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IS THERE A COMPLEMENTARY RELATIONSHIP BETWEEN PRODUCT AND PROCESS INNOVATION ON PRODUCTIVITY IN TAIWANESE MANUFACTURING FIRMS?*

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Abstract

As a newly-industrialized country, Taiwan has gone through a vast industrial transformation. To reflect the impacts of innovation on firms' performance, we adopt a modified CDM (Crépon et al., 1998) model and focus on the innovation activities of Taiwanese manufacturing firms, especially on the comparison between OEM and non-OEM. Two data sources are uniquely compiled; one is the TTIS-II, and the other is the ICSC. Our findings suggest that considering the whole sample, only process innovation will improve both TFP growth and labor productivity growth. However, there exists a complementary relationship between product and process innovation on productivity among OEM.

Keywords: innovation, R&D, productivity, complementarity, innovation surveys
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I. *Introduction*

Successful firms not only respond to their current customers or organizational needs, but often become involved in developing an idea, product, process or service that allows them to meet the future demand both rapidly and effectively. For many years innovation has been of great interest because it is regarded as a key element of productivity growth for enterprises that plays a key role in firm survival (Cefis & Marsili, 2005; Buddelmeyer et al., 2010; Sharif & Huang, 2012). Innovation activities not only stimulate national economic growth and international patterns of trade, but also increase a firm's capacity to absorb and make use of all kinds of knowledge. In recent years, firms have faced an extremely rapidly changing environment that is characterized by globalization, a great diversification of demand and the emergence of new competitors. Firms try to implement various kinds of innovations such as introducing new products and using new technologies or designs to sustain their growth. This has especially been the case since 2008 when the global financial crisis hit major economies across the whole world and resulted in many firms shutting down. Iwasaki (2012) finds that even though there was a sharp increase in the number of liquidated firms per 1,000 Russian companies after September 2008 (a rise from 2.8% to 3.7%), innovation activity was also an important preventive factor against the market exit of firms. Besides, Sidorkin & Srholec (2014) show that the likelihood of the firm going bankrupt decreased by 1.8% during the economic crisis as long as it introduced product or process innovation and there was also a 10% increase in the share of sales from new products or services before the economic crisis broke out.

To examine the importance of innovation to firms' performances, there are a large number of empirical studies on the link between different types of innovation and productivity in different countries - including the US (Lichtenberg & Siegel, 1991), Italy (Parisi et al., 2006; Hall et al., 2009), France (Hall & Mairesse, 1995; Mairesse & Mohnen, 2005; Mairesse & Robin, 2010), and the Netherlands (Polder et al, 2010) among many others. Those previous studies, which are based on developed countries, however, do not obtain consistent findings. For instance, Parisi et al. (2006) and Hall et al. (2009) show that a firm's adopting either one kind of innovation activity or R&D leads to positive productivity growth. However, Mairesse & Robin (2010) conclude that only product innovation brings positive effects to labor productivity.

In previous studies, the complementarity or substitutability of R&D strategies has been widely explored in regard to firm productivity, e.g., the complementarity of the R&D sourcing strategies (Veugelers & Cassiman, 1999; Hou & Mohnen, 2011) or R&D cooperation strategies (Cassiman & Veugelers, 2006). They test whether different types of R&D cooperation or knowledge acquisition are complementary in improving productivity. However, few studies have attempted to inspect the complementary relationship between innovation and productivity.[1] It is crucial to fill this gap since R&D serves as the input for the knowledge production function, while innovation (product or process innovation) is the output of the knowledge production function and is the input for the production function (e.g., a typical Crépon model).

[1] Most studies including Mairesse & Robin (2010), Griffith et al. (2006) and Hall et al. (2009) use two separate equations for product innovation and process innovation. Two exceptions are Miravete & Pernís (2006) and Polder et al. (2010). The former finds that there is a significant association between product and process innovation, and the latter shows that organizational innovation is complementary to process innovation.

It is thus more intuitive to treat R&D activities and innovation strategies as two key factors in determining different stages of firm productivity. A good understanding of the interrelation between different types of innovation strategies not only sheds light on firms' determinants of such activities, but also provides governments with a sound basis for industry policies. Besides, a firm may choose either one of the innovation methods or both of them - reflecting different managerial implications. For example, if only product or process innovation brings more obvious advantages than the other type, the firm should focus on that particular innovation. However, if adopting both types of innovation is more helpful to a firm's productivity, the firm may have to spread all its efforts on both innovations with or without the government's assistance. Therefore, the interaction between various types of innovation strategies on firm productivity deserves a careful investigation.

According to the Oslo Manual (OECD, 2005), innovation by definition refers to the implementation of a new or significantly improved product (including a good or service) or process, a new marketing method, or a new organizational method. Therefore, innovations can be classified into four types: product innovations, process innovations, marketing innovations and organizational innovations. Mothe and Nguyen Thi (2012) indicate that product and process innovation are usually seen as technological innovations, which are more prominent in manufacturing than services. Besides, they find that the non-technological (organizational, marketing, and management, etc.) factors have greater influences on the service sector. Since the manufacturing industry has been the imperative driving force in Taiwanese economic development over the past several decades, we focus on technological innovations in the empirical application.

In this paper we aim to uncover the productivity effect of various innovation activities and their interrelationship based on the second Taiwan Technological Innovation Survey. The contribution of this article is three-fold. First, as just mentioned, there are many previous studies about innovation behavior in developed countries, but very limited literature focuses on the innovation activities in newly-emerging countries. Innovation activities in those countries, however, might be more active and need a thorough exploration. This paper fills this gap in the literature by studying different innovation strategies vs. firm productivity nexus for the case of a newly-industrialized country - Taiwan. From the previous literature, we see that the impact of product innovation or process innovation on firms' productivity is mixed in advanced countries. However, Taiwanese industrial structure is dominated by small and medium enterprises (SMEs), and many of the manufacturing firms are classified as Original Equipment Manufacturer (OEM) or Original Design Manufacturer (ODM). According to Kuo (2015), SMEs play an important role in Taiwanese industry structure, and most of them produce as an OEM or ODM. Moreover, Taiwanese firms have highly concentrated on mechanical equipment industry and electric and electronics industry and also have outstanding performances in these industries. Based on the data compiled by Directorate General of Budget, Accounting and Statistics (DGBAS) under the Executive Yuan, the contributions to percent change in real GDP by ICT industry is almost the same as the whole manufacturing industry. For instance, the contributions of manufacturing industry from 2011 to 2014 are 1.97, 1.07, 0.48 and 2.28, while the contributions of ICT industry are 1.87, 1.35, 0.27 and 1.91. Therefore, with these unique characteristics, this paper can lead to a better understanding of manufacturing firms' innovation decisions and performances in a special economy which is SME-dominant, OEM/ODM-oriented and highly focused on electric, electronics and mechanical equipment industries, and further provide useful policy implications.

Secondly, a uniquely compiled firm-level data set in Taiwanese manufacturing firms is utilized to facilitate our empirical investigation. Taiwan conducted its first innovation investigation in 2003 in accordance with the European Community Innovation Survey (CIS), which not only provides information about the operation of the innovation system in Tai-wan, but also makes it possible to empirically compare the Taiwanese innovation activities with similar activities in developed countries. In particular, we match the Taiwan innovation survey during 2004 to 2006 with Taiwan Commerce and Service Census data in 2001 and 2006 to obtain the total factor productivity growth to measure the firm's productivity. Finally, we classify four types of innovation strategies, which are product innovation only, process innovation only, both types of innovations, and non-innovation, and then specify structural econometric models of production, innovation and R&D decisions to explore the productivity complementarities among these innovation strategies. Specifically, a series of modified CDM-type (Crépon et al., 1998) regressions are performed to alleviate the selection and endogeneity problems.

The remainder of this paper is organized as follows: In the next section we provide the background information related to the industrial evolution in Taiwan over the past few decades. Section 3 reviews previous studies on the link between innovation activities and firm productivity. The econometric strategies adopted to identify the complementarities among different innovation activities are proposed in Section 4. We describe the data sources and relevant variables in Section 5. Section 6 presents the descriptive evidence and the main findings in this article. The last section concludes.

II. *Industrial Transition in Taiwan*

Wang (1995) indicates that the Taiwanese government approved a ten-year IT development plan between 1980 and 1989. In this plan, there were two main goals: the first was to develop a new industry and the second was to promote this industry for exports. The information and computer industries were considered to be "strategic industries" and the government provided special assistance to them, including preferential loan services from development funds and financial institutions, the inclusion of computer-related strategic products in the Statute for the Encouragement of Investment, and so on. According to Fuller (2002), the Taiwanese government also set up the Hsinchu Science-based Industrial Park (HSIP) in 1980. The science park provides tax breaks and other incentives for the high technology companies, and it also ensured that the companies received adequate supplies of water and electricity. However, at that time, the high-tech industry was basically characterized by a low value-added Original Equipment Manufacturer (OEM) type of production.

During the 1990s (Fuller, 2002), there was a notable movement of Taiwanese IT hardware production out of Taiwan to cut costs. Taiwanese government also launched its Ten-Year Plan 1990-2000 and Statute for Upgrading Industry and, hoping to transform Taiwan from an OEM country which earned profits from assembly into a technological leader. Tsai and Wang (2004) state that from the late 1980s to the early 1990s, the government directs a lot of innovation alliances to promote industrial upgrading. Besides, the government also provided technical support, research grants, tax incentives such as investment tax credits for R&D, financial support especially for SMEs and innovation incubators to encourage innovation. Besides, in early 1990s, Taiwanese government chose ten emerging industries including information technology, communication technology, consumer electronics, semiconductor, precision machinery, aerospace industry, high technology material, pharmaceutical, medical and pollution abatement as the growth engines. The government provided assistances such as tax exemption or tax credit of investment up to five years. They also gave subsidies for innovative product and technology development up to fifty percent. Among ten industries, the government paid much attention to information and communication technology industries, semiconductor and consumer electronics industry. In 1995, the government approved a plan which was aimed to develop Taiwan as the so-called Asia-Pacific Regional Operations Center (APROC) through three stages. The most important goal was to build up Taiwan as a technology island and an Asia-Pacific or world knowledge-based manufacturing center. The government still focused on the ten emerging industries, and planned to set up some intelligent industrial parks. In addition to the common support, the government also cut the red tape to create a manufacturing-friendly environment.

OECD (1996) proposes the idea of "knowledge-based economy" and concludes that the production, use, and distribution of knowledge and information are the driving forces for economic growth. Considering that lacking innovative technology was prevalent to Taiwanese SMEs, the Ministry of Economic Affairs in 1999 benchmarked a United States government program - Small Business Innovation Research (SBIR) to encourage SMEs to conduct innovative activities on technology or product by providing SMEs subsidy. Through the efforts of government and the private sector over the past few decades, whether Taiwanese industries succeed in transformation remains to be observed. However, enterprises are working hard to become technology-intensive or knowledge-intensive firms to maximize profits. According to the 2006 White Paper on Taiwan's Industrial Technology, business enterprise expenditures on R&D (BERD) grew by 8.71% between 2000 and 2004. In addition, Huang and Yang (2010) find that there is a huge progress in Taiwan's innovative activities. The number of domestic patent applications increases from 18,372 in 1986 to 39,663 in 2003. As applicants for US patents, the number grows from 208 in 1986 to 5,298 in 2003.

