of the studies relating to the impact of uncertainty on investment decisions focused on the sector or industry level. With an aim to enhance the understanding of firm level decision behaviours, the purpose of the research is to explore what are the factors influencing firms? innovation investment decisions under uncertainty.

In examining firms? innovation investment decisions under uncertainty, normative real options approach predicts that uncertainty may induce the wait and see effect of investment decisions; yet empirical studies found mixed results. On the one hand, these mixed findings may be attributed to the types of uncertainties and industry context examined in the studies. On the other hand, it may suggest that there are other factors shaping firms? technological investment choices.

The research focuses on firms? technological innovation decisions: the research setting is the case study of three Taiwanese solar PV firms, with the selection of different solar PV technologies and the evidence of participating government R&D innovation projects in recent years. I organize my research around the questions: how do firms differ in the technological investment decision-making under policy uncertainty? How does the perception toward policy and technological uncertainty affect firms? innovation investment decisions? And, in what ways does the technological choice and complementary assets influence the firms? propensity toward investment options? Next, I review the theoretical perspectives and discuss the method of my case selection and data collection/analysis. Then I present my case study design starting with the evidence of policy and technological uncertainty in the solar PV industry, followed by

the propositions developed from theoretical perspectives.

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Claire K. Wan[1]

Introduction

Despite the rising expectation on the renewable energy technologies, the alternative energy sources still heavily rely on government support policies. However, constant changes in government incentive programs and policies have created high level of uncertainty. As the renewable energy sector is striving to achieve grid parity through technology advancement and adoption, how to boost the technological innovation investments has been a major issue in the renewable energy industry sector. Most of the studies relating to the impact of uncertainty on investment decisions focused on the sector or industry level. With an aim to enhance the understanding of firm level decision behaviours, the purpose of the research is to explore what are the factors influencing firms' innovation investment decisions under uncertainty.

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study design starting with the evidence of policy and technological uncertainty in the solar PV industry, followed by the propositions developed from theoretical perspectives.

Theoretical perspectives

Real options logic

In examining investment decisions under uncertainty, real options approach has been used as a decision analysis tool (Adner & Levinthal, 2004; Dixit & Pindyck, 1994). Despite the criticism of its limited use as a tool in the real organizational setting(Bowman & Moskowitz, 2001; B. Kogut & Kulatilaka, 2004); as the real options theory offers a reasoning logic which can characterize the uncertainty, irreversibility and flexibility inherent in innovation investment decisions, scholars applied real options logic as a strategic heuristic in organizational innovation decisions (Adner & Levinthal, 2004; B. Kogut, 2001; McGrath & Nerkar, 2004). As a strategic heuristic in hedging the future opportunity from uncertainty, the real options logic is applied in my research as an analytical framework for firms' innovation investment decisions: firms' R&D investments, especially innovation investments in new technology, are considered as strategic actions and flexible in terms of investment timing and amount (McGrath, 1997; McGrath & Nerkar, 2004).

In applying real options logic in investment decision making under uncertainty, scholars argued that the use of real options logic is inevitable connected with behavioural biases considered in decision rules; and the process is not that different from the process of exploratory search articulated by the traditions of organizational theorists (Adner & Levinthal, 2004; B. Kogut, 2001; B. Kogut & Kulatilaka, 2004). Extended this line of argument, I complement the real options analytic framework with behavioural decision model and organizational decision theories.

Behavioural and organizational decision perspective

Behavioural theory highlights the inherent use of three heuristics in decision making under uncertainty : 'representativeness', 'availability of instances or scenarios' and 'adjustment from an anchor'(Tversky & Kahneman, 1974, 1981). In prospect theory, Kahneman and Tversky proposed that decision behaviours are affected by the expectation on relative potential decision outcomes to the predetermined reference points(George, Chattopadhyay, Sitkin, & Barden, 2006; Kahneman & Tversky, 1979). The analytical perspective from the behavioural decision model is applied to examine the two key elements in the real options framework: first, the framing of the prospect and contingency, corresponding to the interpretation of market signals under uncertainty; second, the assessment of options and outcomes, directly pointing to the evaluation of the option investment.