III. *Literature Review*

Recently, many studies have attempted to evaluate the impact of generic innovation activities as well as product and process innovation on firm labor productivity or total factor productivity (Chudnovsky et al. 2006; Griffith et al., 2006; Parisi et al., 2006; Hall et al., 2009; Mairesse & Robin, 2010; Polder et al. 2010 among many others). A great number of papers discuss the relationship between product or process innovation and a firm's performance separately. There are basically three different points of view regarding the results. First, only product innovation brings a significant and positive effect to bear on productivity (Mairesse & Robin, 2010). Second, process innovation is more helpful for firm productivity (Parisi et al., 2006; Masso & Vahter, 2007; Hall et al., 2009). Lastly, the results of the link between product/process innovation and firm performance are mixed (Griffith et al., 2006).

Mairesse and Robin (2010) use firm-level data from the third and fourth waves (CIS3 and CIS4) to investigate the effect of innovation on labor productivity in France. They estimate a nonlinear econometric model with five equations as a variant of the CDM model. They find that product innovation appears to be the main driver of labor productivity, whereas the influence of process innovation is either not significant or is close to zero. Parisi et al. (2006) use survey data from an Italian investment bank instead of CIS data and imply that process innovation has a large impact on productivity. Furthermore, R&D spending is strongly positively associated with the probability of introducing a new product, whereas fixed capital spending increases the likelihood of introducing a process innovation. Masso & Vahter (2007) use a CDM model to study whether there is significant association between the product or process innovation of firms and their productivity in Estonia, which is classified as a small catching-up economy. They show that process innovations have a strong positive effect on productivity, but there is no effect of product innovations. Hall et al. (2009) use data from another Italian commercial bank. They apply the model to data on Italian SMEs and find that product innovation has a positive impact on firms' labor productivity, but process innovation has a larger effect via the associated investment. As for mixed results, Griffith et al. (2006) use firm-level data from the third wave of Community Innovation Surveys to compare the role that innovation plays in productivity across four European countries, namely France, Germany, Spain, and the UK. They find that the determinants for firms to decide to engage in formal R&D are similar across countries, but the results for labor productivity are mixed. Process innovation only brings about higher productivity in France, while product innovation is associated with higher productivity in France, Spain, and the UK, but not in Germany.

As discussed above, the individual relationship between process/product and firm productivity has been explored in most studies, which makes it difficult to evaluate the complementarity of different innovation modes, in particular product vs. process innovation.[2] Only a few previous studies discuss the scenario that a firm engages in product innovation, process innovation, both kinds of innovation activities or activities other than these two innovation types.

Chudnovsky et al. (2006) use panel data from innovation surveys in Argentina from 1992 to 2001 to analyze the determinants of innovative inputs and outputs and their impacts on manufacturing firms' productivity in Argentina. They take the non-innovator as the comparison group, and study the impact that only the product innovator, only the process innovator and both product and process innovator have on the labor productivity of the firm. The results state that engaging in innovation activities enhances the probability of becoming an innovator, and innovators perform better than non-innovators in terms of labor productivity. Miravete & Pernís (2006) develop a structural discrete choice model of production and innovation decisions and use the data of Spanish firms to estimate the complementarity and induced correlation among scale, product, and process innovation. They find that there is significant complementarity between product and process innovation. Martin & Nguyen Thi (2015) study the relationship between innovation and productivity conditional to R&D activities and ICT use during the innovation process. They use product innovation, process innovation, organizational innovation and innovative performance as four indicators of innovation outputs. As for product innovation and process innovation, the results indicate that there is no significant impact of these innovation outputs on labor productivity, while organizational innovation controlled for ICT use

[2] As mentioned in Section 1, many studies have extensively explored the complementarity of R&D strategies, for instance, Veugelers & Cassiman (1999), Cassiman & Veugelers (2002), Hou & Mohnen (2011) and Lin et al. (2013).

is a crucial issue for labor productivity. Goedhuys & Veugelers (2012) use World Bank ICS 2000-2002 data from Brazilian manufacturing firms to identify innovation strategies of firms and their effect on successful process and product innovations. Besides, they explore the importance of process and product innovations to firm growth. The results indicate that innovative performance is an important driver of firm growth, particularly the combination of product and process innovations. Martínez-Ros & Labeaga (2009) explore the effect of the firm's persistence on the development of product and process innovation. They use the Spanish Industrial Survey on Business Strategies (Encuesta sobre Estrategias Empresariales, ESEE) from the Ministry of Science and Technology for the period 1990-1999. It shows that complementarities between two innovations are important when the managers decide to continue innovating.

The study of innovation complementarity has been extended to cover more than two innovation strategies; see Mohnen & Hall (2013) for an extensive survey. Polder et al. (2010) extend the commonly used CDM model from two types of innovation to three types including product, process and organizational innovation. They show that product and process innovation are complementary to each other while the combination excludes organizational innovation. Among the three types of innovation, process innovation and organizational innovation are complements, while product and organizational innovation are substitutes. Schmidt & Rammer (2007) use data from German CIS4 to analyze the relationship between non-technological innovation and technological innovation, and their effects to firm performance and success with product and process innovation. They conclude that non-technological innovation such as new organizational methods or new marketing methods spurs success with product and process innovation. Ballot et al. (2011) combine information from CIS4 for France and the UK to explore the relationships among product, process and organizational innovation. The results suggest that rather than engaging in the three types of innovation at the same time, either a process-product innovation complementarity, or an organization-product innovation complementarity gives rise to a similar performance. The summaries of the related studies on complementarity in innovation strategy are listed in Table 1.

Table 1. Literature Summary of Innovation Complementarities

Author	Data period	Sample	Methodology	Results
Chudnovsky et al. (2006)	1992-2001	1992-1996 1,639 firms 1998-2001 1,688 firms	CDM model & multinomial Logit model	Innovators performed better than non-innovators in terms of labor productivity
Miravete & Pernís (2006)	1988-1992	432 firms	Supermodularity & discrete choice model	Significant complementarity between product and process innovation
Schmidt & Rammer (2007)	2002-2004	5,476 firms	bivariate probit model	Non-technological innovation spurs success with product and process innovation
Martínez-Ros Labeaga (2009)	1990-1999	11,547 firms, but unbalanced panel	a discrete choice random effects model	Complementarities between two innovations are important when the managers decide to continue innovating
Polder et al. (2010)	CIS2002, CIS2004, CIS2006	Manufacturing: 8,537 firms; Services: 18,461 firms	CDM model	Product and process innovation increase TFP only in combination with organizational innovation
Ballot et al. (2011)	CIS4 (2002-2004)	3,627 firms for the UK and 5,691 firms for France	testing complementarity-in-use and complementarity-in-performance	Rather than doing the three types of innovation at the same time, either a process-product innovation complementarity, or an organization-product innovation complementarity reaches a similar performance
Martin Thi & Nguyen (2011)	CIS2006; 2004-2005	364 firms	CDM model	There is no significant impact of product and process innovations on labor productivity, but organizational innovation controlled for ICT use is a crucial issue for labor productivity
Goedhuys & Veugelers (2012)	2000-2002	1,642 manufacturing firms	3 stages & multinomial Logit model	Innovative performance is an important driver for firm growth, particularly the combination of product and process innovations

IV. *Methodology*

The standard model used in the literature to study the determinants and effects of innovation is the three-stage model proposed by Crépon et al. (1998), known as the CDM model. The rationale is that the innovation input (e.g., spending on R&D) does not directly affect firm performance such as the firm's productivity. Instead, the innovation input leads to the generation of knowledge, that is, the innovation output, which influences the firm's productivity. According to Hall and Mairesse (2006), there are three main contributions of the CDM model. First, it uses a systematic model to integrate separate strands of empirical research. Second, it makes good use of new information provided by innovation surveys such as quantitative and qualitative indicators. Third, it uses estimation methods to correct the sample selection and the endogeneity problem associated with the explanatory variables. Therefore, the relationship among R&D, innovation and firm productivity can be more accurately assessed empirically.

In this paper, we will also use this structural model to link innovation and productivity. The basic structure of the model describes how firms decide whether to engage in research and development or not, and the intensity of R&D is derived as a result of this selection. As we mentioned above, previous studies either use the Bivariate Probit model (Griffith et al., 2006 ; Hall et al., 2009 and Mairesse & Robin, 2010) or the Probit model for process innovation and the Tobit for product innovation (Mairesse & Mohnen, 2005). In order to take into consideration the possibility that a firm might choose two ways of innovation at the same time instead of either innovation, we will use a Multinomial Logit model to estimate the second stage, which is known as the knowledge production function. The third and the last stage is the production function equation. The model consists of five equations:

$$\mathrm{RD}_i^* = \mathbf{I}(x_{1i}'\beta_1 + u_{i1} > 0) \tag{1}$$

$$\ln \mathrm{RD}_i = x_{2i}'\beta_2 + u_{i2} \tag{2}$$

$$\mathrm{Innotype}_i^j = \alpha_3^j \ln \mathrm{RD}_i x_{3i}'\beta_3 + u_{i3}^j \tag{3}$$

$$\mathrm{TFPgrowth}_i = \alpha_4 \mathrm{Innotype}_i^{j*} + x_{4i}'\beta_4 + u_{i4} \tag{4}$$

$$\mathrm{LPgrowth}_i = \alpha_5 \mathrm{Innotype}_i^{j*} + x_{5i}'\beta_5 + u_{i5} \tag{5}$$

where $\mathbf{I}(.)$ is the indicator function, which equals 1 if the firm has (or reports) positive R&D expenditures, and 0 otherwise. The β_k ($kk = 1, \cdots, 5$) and α_k($k = 3, 4$ and 5) are the parameters that we are interested in. The x_{ki}'s ($kk = 1, \cdots, 5$) are vectors of independent variables, and the u_i's are random error terms.

The variable (RD_i^*) is the unobserved latent variable representing the firm's innovative effort. In some cases, for firms to be without research and development expenditures do not necessarily mean that they are not capable of engaging in R&D. Instead, they choose not to engage in R&D activities based on careful considerations. Therefore, to truly reflect this situation, we use a Heckman-type sample selection model, which is also known as a Tobit type II model. More specifically, Equation (1) represents whether the firm selects to engage in R&D or not. It explains the probability that firm i engages in R&D, and is specified as a Probit model. Equation (2) shows the R&D intensity of firm i, conditional on this firm's engaging in R&D, where we define R&D intensity as the ratio of R&D activity expenditures to the number of employees according to Mairesse & Robin (2010).