In the context of firms' decision making process, Cyert and March proposed that firms' decisions are shaped by perceptions. Under the assumption that firms react to environmental change through 'observation and interpretation', Cyert and March defined expectation, one of the three pillars in organizational decision framework, as the ways inferences were drawn from the available information, as well as the ways firms search for information and alternatives in the decision process (Cyert & March, 1963). As the search process is defined as the activities of exploring new opportunities and innovation (March, 1991), scholars suggested that such exploratory search can be compared with the investment decisions under the real options framework(Adner & Levinthal, 2004; B. Kogut, 2001). However, comparing with the real options approach, scholars argued that the so called 'slack search process', the ways organizations cope with uncertainty and initiate innovation investment, is less controlled and path dependent (Adner & Levinthal, 2004; B. Kogut, 2001; March, 1991; Nelson & Winter, 1982). Therefore, scholars implies that, complementing the real options logic with organizational search process, innovation investment under uncertainty is a function of decision rules and organizational capability(B. Kogut & Kulatilaka, 2004). Following this line of argument, the influence of path dependent search on firms' innovation investment is examined in the analytic framework.

Profit from Innovation (PFI) Framework and complementary assets

The valuation of innovation investment under uncertainty is context dependent: industry structural and technological environment influence firms' innovation investment decisions (D. J. Teece, 2010). In analyzing firms' innovation investment decisions, PFI framework provides the rationale predicting different innovation challenges among technologies from the lens of innovation ecosystem(D. J. Teece, 1986). Among the three building blocks in the PFI framework: appropriability regimes, dominant design and complementary assets, the role of complementary assets is highlighted and linked to the firms' innovation decisions – the motivation that the firms would leverage specialized complementary assets to capture the profit from innovation investments(D. Teece, 2006; D. J. Teece, 1986). Complementary assets can be categorized as generic or specialized assets, and the idea has been extended to the concept of core vs. complementary resources/capabilities and specialized vs. generic resources/capabilities(Helfat & Lieberman, 2002). As my research aims at exploring firms' technological innovation investments, I focus on the building or leverage of core and specialized resources/capabilities such as the technology know-how and research and development. Applying the real options logic in PFI, firms may choose to invest internal technological development or license external technologies (B. Kogut, 2001; D. Teece, 2006) under uncertainty situations. On the other hand, from the path dependent perspective, firms' choices are influenced by prior experiences (D. J. Teece, Pisano, & Shuen, 1997), including the firm owners' complementary resources/capabilities(Helfat & Lieberman, 2002). Built on this line of argument, the concept of complementary assets is examined from the perspectives of industry context and the firm- level resources/capabilities.

Method

I use the case oriented approach because my research inquiry involving 'the search for patterns of multiple conjunctural causation' (Ragin, 2004), and the attention of each selected case is necessary in examining the propositions. I adopt the multiple case design, as the replication logic serves the purpose of assessing the outcomes from different combinations across cases. Therefore each case is treated as an experiment and the findings of each case can lead to the prediction of different pattern.

According to my research question, the unit of analysis is 'innovation investment decisions'; multiple level of analysis on the industry and firm level will be conducted to examine firms' innovation investment decisions. The research design and methodology is based on the concept that firms' behaviours are influenced by senior manager's perception (Cyert & March, 1963; Starbuck, Barnett, & Baumard, 2008); as well as the premise of management discretion (B. Kogut, 2001). The senior managers interviewed are those who are leading the firms' innovation investment projects and influential to the firms' R&D strategy.

Case selection

To clarify and my claims about the potential causes of firms' behaviours, I define the below sufficient conditions for the case population. First, previous studies have shown that senior managers' perception toward uncertainty is varied in different industry and institutional environment (Kaplan & Tripsas, 2008; Sutcliffe, 1998). Therefore, to exclude these factors, my research setting would be in a single industry and in the same country. Second, solar PV industry is selected because: (1) solar Photovoltaic (PV) industry is an emerging industry characterized by uncertainty and reliance on government policy; (2) there is a variety of solar PV technologies, which sets the condition of technological uncertainty. Third, as the firm's position in the industry value/supply chain is expected to influence the firm's innovation investment strategy (Adner & Kapoor, 2010; D. J. Teece, 1986), I focus on firms in the similar position in the industry value chain. Finally, Taiwan solar PV industry is chosen, because there is a presence of firms employing different PV technologies in the industry. I target mid stream cell manufactures, where the differentiation of technology is salient in the solar PV industry value chain, and therefore can help sharpen the concept about the influence from technological uncertainty.

Next, as my research question concerns firms' technological innovation decisions, I select firms that have demonstrated such action (or intent) based on publicly available evidence. The criterion I use is the evidence of participating government funded R&D innovation project. I choose two government programs from Ministry of Economic Affairs (MOEA) as the reference points: one is Industrial Technology Development Program (ITDP) and the other is Industrial Technology Innovation Program (code name MNCD); for the reason that the two programs are benchmarking government program for R&D innovation projects in terms of the scale and the strict review process (reviewed by a group of experts from academia and the research community). There are total eight PV cell firms (four crystalline silicon (c-Si) firms, two amorphous/tandem silicon thin film (a-Si/μc-Si TF) firms, one Copper-Indium-Gallium-Selenide Thin film (CIGS TF) firms and one Dye Sensitised Solar Cell (DSSC) firm that have been awarded with either ITDP or MNCD program funding in the past five years. For the resource constraints reason, I chose one c-Si firms, one a-Si/μc -Si TF firm and one CIGS TF firm for in-depth case analysis: first, the c-Si firm and a-Si/μc -Si TF firm that I chose have been awarded with both government program funding. Second, I chose the only one CIGS TF firm. Finally, I omit the DSSC firm because the firm has withdrawn the DSSC product line last year. I considered the selection is representative as the profile of the three firms shows certain level of heterogeneity to facilitate proposition development.

Table 1. Selected firms (in anonymous code name)

	T firm	Y firm	N firm
Technology	c-Si	a-Si TF	CIGS TF
Product lines	c-Si Solar cell (Major); wafer and ingot; PV system, system integration.	a-Si/μc-Si TF module; some system integration	CIGS TF module
Market Type	Public	Private	Private
Establishement	1981	2007	2007
Ownership (major shareholder)	Semiconductor firm	LCD optics firm	a -c-Si cell firm and an equipment supplier firm
MOEA project (Industrial Technology Development Program)	2	1	1
MOEA project (R&D Centre Program)	1	1	0

Source: the author

My criterion in selecting firms (the record of being awarded with government programs) firstly serves a good reference as the firms' focal technological innovation projects. In addition, I investigate the firms' R&D spending level and if there is other concurrent R&D innovation projects. The investigation period is from 2007 to 2011. Basically, the two thin film firms were established in 2007.

Data collection

Archival document

I construct the case study based on extensive desktop research from different sources of archival documents. First, I reviewed various sources of industry reports, including reports from governments, NGO, industry associations, investment banking and professional solar PV industry analyst to gain insights on the overall development of the policy, market and technologies in the solar PV industry. Next, I reviewed the relevant business news and annual reports (only available for the public firm) regarding the case firms and their major owners. I also reviewed the summary of the firms' MOEA government projects with the help from MOEA officials.

Interviews

First, to gain a broader perspective on the recent development of the PV industry, I conducted several informal interviews with the industry participants during several international solar PV trade conferences. Then before interviewing the case firms, I conducted expert reviews with several industry professionals to validate the relevance of my interview questions. I decided to interview the project leaders of the MOEA programs. In fact, these project leaders are the head (or formerly the head) of the firm's R&D department and among the firms' top management team. I adopt two perspectives in designing the interviews. First, in order to examine interviewees' perception toward uncertainty, I used structured questions along with the scenario analysis in the first section of the interview. This concept has been widely used in the management cognition/perception studies. (Milliken, 1990; Sarasvathy, Simon, & Lave, 1998; Thomas, 1993). Then in the second section, I interviewed the retrospective decision process of the focal R&D projects (MOEA projects) as well as questions regarding the firms' R&D investment and strategy. To triangulate the interview results, besides the focal interviews on the case firms' R&D head; I conducted interviews with the other one senior member (not in the R&D department) of the firm. Also, I conducted interviews with the MOEA government officials as well as the research institute members collaborating with the firms in the MOEA projects.

Data analysis

First, the result of the scenario analysis section serves as the basis to examine how firms perceive the relative impact of policy and technological uncertainty. Based on the concept of three types of 'perceived uncertainty' ((Milliken, 1987), I operationalize 'state uncertainty' as the assessment of uncertainty; 'effect uncertainty' as framing the issues of the uncertainty; and 'response uncertainty' as evaluating the industry leaders'/competitors' actions. After consolidating the firms' response, the similarity of patterns among firms is analyzed. Second, I cross-analyzed the firms' interview results and MOEA projects with the attributes of technological innovation in different PV technologies – combined with desk research, industry expert interviews and the growth and type of patent application. Finally, I cross –analyzed the interview results with the firms' background information, including the owners' industry experiences and prior investments.