Equation (3) specifies the knowledge production function. The dependent variable is the innovation output (Innotype), which represents the different types of innovation that firms might choose as innovation activities. As for the $\mathrm{Innotype}_i^j$ variable, $j = 1$ to 3 means product innovation only, process innovation only and both types of innovation, respectively, and $j = 4$ represents no innovation (the reference group). In a departure from previous studies, we use the Multinomial Logit model to estimate the innovation equation, allowing for four different innovation strategies. Besides, the independence of irrelevant alternatives (IIA) test is performed to ensure the validity of the Multinomial Logit model.

To measure firm performance, we adopt total factor productivity growth (TFPgrowth) to more accurately estimate firm productivity. Equation (4) describes the TFPgrowth as a function of the (fitted) innovation output ($\mathrm{Innotype}^*$) and some explanatory variables. Here, we use the Cobb-Douglas production function and the main inputs are labor, capital and intermediate goods. As for the TFPgrowth measurement, we take the estimator developed by Levinsohn and Petrin (2003) to deal with the simultaneity issue in the firm's production function and calculate the growth rate between two periods. They measure output with sales or value-added, capital stock as being proxied by the tangible fixed assets in the firm, intermediate goods as being proxied by material and energy costs, and labor as being measured by the number of employees. Besides, we also adopt labor productivity growth (LPgrowth) in Equation (5) which is widely utilized as a performance measurement such that we can compare the results with related studies.[3] We follow the definition by Griffith et al. (2006) and Gallego et al. (2013) that labor productivity is the ratio of real value-added to total workforce used in the production process or delivery of a service.

We follow the conventional estimation procedure (e.g., Crépon et al., 1998; Hall et al., 2009) to estimate Equations (1) to (5). In the first step, we estimate Equations (1) and (2) by the maximum likelihood approach. Then, the fitted value obtained from the first step is then plugged into Equation (3) to tackle the simultaneity problem between R&D and the expectation of innovative success, where the bootstrap standard errors are employed to correct the estimation effect from the first step. Lastly, the predicted probability of conducting each type of innovation from the second step and other controls are included in the productivity estimation. Once again, the bootstrap method is utilized to correct for the standard errors in Equation (4) and Equation (5).

V. *Data and Variables*

1. Data Sources

To empirically evaluate the relationship between innovation and productivity, two sources are combined to construct a rich data set. The first is the Taiwan Technological Innovation Survey II (TTIS-II), which is an innovation survey of Taiwan from 2004 to 2006 conducted by the National Science Council. Due to the importance of technological innovation to the future development of technology, the National Science Council and the Ministry of Economic Affairs started to conduct the first Taiwan Technological Innovation Survey between 2002 and 2003. We choose to use TTIS-II because it has a larger sample and can provide us with more individual firm information to explore the determinants of an innovative firm engaging in R&D activities. The questionnaire and sampling procedure of TTIS-II are based on the fourth edition of the European Community Innovation Survey (CIS4) and the OSLO Manual 2005. This survey gives us a general idea about the innovation behaviors of 10, 013 Taiwanese firms (including manufacturing and service firms).

The second data source is the Industry, Commerce and Service Census (ICSC), which is compiled by the Directorate-General of Budget, Accounting and Statistics, Executive Yuan every five years. The first census was conducted in 1954, and the purpose was to collect the data for industry, commerce and service industries including operations, resource distribution, and industrial structures so that the government could formulate the appropriate industrial policies. In order to calculate the total factor productivity growth rate (TFPgrowth), we use the firm information on intermediate inputs from ICSC in 2001 and 2006. There are 935,316 and 1, 105,102 observations in the 2001 and 2006 censuses, respectively. In the 2001 census, 200,890 firms are manufacturing firms and 734,426 firms belong to the service industry. In the 2006 census, there are 226, 048 manufacturing firms and 879, 054 service firms. The detailed computation of TFP is referred to the Appendix.

[3] We thank an anonymous referee for directing us to utilize an alternative productivity measurement.

Two data sources with firms which have the same sample identifier are matched to obtain 4,563 manufacturing firms. However, after removing unreasonable observations and excluding the samples with incomplete information, we finally have 2, 195 observations in our study. Furthermore, our sample is reduced to 1,016 firms when we calculate TFP growth rate and 1, 046 firms considering the labor productivity growth. According to the 2-digit industry classification, these sample firms come from a variety of industries such as metal product manufacturing, food and drinks manufacturing, and so on. However, we use the main industry classification from the 8th Standard Industrial Classification revised by the Directorate-General of Budget, Accounting and Statistics, Executive Yuan in 2006, to divide our sample into 12 industries, which include the food, beverage and tobacco (did1), textile and leather (did2), paper making and publishing (did3), petroleum, plastic and chemical product (did4), non-metal product (did5), basic metal (did6), metal product (did7), electric and electronics (did8), mechanical equipment (did9), transportation equipment (did10), furniture manufacturing (did11) and other manufacturing (did12) industries.

2. Choice of Independent Variables

In Equation (1), the x_1 vector of regressors includes all the variables that affect the firms' decisions to engage in R&D or not. First, as pointed out by Mairesse & Robin (2010), firm size is a factor that influences the probability of choosing to engage in R&D, but not the amount of investment in R&D activities. Therefore, we include the variable firm size, which is measured by the number of employees that are hired in 2006, and is originally represented by a 6-category variable in TTIS-II: (1) less than 5 employees, (2) 5 to 29 employees, (3) 30 to 49 employees, (4) 50 to 199 employees, (5) 200 to 499 employees, and (6) over 500 employees. To avoid too few observations in each category, we decide to classify firm size into three groups following Arbeláez & Torrado (2011), which include small (less than 50 employees), medium (50 to 199 employees), and large (over 200 employees).

Besides, several characteristics of firms such as the average wage (average wage), average capital (capital intensity) and firm age (firmage) are included in Equation (1). According to Hall et al. (2009), although the coefficients are not statistically significant, it seems that younger firms may be more motivated to conduct R&D than older firms. Moreover, Aw and Hwang (1995) find that exporters have higher levels of productivity than those who sell only in the domestic market. However, considering there may exist the reverse causality resulted from average wage, capital intensity and export, we use the average wage and capital intensity from the previous period instead of the current period. We also consider the dummy variable export in our setting with a value of one meaning that the firm reports exporting in the previous period. Huang et al. (2010) show that being an employee with a higher education (a university-level education) is positively correlated with being an in-house R&D performer. We also add the variable highedu to represent the proportion of employees with a higher education to overall employees in order to explore the linkage between higher education and the tendency to engage in R&D activities.

Moreover, x_1 includes two dummy variables which show how firms protect their R&D or innovation outputs that might influence their desire to be involved in R&D activities. Neuhaeusler (2009) states that there are two common ways to exclude third parties from the exploitation of one's own innovative outputs. One consists of the so-called formal protection mechanisms, including patents, trademarks, industry designs and copyright, which give innovators an exclusive but usually timely limited right to use their results and the other comprises informal protection instruments, which cover different actions that firms can undertake to protect their innovations. Therefore, the first dummy (formal protection) that we construct is equal to 1 if a firm uses patents, design patterns, trademarks or copyrights and to 0 otherwise. The second dummy (strategic protection) is equal to 1 if a firm uses complexity of design, secrecy or its lead-time advantage on competitors and to 0 otherwise.

Besides, in Equation (1) we make use of several dummy variables to describe the information sources and cooperation for innovation activities. The dummy variable (cooperation) is equal to 1 if a firm reports cooperation with other firms or institutions for innovation. Other dummy variables (internalinfo, marketinfo, publicinfo and otherinfo) represent the information sources of innovation activities, which are from intra-company data, markets such as consumers or competitors, public sources including universities or the government and other sources.

To consider the influence that financial support from outside the company brings on firm's R&D strategy, we add an additional dummy variable (fund) to represent the support from government or other resources. Moreover, x_1 also includes industry dummy variables (did1,..., did12) which help us understand the tendency of different industries to engage in R&D activities. We also add four dummy variables which are related to four production and innovation types: OEM (Original Equipment Manufacturer), ODM (Original Design Manufacturer), OBM (Original Brand Manufacturer) and Other (Fast Second, Focus and Disruptive). According to Sumantri & Nasution (2013), there are three main production models in outsourcing manufacturing industry: original equipment manufacturer (OEM), original design manufacturer (ODM), and original brand manufacturer (OBM). Original equipment manufacturers produce goods from semi-commodities to final products and provide full-package of supply. Original design manufactures design products for customers or co-design products with the customers, and sometimes sell their products to OEMs (Van Liemt, 2007). Besides, the original brand manufacturers design, manufacture, and sell the merchandise with their own brand. As for other production models, Buisson & Silberzahn (2010) state that the Fast Second approach was first defined by Markides & Geroski (2005) who believe that instead of being the pioneers to create a new market, companies should follow the main specification and focus on the newly created market in a second position. Tanwar (2013) mentions that Focus Strategy is one of the three strategies proposed by Michael Porter. It indicates that firms should target a specific and narrow market rather than competing with the leading firms. As for Disruptive Innovation, it is one of the emerging technological innovation proposed by Christensen (1997) (Markides, 2006; Yu & Hang, 2009). The main idea is to develop new markets or non-mainstream markets by lower cost or other characteristics, and in the future may disrupt the existing market. Furthermore, since the mechanical and electronics industries are two strategic areas that the government invest a great amount of resources in and they are also the industries where OEM production dominates, we will use the interaction terms (d8large and d9large) to discuss the determinants of R&D decision, innovation strategies and productivity growth of large scale enterprises and compare with small and medium firms in these two specific industries. The explanatory variables (x_2) used in Equation (2) are the same as those used in

Equation (1), except for the three firm size dummies, four dummies that represent production and innovation modes and two interaction terms. That is, firm size and production type influence the probability of a company's deciding to implement an R&D strategy rather than focusing on the R&D intensity.

Following the approach in previous studies (e.g., Mairesse & Robin, 2010), the regressors they use in the bivariate Probit model for product innovation equation and process innovation equation include the log of R&D intensity from the previous equation and some exogenous variables such as firm size and the industry dummies. In addition, Lin et al. (2014) estimate the innovation activities with a control of R&D, capital intensity, firm age, firm size, industry dummies and so on. Therefore, the explanatory variables contained in x_3 for different types of innovation activities in Equation (3) are similar to x_1, except for the factors that affect the firm's choice to engage in R&D activities (i.e., export, formal protection, strategic protection, cooperation, highedu, internalinfo, marketinfo, publicinfo, otherinfo, OEM, ODM, OBM and Other).

Regarding to the firm performance equation, the innovation production function is included in our regression following the setting in Mairesse & Robin (2010). Firm size, firm age and industry-specific dummies are common covariates that are controlled in the firm productivity estimation, e.g., Mairesse & Robin (2010), Lee et al. (2013), Lin et al. (2013), and many others. In the last stage, the vector of x_4 and x_5 include all the variables in x_3 except for capital intensity, and further include some variables that might influence a firm's total factor productivity or labor productivity growth such as export and production types (OEM, ODM, OBM and Other). Furthermore, we also include the interaction terms OEMProd, OEMProc, ODMProd, ODMProc, OBMProd, OBMProc, OtherProd, OtherProc to examine the innovation effects on various types of manufacturers.

VI. *Empirical Results*

1. Descriptive Statistics

To help us to find the interrelations among R&D, innovation and the firm's productivity, it is useful to have a brief understanding of the characteristics of innovative and R&D firms. Table 2 presents the summary statistics based on the whole sample. The average TFP growth rate is 1.035, and the maximum and minimum are 64.153 and 0.0006 respectively, which imply a huge gap between the most productive firm and the least productive firm. The sample mean for (log) RD intensity is 4.203. We also find that 46.00% of our observations are large firms, which have more than 200 employees and usually can afford R&D and innovation activities. 35.80% are classified as medium-sized firms, while only 18.20% are small firms which have less than 50 employees. The average firm age is 24.41 years. More than one third of the firms choose protection mechanisms to protect their innovation outputs, where 37.40% report selecting formal protection and 44.80% of the overall observations opt for strategic protection. In our sample, 69.50% of the firms report exports in the first period and only 16.00% receive funding from the government or any other channel during the innovation process. As for the proportion of employees with a university level education, the average proportion is 42.25%.

TABLE 2. SUMMARY STATISTICS

	Mean	Std. Dev.	Min	Max
TFPgrowth	1.035	2.705	0.0006	64.153
Log (Rd intensity)	4.203	2.049	-3.989	9.594
Firm size				
Small	0.182	0.386	0	1
Medium	0.358	0.480	0	1
Large	0.460	0.499	0	1
Protection measures				
Formal protection	0.374	0.484	0	1
Strategic protection	0.448	0.498	0	1
Firmage	24.407	11.428	3	61
Export	0.695	0.461	0	1
Fund	0.160	0.367	0	1
Highedu	42.253	28.727	0	100
Log (Average wage)	6.090	0.382	5.251	7.332
Log (Capital intensity)	6.759	1.166	1.371	11.333
Cooperation	0.365	0.482	0	1
Information sources				
Internalinfo	0.355	0.479	0	1
Marketinfo	0.510	0.500	0	1
Publicinfo	0.312	0.464	0	1
Otherinfo	0.395	0.489	0	1
Industry dummies				
food, beverage & tobacco	0.049	0.216	0	1
textile & leather	0.095	0.294	0	1
paper making & publishing	0.022	0.146	0	1
petroleum, plastic & chemical product	0.165	0.372	0	1
non-metal product	0.037	0.190	0	1
basic metal	0.062	0.241	0	1
metal product	0.094	0.291	0	1
electric & electronics	0.289	0.454	0	1
mechanic equipment	0.086	0.280	0	1
transportation equipment	0.064	0.245	0	1
furniture manufacturing	0.012	0.108	0	1
other manufacturing	0.025	0.155	0	1
Production types				
OEM	0.313	0.464	0	1
ODM	0.280	0.449	0	1
OBM	0.204	0.403	0	1
Other	0.155	0.362	0	1

The mean of (log) average wage and capital intensity from the first period are 6.09 and 6.76. Regarding the innovation information sources and cooperation, each source is important for firms to get involved in innovation activities. In particular, more than half (51.00%) of the observations have information from the market including suppliers, customers and competitors; 36.50% cooperate with other firms or institutions during the sample period. Among twelve industry dummy variables, electric & electronics takes the biggest portion (28.90%). The following main industries are petroleum, plastic and chemical product (16.50%), textile and leather (9.50%) and metal product (9.40%). Since a firm can select more than one production type, OEM, ODM, OBM and Other takes the portion of 31.30%, 28.00%, 20.40% and 15.50%, respectively.[4]

Table 3 shows the summary statistics based on four different innovation classifications. 468 firms, 46.06%, do not engage in any innovation activity, while 148 firms (14.57%), 157 firms (15.45%) and 243 firms (23.92%) choose only production innovation, only process innovation and both innovations, respectively. Among the four types, firms that engage in both innovation activities have the highest TFP growth rate (1.209), followed by only process innovation (1.208), no innovation (0.962) and only product innovation (0.797). As for the firm's innovation behavior, in the group engaging in product innovation only, large firms (48.00%) and medium firms (35.10%) are the main forces that pursue this type of innovation. In the group conducting process innovation only, large firms (52.90%) and medium firms (38.20%) are both the major firms. Regarding the capability to afford innovation activities, in the group involved in both innovations, large firms account for 59.30%; in the no innovation group, even though small firms account for 26.10%, which is less than the percentages for medium firms (37.80%) and large firms (36.10%), the percentage is greater than that where firms select either or both innovation activities. Regarding the firms that engage in any innovation activities, the percentage choosing strategic protection measures is greater than that selecting formal protection. Besides, for any innovation type, the percentage reporting exports exceeds 70%, except no innovation (67.10%). In addition, the percentage of employees with a higher education is over one third for every category and for only product innovation (50.993%) and both innovations (49.663%) in particular. As for only product innovation, process innovation and both innovations, market is the most important information source, accounting for over 90% (94.60%, 93.00% and 95.50%, respectively). Besides, among all the industries, the percentage that electric and electronics firms involve in only product innovation (31.10%), process innovation (28.00%), both innovations (32.90%) and no innovation (26.50%) is the highest respectively, followed by petroleum, plastic and chemical product industry (15.50%, 21.00%, 16.00%, and 15.60%, respectively). For each innovation activity, the percentage that OEM firms engage in a particular innovation activity outpaces ODM, OBM and Other (see the bottom of Table 3).

[4] We acknowledge that in the TTIS-II data only innovative firms are required to answer OEM, ODM, OBM or Other types. Therefore, it is shown that the proportions of those types (0.313, 0.280, 0.204 and 0.155, respectively) using entire sample (including non-innovative firms) are somewhat lower than those of the common thought that Taiwanese manufacturing firms are OEM-oriented. The ratios of OEM, ODM, OBM, and Other are significantly increased to 0.576, 0.527, 0.369, and 0.284, respectively if we focus on the innovative firms only. We have also experimented with the empirical analysis on the firm productivity based on the sub-sample of the innovative firms and similar findings are obtained.

TABLE 3. SUMMARY STATISTICS FOR DIFFERENT INNOVATION TYPES

	Product	Process	Both Innovations	No Innovation
No. of firms	148 (14.57%)	157 (15.45%)	243 (23.92%)	468 (46.06%)
TFPgrowth	0.797	1.208	1.209	0.962
Log (Rd intensity)	3.915	4.369	4.601	4.013
Firm size				
Small	0.169	0.089	0.099	0.261
Medium	0.351	0.382	0.309	0.378
Large	0.480	0.529	0.593	0.361
Protection measures				
Formal protection	0.703	0.631	0.728	0
Strategic protection	0.845	0.790	0.848	0
Firmage	23.811	24.822	24.198	24.566
Export	0.703	0.732	0.712	0.671
Fund	0.264	0.312	0.309	0
Highedu	50.993	38.849	49.663	36.783
Log (Average wage)	6.115	6.152	6.127	6.042
Log (Capital intensity)	6.777	6.990	6.865	6.621
Cooperation	0.581	0.675	0.737	0
Information sources				
Internalinfo	0.676	0.643	0.658	0
Marketinfo	0.946	0.930	0.955	0
Publicinfo	0.527	0.561	0.621	0
Otherinfo	0.716	0.726	0.745	0
Industry dummies				
food, beverage & tobacco	0.047	0.045	0.053	0.049
textile & leather	0.074	0.070	0.049	0.135
paper making & publishing	0.027	0.019	0.012	0.026
petroleum, plastic & chemical product	0.155	0.210	0.160	0.156
non-metal product	0.027	0.025	0.053	0.036
basic metal	0.047	0.089	0.066	0.056
metal product	0.074	0.102	0.082	0.103
electric & electronics	0.311	0.280	0.329	0.265
mechanic equipment	0.122	0.038	0.115	0.075
transportation equipment	0.074	0.096	0.049	0.058
furniture manufacturing	0.007	0.013	0.008	0.015
other manufacturing	0.034	0.013	0.021	0.028
Production types				
OEM	0.534	0.611	0.588	0
ODM	0.493	0.529	0.527	0
OBM	0.345	0.318	0.436	0
Other	0.216	0.280	0.333	0

2. Estimation Results

1) R&D equation

The estimates of the modified CDM model are presented in Tables 4−7. We first report the estimates for the R&D selection function and R&D intensity equation in Table 4. There are three panels in the R&D equations. R&D equation (A) shows the estimates of the complete specification; panel (B) represents the outcomes when we neglect two kinds of innovation output protections, and R&D equation (C) states the results when we exclude the average wage and capital intensity variables.

From panel (A) in Table 4, we find that the export, firmage, average wage, capital intensity, highedu and firm size dummies are significantly and positively related to the firms' decision to conduct R&D, which means that firm's exporting in the previous period, older firms, firms with higher average wages and capital intensity have higher probabilities of engaging in R&D activities. Moreover, a firm with a higher proportion of highly educated employees is more prone to engage in research and development. As for the firm size, medium and large firms have higher probabilities than small firms of engaging in R&D, and the probability increases significantly with the firm size. This reveals that there is a greater propensity for larger firms to undertake R&D, which is consistent with the empirical literature (e.g., Griffith et al., 2006; Lee, 2008; Berger, 2010; Mairesse & Robin, 2010). Besides, if a firm takes action to protect its innovation output, this should increase the chances of such a firm engaging in R&D. However, we find that both types of protections are not significantly associated with the firm's decision to engage in R&D activities from panel (A). As for the R&D decisions for different industries, compared with the food, beverage and tobacco industry, the paper making & publishing industry is the only industry that significantly chooses not to be involved in R&D activities. In addition, large firms in the electric & electronics industry reveal a higher propensity to engage in R&D activities even though the tendency is significant only in panel (C). Moreover, there is no significant result showing which type of manufacturing firms (OEM, ODM, OBM and Other) tend to engage in R&D activities.

In the second column of each panel of R&D equations, the relationship between the R&D intensity and some explanatory variables is reported if a firm chooses to engage in R&D. We obtain a positive and significant coefficient for the exporting firm, suggesting that if a firm exports in the previous period, the more intensive its R&D input will be. This coincides with the result from Harris & Moffat (2011) which shows that in both manufacturing and services, being involved in exporting increased the probability of expending more resources on R&D. However, as for firmage, the result is very different from that in the selection equation. The estimation coefficient of firmage in the R&D intensity equation tends to be significant and negative. The reason may be that older firms have already set up R&D infrastructures or invested in personnel training. In addition, a firm with a higher average wage has a tendency to exhibit higher R&D intensity. The innovation output protection, innovation cooperation with others and source of innovation information might influence R&D intensity but this argument is 0not supported by our empirical results. Regarding the industry effect, it can be clearly seen that the textile & leather, paper making & publishing, non-metal product, basic metal, metal product, transportation equipment and other manufacturing industries have significantly less R&D intensity than the food, beverage & tobacco industry.