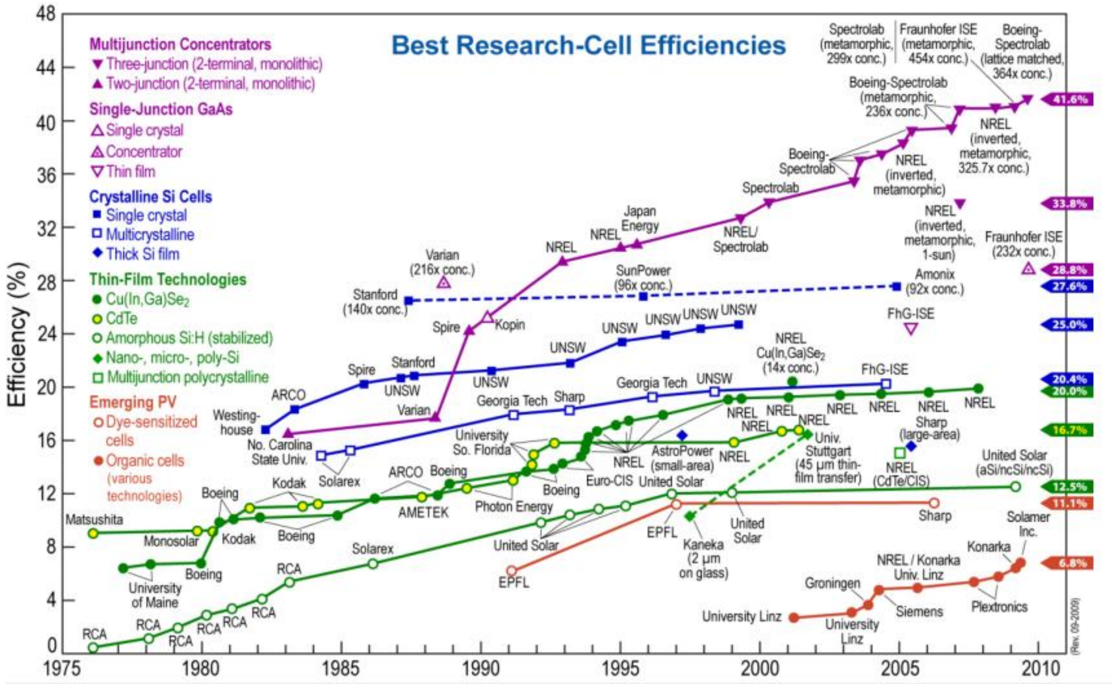
Policy and technological uncertainty in the solar PV industry

Solar PV has been a fast growing renewable energy technology for the past few years: compared with other main renewable power sources, solar PV currently has the highest growth rate, and the 19% annual growth rate to 2020 is expected to reach the worldwide clean energy target in 2020 (IEA, 2011). Government policy support has been the driving force for the solar PV market. Among various support measures, Feed-in-Tariffs (FIT) is the most favourable and generous support measure for the solar PV(IEA, 2009; O'Rourke, Kim, & Polavarapu, 2010). FIT is widely implemented in EU countries, making EU the most attractive market for the solar PV. The design and implementation of the FIT program has driven the growth of the solar PV market, because the program provides guaranteed return (ROI) for the solar PV projects. Despite the adoption of the various government support measures, constant change in government incentive schemes has created high level of uncertainty. The fact that market concentration in EU and unclear outlook in other regions implies that the PV industry is particularly affected by the inherent political and economic factors that influence the government policy. In another word, policy uncertainty represents market uncertainty for the solar PV firms.

Currently Crystalline Silicon (c-Si) technology accounts for 85 to 90% of the global PV market share (IEA, 2009). Besides the c-Si based technology, there is a wide range of PV technologies according to the differences in materials and manufacturing technologies of PV cell. Thin film based technology accounts for around 10-15% of the market; however the majority of this share is from one company – First Solar, using Cadmium Telluride (CdTe) thin film technology. Amorphous thin film (a-Si and a-Si/μc -Si TF) and Copper-Indium- Diselenide and Copper-Indium-Gallium-Diselenide (CIGS TF) are the other thin film based technology families and are still categorized as emerging technologies due to the immature mass production technologies. A number of other emerging PV technologies, including concentrator PV (CPV) and dye sensitized solar cell (DSSC, a branch of organic PV cell) currently only account for less than 1% of the market.