The results in panel (B) are very similar to those in panel (A). Nevertheless, the estimates in panel (C) for which we drop average wage and capital intensity reveal a little discrepancy. Firms with funding have less R&D intensity, and this implies that firm's obtaining funding outside the firm will result in less R&D expenditures by itself. Compared with the R&D selection equations in panels (A) and (B), the firm size effects in panel (C) are much stronger

Table 4. Estimation Results of the R&D Equations

	R&D Equations (A)		R&D Equations (B)		R&D Equations (C)	
	Selection	*Intensity*	*Selection*	*Intensity*	*Selection*	*Intensity*
Export	0.314***	0.373***	0.314***	0.370***	0.642***	0.055
	(0.072)	(0.135)	(0.072)	(0.135)	(0.059)	(0.123)
Firmage	0.017***	-0.021***	0.017***	-0.022***	0.021***	-0.023***
	(0.004)	(0.005)	(0.004)	(0.005)	(0.003)	(0.005)
Log (Average wage)	0.425***	1.271***	0.425***	1.272***	-	-
	(0.098)	(0.164)	(0.098)	(0.164)		
Log (Capital intensity)	0.118***	-0.021	0.118***	-0.023	-	-
	(0.032)	(0.054)	(0.032)	(0.054)		
Formal protection	0.120	0.042	-	-	-0.032	0.057
	(0.106)	(0.151)			(0.083)	(0.145)
Strategic protection	-0.117	0.151	-	-	0.078	0.169
	(0.126)	(0.182)			(0.096)	(0.180)
Cooperation	0.115	0.061	0.105	0.075	-0.043	0.138
	(0.105)	(0.146)	(0.104)	(0.145)	(0.083)	(0.142)
Highedu	0.003**	0.001	0.003**	0.001	0.002**	0.003**
	(0.001)	(0.002)	(0.001)	(0.002)	(0.001)	(0.002)
Fund	-0.0001	-0.123	0.008	-0.118	0.043	-0.375**
	(0.109)	(0.151)	(0.109)	(0.151)	(0.088)	(0.148)
Internalinfo	-0.038	0.013	-0.042	0.032	0.094	0.113
	(0.102)	(0.143)	(0.100)	(0.142)	(0.079)	(0.139)
Marketinfo	-0.160	-0.058	-0.17	0.028	-0.113	-0.070
	(0.142)	(0.198)	(0.132)	(0.178)	(0.108)	(0.193)
Publicinfo	0.174	0.149	0.178	0.146	0.135	0.122
	(0.122)	(0.172)	(0.121)	(0.172)	(0.097)	(0.164)
Otherinfo	0.078	-0.011	0.068	0.038	0.061	-0.064
	(0.130)	(0.197)	(0.126)	(0.191)	(0.102)	(0.187)
Firm size (*ref.: Small*)						
Medium	0.950***	-	0.942***	-	1.130***	-
	(0.077)		(0.076)		(0.058)	
Large	1.552***	-	1.546***	-	1.704***	-
	(0.120)		(0.120)		(0.095)	
Industry dummies (*ref.: food, beverage & tobacco*)						
textile & leather	-0.12	-1.152***	-0.135	-1.165***	-0.258*	-0.864***
	(0.173)	(0.296)	(0.172)	(0.295)	(0.141)	(0.288)
paper making & publishing	-0.485**	-1.466***	-0.491**	-1.486***	-0.663***	-0.927**
	(0.203)	(0.385)	(0.201)	(0.384)	(0.159)	(0.367)
petroleum, plastic & chemical product	0.124	-0.410	0.118	-0.429	0.034	0.204
	(0.172)	(0.272)	(0.171)	(0.271)	(0.139)	(0.265)
non-metal product	0.246	-1.427***	0.235	-1.435***	0.133	-1.035***
	(0.239)	(0.363)	(0.238)	(0.364)	(0.196)	(0.365)
basic metal	-0.118	-1.808***	-0.133	-1.822***	0.020	-1.484***
	(0.213)	(0.331)	(0.212)	(0.330)	(0.174)	(0.323)
metal product	-0.021	-1.561***	-0.034	-1.573***	-0.329**	-1.067***
	(0.176)	(0.297)	(0.175)	(0.296)	(0.140)	(0.291)
electric & electronics	0.158	-0.096	0.150	-0.112	0.141	0.460*
	(0.172)	(0.268)	(0.171)	(0.267)	(0.134)	(0.255)
mechanical equipment	0.033	-0.420	0.019	-0.427	-0.214	-0.002
	(0.186)	(0.299)	(0.185)	(0.299)	(0.147)	(0.288)
transportation equipment	0.254	-0.869***	0.247	-0.882***	-0.055	-0.396
	(0.200)	(0.307)	(0.199)	(0.307)	(0.162)	(0.305)
furniture manufacturing	0.110	-0.969	0.114	-0.987*	-0.004	-1.285**
	(0.310)	(0.599)	(0.309)	(0.598)	(0.232)	(0.533)
other manufacturing	0.098	-0.914**	0.089	-0.933**	-0.075	-0.438
	(0.247)	(0.400)	(0.246)	(0.400)	(0.182)	(0.373)
OEM	-0.094	-	-0.090	-	-0.078	-
	(0.101)		(0.100)		(0.077)	
ODM	0.155	-	0.154	-	0.129*	-
	(0.099)		(0.096)		(0.077)	
OBM	0.076	-	0.085	-	0.104	-
	(0.108)		(0.107)		(0.084)	
Other	-0.0001	-	0.001	-	-0.008	-
	(0.111)		(0.111)		(0.087)	
elec. & elec. * large	0.288	-	0.292	-	0.272*	-
	(0.196)		(0.196)		(0.148)	
mech. equip. * large	-0.070	-	-0.043	-	0.169	-
	(0.289)		(0.287)		(0.249)	
obs	2,195	2,195	2,195	2,195	3,692	3,692

for both medium and large firms. As far as the industry effect is concerned, almost all impacts of R&D intensity from panel (C) (where more observations are utilized due to dropping average wage and capital intensity variables) are greater than those of panels (A) and (B).

2) Innovation equation

Table 5 lists the estimation results for two knowledge production functions. The first estimation in panel (A) considers all the explanatory variables, and the other in panel (B) excludes the effect of firmage. The Multinomial Logit model with four choices is estimated, i.e., firms engaging in product innovation only, process innovation only, both types of innovation as well as no innovation. It is intuitively obvious to observe that R&D intensity has a significant and positive correlation with production innovation, process innovation and both innovations, indicating that if a firm has a larger R&D intensity, it tends to engage in innovation activities. This result is in line with Ulku (2007) who concludes that R&D intensity increases the rate of innovation in four manufacturing sectors from 17 OECD countries.

The variable fund has a substantially positive effect on either type of innovation or both innovations in panel (A) of Table 5. Kim & Lee (2011) show that government funding brings about a positive influence on innovation output at the firm level. Even though the variable fund we have used in this paper includes government funding and other funding, it is reasonable to expect that firms' incoming funds will increase the probability of engaging in innovation activities. Firmage is significantly positively correlated with all kinds of innovation activities comparing with no innovation. In other words, older firms may tend to engage in not only R&D, but also innovation activities in order to maintain competitiveness and sustained growth. Besides, firm size also has a positive correlation with process innovation and both innovations. In comparison with small firms, medium and large firms are inclined to engage in both innovations and process innovation, and they especially have a higher probability of engaging in both innovations. Vakhitova & Pavlenko (2010) find that in accordance with other empirical findings, the probability of engaging in product innovation as well as process innovation increases with firm size. The estimated coefficients of the industry dummies show that most of the estimates are significant except for the furniture manufacturing industry. Among all the significant estimates, only electric & electronics industry is less prone to engage in process innovation or both innovations, while other industries are more likely to engage in innovation activities. This phenomenon might imply that most of Taiwanese electric & electronics firms or mechanical equipment firms are OEM firms. Those firms are better characterized by manufacturing capability rather than innovation capacity in the sense t hat their products are mainly customer or market oriented. In the second innovation production function panel, we do not take firmage into consideration. Compared to the estimation results in panel (A), panel (B) in Table 5 reaches a very similar conclusion that firm size matters in regard to three types of innovation activities, but the coefficients for RD intensity, average wage and industry dummies are smaller than panel (A). Panel (B) further indicates that both medium and large firms are significantly associated with product innovation as well. Lastly, to test the validity of Independence of Irrelevant Alternatives assumption, the Chi-square value of Hausman test for product innovation only, process innovation only, both innovations and no innovation are 0.948 (p-value = 1), 6.431 (p-value = 1), 8.008 (p-value = 1) and 0.981 (p-value = 1) respectively, showing that innovation choices are independent of each other.

Table 5. Estimation Results of the Innovation Production Function

	Innovation Production Function (A)			Innovation Production Function (B)		
	Product	*Process*	*Both*	*Product*	*Process*	*Both*
Log (Rd intensity)	6.375***	6.689***	7.004***	3.366***	3.544***	3.557***
	(0.427)	(0.532)	(0.457)	(0.305)	(0.301)	(0.312)
Fund	19.102***	19.237***	19.252***	19.818***	19.939***	19.923***
	(0.543)	(0.554)	(0.537)	(0.576)	(0.584)	(0.568)
Firmage	0.115***	0.119***	0.129***	-	-	-
	(0.011)	(0.013)	(0.012)			
Log (Average wage)	-8.281***	-8.445***	-8.973***	-4.111***	-4.073***	-4.193***
	(0.601)	(0.761)	(0.655)	(0.448)	(0.441)	(0.453)
Log (Capital intensity)	0.078	0.081	0.033	0.073	0.071	0.023
	(0.080)	(0.077)	(0.074)	(0.074)	(0.072)	(0.065)
Firm size (*ref.: Small*)						
Medium	0.058	0.453**	0.513**	0.372**	0.801***	0.881***
	(0.202)	(0.230)	(0.212)	(0.185)	(0.219)	(0.202)
Large	0.140	0.615**	1.038***	0.971***	1.479***	1.964***
	(0.276)	(0.280)	(0.274)	(0.254)	(0.250)	(0.241)
Industry dummies (*ref.: food, beverage & tobacco*)						
textile & leather	6.183***	5.747***	5.985***	2.935***	2.329***	2.244***
	(0.572)	(0.637)	(0.570)	(0.522)	(0.466)	(0.458)
paper making & publishing	8.678***	8.398***	8.866***	4.165***	3.691***	3.719***
	(0.769)	(0.895)	(0.815)	(0.656)	(0.677)	(0.676)
petroleum, plastic & chemical product	1.479***	1.439***	1.501***	0.669	0.575*	0.554
	(0.427)	(0.385)	(0.357)	(0.450)	(0.349)	(0.341)
non-metal product	8.570***	7.947***	9.862***	4.289**	3.442*	4.942***
	(1.629)	(2.394)	(0.797)	(1.804)	(2.020)	(0.696)
basic metal	10.905***	10.998***	11.739***	5.485***	5.309***	5.506***
	(0.895)	(1.007)	(0.899)	(0.732)	(0.638)	(0.660)
metal product	8.636***	8.687***	9.328***	3.962***	3.794***	3.967***
	(0.745)	(0.839)	(0.730)	(0.634)	(0.559)	(0.566)
electric & electronics	-0.353	-0.896**	-0.788**	-0.469	-1.049***	-0.950***
	(0.456)	(0.392)	(0.374)	(0.455)	(0.371)	(0.353)
mechanical equipment	2.472***	1.320***	2.018***	1.283***	0.047	0.639
	(0.467)	(0.505)	(0.444)	(0.479)	(0.450)	(0.412)
transportation equipment	4.646***	4.660***	4.228***	2.379***	2.267***	1.593***
	(0.533)	(0.499)	(0.513)	(0.525)	(0.401)	(0.446)
furniture manufacturing	4.874	5.071	5.189	2.237	2.297	2.146
	(5.508)	(3.131)	(4.576)	(6.038)	(4.081)	(3.961)
other manufacturing	4.776***	3.699**	4.790***	2.333***	1.123	1.956***
	(0.654)	(1.524)	(0.611)	(0.638)	(1.320)	(0.576)
elec. & elec. * large	-0.264	-0.596*	-0.205	-0.564	-0.889***	-0.522*
	(0.347)	(0.338)	(0.304)	(0.369)	(0.346)	(0.296)
mech. equip. * large	-0.252	-0.974	-0.511	-0.0001	-0.700	-0.229
	(0.554)	(1.151)	(0.561)	(0.579)	(1.065)	(0.529)
obs	2,195	2,195	2,195	2,195	2,195	2,195

3) Productivity equation

The last estimation is to link the relationship between different innovation types and firm productivity. The production function estimation in terms of total factor productivity growth rate is reported in Table 6, where TFPgrowth (A) considers the full set of independent variables, while TFPgrowth (B) excludes the firmage variables, TFPgrowth (C) drops the effect of export, and TFPgrowth (D) estimates the production function without average wage. In panel (A), we find that a firm's adopting process innovation only has a significantly positive effect on total factor productivity growth. Our result coincides with the finding of Parisi et al. (2006), Masso & Vahter (2007) and Hall et al. (2009) that process innovation is beneficial to firm productivity growth. This is not surprising because Taiwan has been dominated by small and medium enterprises (SMEs) and most of the manufacturing firms are OEM-type enterprises. According to the data released by Small and Medium Enterprise Administration, MOEA in 2014, Taiwan is a SME dominant economy which is composed of 97.64% small and medium firms. In particular, up to 96.09% of manufacturing firms are SMEs.[5] Mañez et al. (2013) use the sample of Spanish manufacturing SMEs to show that even though the extra productivity growth exists for merely one period, process innovation does increase the total factor productivity for SMEs. Besides, Taiwan is at the stage of economic development where improving productivity cannot easily be achieved by developing more value-added products or new products or creating our own brands but by improving the production process or doing the work to the best of its ability such as Shokunin spirit. However, the coefficient for both innovations is not significant, implying that in our study we do not find a complementary relationship between product innovation and process innovation on total factor productivity growth in the Taiwanese manufacturing sector.

Furthermore, the coefficient estimate of export is significant and negative. This implies that firms exporting in the previous period do not necessarily have higher total factor productivity growth rate. As for firm size, compared with small firms, the coefficients of medium and large firms are not significant. Among industry dummy variables, industries such as petroleum, plastic & chemical product, non-metal product, basic metal, metal product, electric & electronics and mechanical equipment industries have greater total factor productivity growth rate than the reference industry, i.e., the food, beverage & tobacco industry.

Comparing all types of manufacturers, only other types of manufacturers have significant and negative coefficients. As for the interaction terms, all the coefficients are not significant except ODMProd, representing that to ODM firms product innovation can obviously increase the total factor productivity growth compared with no innovation. The bottom of Table 6 reveals that large firms in the electric & electronics industry do not have a higher TFP growth rate than the smaller counterparts. In sum, our results may relate to the fact that Taiwanese government made an effort to select ten emerging industries in 1990s for investing a great amount of money and providing various kinds of assistance. In particular, the positively significant industrial effects (e.g., information and communication technology, semiconductor and consumer electronics industries) on total factor productivity growth have been observed in our study. Moreover, since the R&D intensity and the acquisition of funding have a major effect on process innovation, the government should facilitate access to R&D via various methods to encourage process innovation and further increase the total factor productivity growth. One is the direct funding such as providing selected R&D program with a certain

[5] The ratio of SME firms in our data is over 50%, which is not as high as that reported by Small and Medium Enterprise Administration, MOEA since TTIS-II consists of 31.54% top 5000 manufacturing firms in Taiwan.

Table 6. Estimation Results of the TFP Growth

	TFPgrowth (A)	TFPgrowth (B)	TFPgrowth (C)	TFPgrowth (D)
Innovation type (*ref.: No innovation*)				
Product innovation only	-1.081	-1.280	-1.356	-0.897
	(1.531)	(1.429)	(1.454)	(1.405)
Process innovation only	2.913**	3.784***	2.513*	2.674**
	(1.455)	(1.332)	(1.358)	(1.351)
Both Innovations	0.385	0.473	-0.028	0.430
	(0.719)	(0.727)	(0.694)	(0.705)
Export	-0.262**	-0.381***	-	-0.268**
	(0.133)	(0.138)		(0.131)
Fund	-0.400**	-0.479***	-0.246*	-0.394**
	(0.161)	(0.166)	(0.142)	(0.173)
Firmage	-0.015***	-	-0.017***	-0.015***
	(0.004)		(0.004)	(0.004)
Log(Average wage)	-0.064	-0.125	-0.086	-
	(0.140)	(0.135)	(0.131)	
Firm size (*ref.: Small*)				
Medium	-0.010	-0.045	-0.001	-0.015
	(0.139)	(0.135)	(0.138)	(0.133)
Large	0.059	-0.058	0.069	0.047
	(0.193)	(0.176)	(0.186)	(0.167)
OEM	-0.114	-0.063	-0.071	-0.117
	(0.240)	(0.225)	(0.217)	(0.240)
ODM	-0.326	-0.372	-0.288	-0.327
	(0.284)	(0.265)	(0.276)	(0.273)
OBM	0.354	0.347	0.404	0.345
	(0.260)	(0.271)	(0.271)	(0.286)
Other	-0.508*	-0.488*	-0.470	-0.509*
	(0.298)	(0.293)	(0.293)	(0.309)
Industry dummies (*ref.: food, beverage & tobacco*)				
textile & leather	0.278	0.446*	0.122	0.264
	(0.261)	(0.260)	(0.259)	(0.293)
paper making & publishing	0.114	0.228	0.006	0.093
	(0.371)	(0.344)	(0.359)	(0.372)
petroleum, plastic & chemical product	0.371*	0.448**	0.244	0.356
	(0.214)	(0.199)	(0.208)	(0.221)
non-metal product	0.878***	1.007***	0.824**	0.835***
	(0.324)	(0.327)	(0.326)	(0.314)
basic metal	0.942***	1.064***	0.857***	0.918***
	(0.228)	(0.229)	(0.231)	(0.236)
metal product	0.277	0.463**	0.149	0.265
	(0.234)	(0.230)	(0.233)	(0.247)
electric & electronics	0.521**	0.755***	0.379	0.497**
	(0.236)	(0.227)	(0.239)	(0.239)
mechanical equipment	0.647**	0.855***	0.523	0.606*
	(0.322)	(0.307)	(0.328)	(0.326)
transportation equipment	-0.061	0.053	-0.176	-0.062
	(0.256)	(0.242)	(0.250)	(0.263)
furniture manufacturing	-0.369	-0.269	-0.499	-0.361
	(0.517)	(0.514)	(0.584)	(0.554)
other manufacturing	0.473	0.736**	0.298	0.429
	(0.355)	(0.349)	(0.361)	(0.377)
OEMProd	-0.256	-0.354	-0.124	-0.276
	(1.110)	(1.139)	(1.113)	(1.155)
OEMProc	0.368	0.161	0.282	0.394
	(1.036)	(0.960)	(0.963)	(0.960)
ODMProd	2.162*	2.232*	2.099*	2.122*
	(1.253)	(1.161)	(1.199)	(1.239)
ODMProc	-1.465	-1.489	-1.383	-1.426
	(1.039)	(0.954)	(1.030)	(1.034)
OBMProd	-1.681	-1.624	-1.736	-1.680
	(1.347)	(1.296)	(1.328)	(1.348)
OBMProc	0.180	0.128	0.155	0.229
	(1.046)	(1.011)	(1.024)	(0.994)
OtherProd	2.204	1.976	2.200	2.201
	(1.405)	(1.392)	(1.462)	(1.430)
OtherProc	0.299	0.329	0.216	0.308
	(1.040)	(1.165)	(1.156)	(1.120)
elec. & elec. * large	0.282	0.364*	0.282	0.276
	(0.207)	(0.200)	(0.199)	(0.198)
mech. equip. * large	0.107	0.159	0.107	0.087
	(0.311)	(0.306)	(0.296)	(0.292)
obs	1,016	1,016	1,016	1,016

amount or ratio of grants, or offering low interest loan to application firms which invest in R&D activities. Also the government could implement R&D tax incentives including tax credits, tax allowances, tax deferrals and tax exemption. Aside from funding, the government can establish a R&D center to nourish the private and public R&D partnership. Finally, high-skilled talents are very important to a firm. The government may help firms obtain the talents needed through exchange of know-how, establishment of outstanding R&D environment and high-quality living standard to attract foreign talents. Regarding the other model specifications, panel TFPgrowth (B) shows that we have the same conclusion that process innovation improves firm's productivity. All other results are very close to those based on TFPgrowth (A), except that the textile & leather, metal product and other manufacturing industry also has higher productivity growth rate than the reference group. Besides, in this panel, large firms in the electric & electronics industry have a higher TFP growth rate, which means that firm size or scale does have a significant influence on TFP growth for electric & electronics firms. In panel TFPgrowth (C) and (D), the results are slightly different to those in TFPgrowth (A), especially the effects of Other and some industry dummies are never significant.

Table 7 shows the estimation results of innovation behaviors on labor productivity growth. Panel (A) considers all the independent variables, while Panel (B) neglects the variable firmage, Panel (C) drops the effect of export and Panel (D) estimates the production function without average wage. In Panel (A), we reach a consistent conclusion with TFP growth that engaging in process innovation can significantly improve firms' labor productivity growth. As for firmage, we find that older firms have less labor productivity growth, which coincides with the results from total factor productivity growth. Compared with small firms, the effect of medium and large firms on labor productivity growth are insignificant. Moreover, industries including non-metal product, basic metal, metal product, electric & electronics and mechanical equipment industry have higher labor productivity growth rate than the reference industry. Regarding the effects of different manufacturers and the interaction terms with innovation types, all the coefficients are not significant. Large firms in the electric & electronics industry do not have higher TFP growth than small and medium firms; instead they have greater labor productivity growth. Other panels show similar results as panel (A), except that export and fund in Panel B have significantly negative effects on the labor productivity growth and the coefficients for petroleum, plastic & chemical product, metal product and other manufacturing turn to be significant.