Efficiency is the PV specific indicator of technology performance, serving as one of the differentiations in technologies. The improvement progress of lab efficiency for c-Si cells and TF has been relatively flat after 2000. While generally thin film cells have lower efficiency than c-Si cells, CIGS cell thin film cells have reported the highest lab efficiency results which almost match the efficiency rates of c-Si technology(Selya & Robert, 2010)

Table 2. Figure 1 Best Research- Cell Efficiencies 1975-2009



Source: US DOE 2010

However, the efficiencies for mass produced PV cells are lower than lab efficiency as the lab results are based on small quantity and under ideal conditions; and the efficiency of PV module is lower than the efficiency of the PV cell (Selya & Robert, 2010). The dominance of the c-Si PV cells for the past decades indicates that the technology is relatively more proven and reliable than other competing technologies. First, scales definitely help: the key to compete in the PV industry is to 'fast transfer innovative technologies to mass production.'(Wawer, 2010). For example, CIGS, the highest efficiency potential in the thin film technology family is currently struggling to ramp up manufacturing. Second, comparing to other PV technologies, c-Si technology generally has the advantage of proved long life time and product reliability. – which is crucial to Levelized cost of Energy (LCoE), the key to technology adoption in the energy sector (Bloomberg, 2010; Selya & Robert, 2010). Further, the development of technology roadmap among industry participants may be an indicator of firms' joint efforts in reducing the uncertainty associated with the technology. For example, with the evolvement of industry interest groups and industry associations in the c-Si technology, currently the Crystalline Silicon PV Technology and Manufacturing (CTM) Group, formed by the European leading solar PV firms has developed the International Technology Roadmap for PV (ITRPV) (EPIA, 2011). On the other hand, because of the variety of the thin film technologies, there is no industry wide technology roadmap developed by a consortium of firms.

Therefore, factors related to commercialization, rather than the technological performance (e.g. efficiency) impact more on the development of different solar PV technologies. I define technological uncertainty as the development pace of new emerging PV technologies relative to the established technologies.

Perception toward policy uncertainty and innovation investment decisions

As discussed in the theoretical framework, the valuation of the innovation investment under uncertainty is context dependent. In the solar PV industry context, the role of policy uncertainty may be particularly important as this industry has been heavily influenced by the market demand driven by government policies. The impact of policy uncertainty on firms' innovation investments has been investigated in several studies and the findings are mixed. In a study using real options modelling, Fuss et al found that while manufacturers may postpone the investment as a result of policy uncertainty, they may also decide to invest earlier when facing with certain degree of uncertainty (Fuss, Szolgayova, Obersteiner, & Gusti, 2008). In an empirical study in German power industry, Hoffman et al found that firms not necessarily postpone investment decisions despite perceiving a high level of regulatory uncertainty from the European CO_2 Emission Trading Scheme. They argued that the reason is because they consider these investment decisions can secure the competitive resources or leverage complementary resources (Hoffmann, Trautmann, & Hamprecht, 2009). In addition, scholars have different views regarding the expectation effect of policy: as some renewable energy studies found that firms' innovation investments involving long payoff time may be reduced as a result of the expectation on policy uncertainty(Nemet, 2009), other scholars argued that the expectation of future policy, rather than current regulatory measures, may have positive impact on firms' innovation investments; because firms' innovation decisions may be based on the prospect of future policy rather than today's valuation price (Popp, Newwell, & Jaffe, 2010). Empirical evidence at the solar PV industry level seems to suggest that the general prediction from the normative real options approach does not hold: firms continued innovation investments despite policy uncertainty. One explanation may be the effect of expectation for future policy prospect. Therefore, proposition 1:

Proposition 1: Firms' perception toward policy uncertainty is not a sufficient condition for influencing firms' innovation investment decisions. Rather, the perceived uncertainty may influence the firms' innovation investment decisions only when the perception relates to the positive prospect of future policy.