To compare our results with previous studies using data from other countries, Table 8 lists the comparison of the innovation effects on firm productivity by country. It is clear to see that the positive impact of process innovation on firm productivity in Taiwan's manufacturing firms is pretty much in line with that from Western countries (Huergo & Jaumandreu, 2004; Parisi et al., 2006; Griffith et al., 2006; Chudnovsky et al., 2006; Masso & Vahter, 2007; Hall et al., 2009; Siedschlag et al., 2010). Moreover, the fact that the complementarity between product innovation and process innovation is not significant in the literature (Huergo & Jaumandreu, 2004; Parisi et al., 2006; Griffith et al., 2006; Masso & Vahter, 2007; Hall et al., 2009; Mairesse & Robin, 2010) is also supported by this study.

TABLE 7. ESTIMATION RESULTS OF THE LABOR PRODUCTIVITY GROWTH

	LPgrowth (A)	LPgrowth (B)	LPgrowth (C)	LPgrowth (D)
Innovation type (*ref.: No innovation*)				
Product innovation only	-2.006	-2.150	-2.211	-1.578
	(1.533)	(1.497)	(1.639)	(1.476)
Process innovation only	3.219*	3.854**	2.917*	2.645*
	(1.650)	(1.539)	(1.584)	(1.439)
Both Innovations	0.045	0.114	-0.257	0.161
	(0.795)	(0.789)	(0.769)	(0.812)
Export	-0.194	-0.285**	-	-0.207
	(0.140)	(0.142)		(0.141)
Fund	-0.272	-0.329*	-0.153	-0.263
	(0.173)	(0.187)	(0.151)	(0.167)
Firmage	-0.012***	-	-0.013***	-0.012***
	(0.004)		(0.004)	(0.004)
Log (Average wage)	-0.145	-0.205	-0.162	-
	(0.140)	(0.137)	(0.135)	
Firm size (*ref.: Small*)				
Medium	-0.099	-0.123	-0.094	-0.110
	(0.150)	(0.128)	(0.147)	(0.139)
Large	0.021	-0.063	0.025	-0.004
	(0.178)	(0.172)	(0.180)	(0.178)
OEM	-0.085	-0.050	-0.048	-0.092
	(0.256)	(0.246)	(0.256)	(0.254)
ODM	-0.436	-0.473	-0.411	-0.446
	(0.298)	(0.311)	(0.283)	(0.293)
OBM	0.149	0.141	0.183	0.129
	(0.295)	(0.321)	(0.300)	(0.302)
Other	-0.109	-0.082	-0.076	-0.108
	(0.317)	(0.326)	(0.326)	(0.341)
Industry dummies (*ref.: food, beverage & tobacco*)				
textile & leather	0.103	0.245	-0.015	0.068
	(0.351)	(0.327)	(0.314)	(0.335)
paper making & publishing	-0.252	-0.157	-0.329	-0.305
	(0.449)	(0.431)	(0.438)	(0.419)
petroleum, plastic & chemical product	0.495	0.576**	0.401	0.462*
	(0.302)	(0.288)	(0.261)	(0.279)
non-metal product	0.854*	0.961**	0.814*	0.745
	(0.506)	(0.479)	(0.486)	(0.456)
basic metal	1.073***	1.187***	1.007***	1.019***
	(0.330)	(0.307)	(0.294)	(0.278)
metal product	0.496	0.656**	0.395	0.464
	(0.320)	(0.293)	(0.285)	(0.294)
electric & electronics	0.591*	0.782***	0.483	0.531*
	(0.337)	(0.298)	(0.301)	(0.299)
mechanical equipment	0.877**	1.053***	0.780**	0.778**
	(0.393)	(0.359)	(0.358)	(0.355)
transportation equipment	0.131	0.243	0.042	0.130
	(0.335)	(0.315)	(0.305)	(0.316)
furniture manufacturing	0.311	0.394	0.219	0.328
	(0.525)	(0.531)	(0.483)	(0.539)
other manufacturing	0.675	0.888**	0.545	0.572
	(0.434)	(0.419)	(0.417)	(0.415)
OEMProd	0.748	0.660	0.801	0.704
	(1.451)	(1.361)	(1.370)	(1.338)
OEMProc	-0.854	-0.976	-0.914	-0.785
	(1.093)	(1.082)	(1.094)	(1.037)
ODMProd	1.260	1.325	1.263	1.194
	(1.406)	(1.383)	(1.488)	(1.480)
ODMProc	-0.322	-0.341	-0.288	-0.219
	(1.181)	(1.116)	(1.131)	(1.103)
OBMProd	0.540	0.590	0.515	0.540
	(1.527)	(1.575)	(1.456)	(1.463)
OBMProc	-0.386	-0.431	-0.405	-0.282
	(1.166)	(1.167)	(1.130)	(1.173)
OtherProd	0.305	0.164	0.247	0.280
	(1.720)	(1.598)	(1.671)	(1.725)
OtherProc	-0.078	-0.134	-0.124	-0.061
	(1.239)	(1.136)	(1.249)	(1.206)
elec. & elec. * large	0.475**	0.539**	0.478**	0.461**
	(0.239)	(0.223)	(0.224)	(0.230)
mech. equip. * large	-0.134	-0.095	-0.134	-0.180
	(0.321)	(0.305)	(0.305)	(0.289)
obs	1,046	1,046	1,046	1,046

Table 8. Innovation Effects on Productivity by Country

Authors	Countries	Product Innovation	Process Innovation	Complementarity
Huergo & Jaumandreu (2004)	Spain	N/A	+	N/A
Miravete & Pernís (2006)	Spain	N/A	N/A	+
Parisi et al. (2006)	Italy	+	+	N/A
Griffith et al. (2006)	France	+	+	N/A
	Germany	not significant	not significant	N/A
	Spain	+	not significant	N/A
	UK	+	not significant	N/A
Chudnovsky et al. (2006)	Argentina	not significant	+	+
Masso & Vahter (2007)	Estonia	not significant	+	N/A
Schmidt & Rammer (2007)	Germany	N/A	N/A	technological innovators that combine their product and process innovations with both marketing and organizational innovations perform better in terms of sales than focusing only on technological innovations
Hall et al. (2009)	Italy	+	+	N/A
Mairesse & Robin (2010)	France	+	not significant for manufacturing firms during 1998-2000 & services firms during 2002-2004; − (negative) for manufacturing firms during 2002-2004	N/A
Polder et al. (2010)		not significant	not significant	product and process innovation only lead to higher TFP when performed in combination with organizational innovation
Siedschlag et al. (2010)	Ireland	+	+	+
Goedhuys & Veugelers (2012)	Brazil	+	not significant	+
This study	Taiwan	not significant	+	not significant

TABLE 9. ESTIMATION RESULTS OF THE INNOVATION PRODUCTION FUNCTION — BY SUB-SAMPLE

	OEMs		non-OEMs	
	Process	*Both*	*Process*	*Both*
Log (Rd intensity)	0.142*	0.134*	0.062	0.148
	(0.084)	(0.081)	(0.096)	(0.092)
Fund	0.122	0.396	0.133	-0.021
	(0.308)	(0.288)	(0.384)	(0.395)
Firmage	0.021	0.013	-0.015	-0.0001
	(0.015)	(0.013)	(0.014)	(0.013)
Log (Average wage)	-0.010	-0.363	0.081	-0.055
	(0.473)	(0.442)	(0.504)	(0.521)
Log (Capital intensity)	-0.132	-0.026	0.047	-0.051
	(0.156)	(0.132)	(0.170)	(0.174)
Firm size (*ref.: Small*)				
Medium	0.032	0.052	0.121	0.218
	(0.554)	(0.541)	(0.623)	(0.566)
Large	-0.038	0.194	0.275	0.770
	(0.611)	(0.589)	(0.735)	(0.710)
Industry dummies (*ref.: food, beverage & tobacco*)				
textile & leather	0.595	-0.226	-0.146	-0.443
	(3.432)	(2.628)	(1.719)	(1.680)
paper making & publishing	0.427	-0.892	-0.222	0.656
	(4.315)	(4.580)	(9.661)	(9.279)
petroleum, plastic & chemical product	0.454	-0.013	-0.079	0.122
	(3.303)	(2.488)	(1.266)	(1.229)
non-metal product	0.278	0.967	-1.036	-0.384
	(7.733)	(5.241)	(5.567)	(3.272)
basic metal	1.115	0.218	-0.206	0.821
	(3.609)	(2.876)	(2.698)	(2.476)
metal product	0.886	0.436	-0.894	-0.082
	(3.348)	(2.549)	(2.135)	(1.308)
electric & electronics	0.396	-0.122	-0.387	-0.018
	(3.294)	(2.542)	(1.349)	(1.284)
mechanical equipment	-0.772	0.079	-1.212	-0.433
	(4.609)	(2.635)	(3.615)	(2.103)
transportation equipment	0.496	-0.041	0.204	-2.128
	(3.303)	(2.492)	(1.657)	(7.021)
furniture manufacturing	0.253	0.233	-0.402	12.188***
	(10.401)	(9.521)	(1.204)	(1.526)
other manufacturing	-1.295	0.045	-1.705	-0.915
	(7.574)	(3.435)	(8.117)	(5.815)
elec. & elec. * large	-0.239	0.188	-0.411	-0.097
	(0.648)	(0.586)	(0.778)	(0.620)
mech. equip. * large	0.338	0.186	-0.832	-0.875
	(4.110)	(1.321)	(6.048)	(1.886)
obs	458	458	335	335

Table 10. Estimation Results of the TFP Growth — by Sub-sample

	OEMs	non-OEMs
Innovation type (*ref.: Product innovation*)		
Process innovation only	1.708	1.900
	(2.751)	(7.359)
Both Innovations	5.875**	-0.286
	(2.582)	(3.046)
Fund	-0.441	0.003
	(0.271)	(0.318)
Firmage	-0.024**	-0.012
	(0.011)	(0.019)
Log(Average wage)	0.326	0.077
	(0.320)	(0.350)
Export	-0.029	-0.217
	(0.183)	(0.283)
Firm size (*ref.: Small*)		
Medium	0.173	0.182
	(0.307)	(0.499)
Large	0.082	0.356
	(0.393)	(0.705)
Industry dummies (*ref.: food, beverage & tobacco*)		
textile & leather	0.874	0.069
	(0.945)	(0.624)
paper making & publishing	1.094	-0.828
	(1.285)	(0.815)
petroleum, plastic & chemical product	0.813	0.581
	(0.688)	(0.538)
non-metal product	-0.150	1.054
	(0.865)	(1.408)
basic metal	1.705*	1.267
	(0.876)	(0.976)
metal product	0.430	0.500
	(0.691)	(1.219)
electric & electronics	0.878	0.367
	(0.764)	(0.809)
mechanical equipment	0.573	0.726
	(0.741)	(1.654)
transportation equipment	0.985	-0.832
	(0.743)	(1.783)
furniture manufacturing	-1.489	1.934
	(1.297)	(1.923)
other manufacturing	-0.066	0.425
	(0.830)	(1.973)
elec. & elec. * large	-0.097	0.533
	(0.498)	(0.552)
mech. equip. * large	-0.364	0.373
	(0.404)	(0.816)
obs	292	217

TABLE 11. ESTIMATION RESULTS OF THE LABOR PRODUCTIVITY GROWTH — BY SUB-SAMPLE

	OEMs	non-OEMs
Innovation type (*ref.: Product innovation*)		
Process innovation only	1.352	0.102
	(3.104)	(6.829)
Both Innovations	7.535***	1.764
	(2.850)	(2.502)
Fund	-0.618**	0.121
	(0.287)	(0.237)
Firmage	-0.014	-0.021
	(0.013)	(0.018)
Log (Average wage)	0.489	0.017
	(0.344)	(0.313)
Export	-0.142	-0.104
	(0.219)	(0.290)
Firm size (*ref.: Small*)		
Medium	-0.366	0.200
	(0.342)	(0.432)
Large	-0.399	-0.046
	(0.444)	(0.632)
Industry dummies (*ref.: food, beverage & tobacco*)		
textile & leather	2.180*	0.053
	(1.311)	(0.591)
paper making & publishing	1.958	-2.255***
	(1.686)	(0.659)
petroleum, plastic & chemical product	1.710	0.407
	(1.179)	(0.470)
non-metal product	0.242	1.131
	(1.303)	(1.223)
basic metal	2.743**	0.608
	(1.305)	(0.806)
metal product	1.325	0.417
	(1.157)	(1.105)
electric & electronics	1.966	-0.266
	(1.224)	(0.680)
mechanical equipment	1.407	0.609
	(1.222)	(1.390)
transportation equipment	2.016*	0.162
	(1.204)	(1.597)
furniture manufacturing	-0.483	0.407
	(1.164)	(1.670)
other manufacturing	0.552	0.177
	(1.335)	(1.718)
elec. & elec. * large	-0.145	0.691
	(0.549)	(0.531)
mech. equip. * large	-0.923*	0.078
	(0.559)	(0.761)
obs	295	220

4) OEM and Non-OEM Sub-sample Analysis

To directly access the determinants of innovation and productivity growth between different production types, this study attempts to estimate the model with sub-sample of OEMs and other types of production.[6] However, the sample will drop drastically after we exclude the firms without innovation behaviors and classify non-OEMs into ODM, OBM and Other types. It is because in TTIS-II survey, only innovative firms are required to answer the question of OEM, ODM, OBM or Other types. Therefore, we use the sub-sample of OEMs and non-OEMs to compare the results of innovation decisions and the effects on productivity. Table 9 presents the estimates of innovation production function. For OEM firms, compared with product innovation only, firms with higher R&D intensity will be more likely to engage in process innovation and both innovations, while other variables have insignificant effects on innovation activities. To non-OEM firms, all the variables have insignificant influences except for the furniture manufacturing firms. They prefer both product innovation and process innovation instead of choosing either one of them. Table 10 reports the empirical results of different innovation decisions on total factor productivity growth. We find that OEM firms engaging in both innovations can significantly generate higher productivity than product innovation only, implying that there exists complementarity between product innovation and process innovation on TFP growth in the sub-sample analysis. However, the effects of innovation activities are not significant to non-OEM firms. As for other variables, the estimates show that the effects for OEMs and non-OEMs are not different except firmage and basic metal industry. No matter in the case of whole sample or sub-sample, older firms have less TFP growth. From Table 11, it is shown that both innovations have higher labor productivity growth only to OEM firms. Besides, in the mechanical equipment industry, large firms do not guarantee greater labor productivity growth. It is noted that we should be cautious interpreting these additional sub-sample results since the sample sizes are small — ranging from 217 to 295. Nevertheless, it deserves a more extensive exploration in our future research when we collect more data.

VII. *Conclusion*

It is well-known that maintaining a sustained growth is the ultimate goal that a firm will seek to pursue. Most firms choose to engage in research and development, personnel training or any other kind of activities that are considered to be innovative behaviors. It is important, however, to figure out whether innovation brings benefits to firms. A good understanding of the interrelation between different types of innovation strategies not only sheds light on firms' determinants of such activities, but also provides governments with a sound basis for industry policies. While it has been well documented in (advanced) Western countries such as England, Italy, France, Germany and the US, it is very rare in less developed countries. This paper uniquely compiled data from two sources (the Taiwan Technological Innovation Survey II and the Industry, Commerce and Service Census) in a newly-industrialized country, Taiwan, in order to empirically examine the relationship between different innovation activities and firm productivity of Taiwanese manufacturing firms. Most notably, most of Taiwanese manufactur-

[6] We thank an anonymous referee for pointing out this research line.

ing firms are OEM firms which produce goods by following the requirements or specifications from other firms or multinational enterprises. It is important for us to have a better understanding of the innovation decisions and how these strategies affect the productivity growth for OEM firms. Moreover, the Taiwan Technological Innovation Survey II is based on CIS4, which enables a direct comparison with previous studies using innovation surveys.

Through the CDM model, we can clearly understand the interrelations among R&D, innovation and productivity. Differing from the traditional concept, R&D does not influence productivity directly, but via innovation. In the first stage, a firm makes a decision as to whether to engage in research and development or not. From our empirical results, we conclude that if a firm has a great portion of revenue from exporting in the previous period, or has a higher average wage, the probability of this firm engaging in R&D is higher, and it has a larger R&D intensity. In addition, medium and large firms that have more capital or personnel are more prone to engaging in R&D.

In the second stage, R&D is viewed as an input for knowledge production, and different types of innovation are the outputs. We find that, compared with no innovation, R&D intensity is positively correlated with product innovation, process innovation and both types of innovation, which means that the higher the R&D intensity, the greater the probability of choosing the above three innovation types. Besides, medium and large firms prefer process innovation or both innovations to product innovation. It might be because both innovations are costly and it is not easy for small firms to afford them. The third stage, which is the most important issue that both firms and our research want to realize, is to clarify the effect that diverse innovations have on a firm's productivity. Since total factor productivity can more accurately reflect a firm's performance, we use two censuses to calculate TFP and further the TFP growth rate. We also use labor productivity growth as the measurement of performance such that we can compare our results with other studies. From our work, we conclude that engaging in process innovation is the only beneficial way for Taiwanese manufacturing firms. Process innovation not only increases total factor productivity growth, but also improves labor productivity growth. Furthermore, comparing the results between OEM firms and non-OEM firms, both innovations will significantly improve total factor productivity growth and also labor productivity growth, especially for OEM firms; while there is no such impact on non-OEM firms. In other words, our results suggest that there does not exist complementarity between product innovation and process innovation in the whole Taiwanese manufacturing firms, but to OEM firms engaging in product innovation and process innovation at the same time does have a multiplier effect on its performance.

Therefore, to increase their productivity, it is important for OEM enterprises to engage in both product and process innovation. In addition to a firm's own effort, the government could formulate some policy measures such as tax incentives, financial support, personnel training, collaboration between industry and university and deregulation to encourage firms to engage in innovation activities and transform from OEM firms to ODM or OBM firms in the future. Furthermore, even though we are interested in the relationship between innovation activities and firm's survival from the global financial crisis in 2008, there is a limitation due to the acquirement of survey data. This issue can be investigated once we combine the Taiwan Technological Innovation Survey III (from 2007 to 2010) and the latest Industry, Commerce and Service Census in 2011, which will be released in 2014.

Appendix

Total Factor Productivity Estimation

The ordinary least squares estimation of TFP will cause omitted variables bias since the firm's choice of inputs is likely to be correlated with any unobserved firm-specific productivity shocks. To solve this problem, the consistent measurement of total factor productivity used in this paper is based on the methodology suggested by Levinsohn and Petrin (2003). They assume a Cobb-Douglas production function and use intermediate inputs to proxy for the unobserved productivity shocks to correct for the simultaneity in the firm's production function.

$$Y_{i,t}=exp(\alpha+\omega_{i,t}+\varepsilon_{i,t})K_{i,t}^{\beta_k}L_{i,t}^{\beta_l}M_{i,t}^{\beta_m}E_{i,t}^{\beta_e}, \qquad (\text{A}-1)$$

where $Y_{i,t}$ denotes the output of firm i in period t, often measured as gross revenue or value added (adopted in this article), $L_{i,t}$ denotes the labor input, $M_{i,t}$ represents the intermediate input, $K_{i,t}$ denotes capital, and $\omega_{i,t}$ denotes firm i's time-specific productivity level. Taking logarithms in Equation (A-1) results in a linear production function, which is expressed as Equation (A-2):

$$y_{i,t}=\alpha+\beta_l l_{i,t}+\beta_m m_{i,t}+\beta_k k_{i,t}+\omega_{i,t}+\varepsilon_{i,t}. \qquad (\text{A}-2)$$

There exists a key issue in the estimation of the production function. Since the input levels are determined by the characteristics of the firm instead of being chosen independently, the input levels and unobservable productivity shocks might be correlated, which means that simply estimating Equation (A-2) can lead to inconsistent results. Based on the Olley and Pakes (1996) approach, Levinsohn and Petrin (2003) suggest an estimation approach using intermediate inputs rather than investment to proxy for the unobserved productivity shocks and solve the simultaneity problem. According to the assumption that the firm's demand for intermediate inputs depends on $k_{i,t}$ and $\omega_{i,t}$:

$$m_{i,t}=m_{i,t}(k_{i,t},\ \omega_{i,t}). \qquad (\text{A}-3)$$

Furthermore, Levinsohn and Petrin (2003) show that the demand function for intermediate inputs is monotonically increasing in $\omega_{i,t}$, which yields the following function:

$$\omega_{i,t}=\omega_{i,t}(k_{i,t},\ m_{i,t}). \qquad (\text{A}-4)$$

We can rewrite Equation (A-2) as follows:

$$y_{i,t}=\beta_l l_{i,t}+\phi_{i,t}(k_{i,t},\ m_{i,t})+\varepsilon_{i,t}, \qquad (\text{A}-5)$$

where

$$\phi_{i,t}(k_{i,t},\ m_{i,t})=\alpha+\beta_m m_{i,t}+\beta_k k_{i,t}+\omega_{i,t}(k_{i,t},\ m_{i,t}). \qquad (\text{A}-6)$$

Our goal is to obtain the coefficient estimates for inputs such as β_l and β_m. Therefore, we define $V_{i,t}=y_{i,t}-\widehat{\beta}_l l_{i,t}-\widehat{\beta}_m m_{i,t}$ and estimate the following equation:

$$V_{i,t}=\beta_k k_{i,t}+g(\phi_{t-1}-\beta_k k_{i,t-1}+\mu_{i,t}+e_{i,t}), \qquad (\text{A}-7)$$

where the $g(.)$ function is a function of lagged values of k and ϕ. In addition, we use a high-order polynomial expression of k_{t-1} and ϕ_{t-1} to approximate $g(.)$.

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