Perceived technological uncertainty, technological choice and the direction of innovation investment decisions

Proposition 1 predicts a shared pattern of perception toward policy uncertainty among firms, supported by the institutional perspective that firms' affiliation of a particular industry may explain certain level of shared environmental perception among senior managers ((DiMaggio & Powell, 1983; Kaplan & Tripsas, 2008; Sutcliffe, 1998). However, this perspective may predict certain shared perception toward some general trend, but fail to explain the potential variation in expectation and the resulting technological innovation investment patterns amongst firms.

Another explanation for the mixed findings of the innovation investment decisions under policy uncertainty may be associated with different sources of uncertainty, such as technological uncertainty. Thus the next proposition examines the impact from technological uncertainty. Industry structural and technological environment will influence the nature of the innovation challenges as well as the motivation for innovation investment decisions (D. J. Teece, 2010). As an emerging industry, solar PV industry is characterized by technological uncertainty and steep cost reduction/learning curve (Porter, 1980). Technological uncertainty in the solar PV industry is directly linked to the commercialisation uncertainty of different PV technologies. The exclusion effect of technological paradigm implies that the affiliation of a certain technology group influences the firm's perception toward technological uncertainty (Dosi, 1982). Therefore, firms employing different solar PV technologies may have different perception toward technological uncertainty and technological investment patterns in response to policy uncertainty. However, an important characteristic of the solar PV industry is that the high capital investment on the equipment suggests that the switch among technologies is costly. Moreover, the high irreversibility of investment is not only on the capital equipment but also in terms of the related capability invested – as manufacturing knowhow (closely associated with technologies) is critical in this industry. Therefore, following is the proposition 2:

Proposition 2: Firms' perception toward technological uncertainty is not a sufficient condition for influencing the firms' innovation investment decisions. Rather, the irreversibility of the investment influences the direction of the firm's innovation investments.

Firms' prior experiences, investment portfolio and innovation option investments.

The irreversibility of the invested capabilities inevitably links to firm-level discussion. The path dependent effect of firms' prior experiences has been much discussed in organisational decision studies. Scholars argued that the path dependent effect may be explained from management cognition (Tripsas & Gavett, 2000) or the combination of resource based, normative and cognitive views (Sydow & Koch, 2009). From the resources/capabilities based view, the concept of path dependent accumulation process is embedded in organizations' decisions (March, 1991; Nelson & Winter, 1982). Regarding firms' investment decisions, the effect of technological path dependence lies in that firms' prior experiences condition their search for information and recognition of opportunities (Nelson & Winter, 1982; D. J. Teece et al., 1997). Applying the real options logic in the concept of capabilities, scholar suggested that firms are less likely to invest options if they already engaged resources/capabilities in current specific areas(B. Kogut, 2001). In a study investigating the impact of R&D portfolio on options investment in pharmaceutical firms, the findings supported the argument that the firm's new technology option investment is negatively related to the firm's prior accumulative technology investment experiences (McGrath & Nerkar, 2004). In investigating the firms' prior technological investment experiences, I include the firm owners' industry experiences and investment portfolio, given the fact of the young age of the two TF firms and the recent ownership change of the c-Si firm. A study of the evolution in the digital camera industry showed that firms' prior industry affiliation influence the firms' investment in designing product features (Benner & Tripsas, 2011). From the resources/capabilities perspective, obvious link was found between the firm parent company's resources/capabilities and the firm's market entry strategy (Helfat & Lieberman, 2002). Therefore, proposition 3:

Proposition 3: The direction of the firms' innovation option investment is influenced by the owners' prior industry experiences and investment portfolio.

Conclusion

The purpose of the research is to enhance the understanding about firms' decision behaviours through exploring the factors influencing the technological innovation investment decisions under uncertainty. By investigating the case study of three solar

PV firms in Taiwan, the research contributes to the refinement of the decision theories in innovation decisions. There is some limitation regarding examining the irrational/behavioural aspect of the decision process in the organizations: the process of these investment decisions may depend on the firm's management style or the owners' risk attitude.

The research contributes to provide policy implications. First, although government incentive policy has been successfully increasing market demand in the past few years, it would be interesting to understand if the subsidy program can drive the incumbent players' technological innovation decisions; or, if the expectation from the future environmental policy could encourage the innovation investment. Further, the research would help the understanding on the effect of government funding for emerging technologies: if the funding support could help reduce uncertainty associated with the technological innovation investments and stimulate the firms' technology option investments.

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