Innovation, R&D and Productivity: Evidence from Thai Manufacturing

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Abstract

This paper empirically examines the relationship between innovation, R&D (Research and Development), and productivity in Thai manufacturing using cross-sectional data from the 2007 Industrial Census of Thailand. We utilize a simplified structural model (CDM model) that describes the link between innovation output, R&D and productivity for the Thai case. Various estimation techniques are used to compare and provide evidence for empirical results. Our findings generally suggest that government aid and plant characteristics play an important role for a plant to engage in R&D and to be innovative, both in terms of process innovation and product innovation. Exporting plants, plants in the central region, and plants that are categorized as Head Branch type are more likely to engage in R&D and be innovative. The type of industry and specific technological characteristics of plants are shown to influence innovation effort and decisions to undertake R&D. On average, plant size, foreign ownership, exporting and product innovation are important drivers of productivity enhancement in Thai manufacturing.

Keywords: Productivity, Innovation, R&D, CDM model, Thailand

JEL Classification: F14, L60, O31

1. Introduction

Research and Development (R&D) has generally been acknowledged as an important factor in fostering development and cultivating new driving forces for economic growth. Today's world economy has been described as a "Knowledge-Based Economy" (OECD, 1996) with knowledge being the most crucial resource and learning being the most important process (Lundvall, 2003). Furthermore, it is widely recognized that R&D and innovation may result in significant improvements in firm performance. Accordingly, innovation and R&D in manufacturing firms can be considered as one of the major reasons for industrial competitiveness in many countries (Porter, 1985). Innovation has been receiving a special attention in many development debates in recent years. Far from being

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a concern of advanced economies alone, the capability to introduce new technologies is now strongly considered in many developing economies as a crucial element in the process of industrialization. It is, therefore, necessary not only for developed economies but also developing economies to encourage innovation and R&D, especially at the plant and firm level, in order for firms to be able to compete successfully in the international market. As a result, innovation has been a key concept in moving many countries into the knowledge-based economy similar to the United States and European countries. Innovation and R&D at the firm level can consequently be considered as a vital step in improving productivity, sustaining the transformation of industrial structure and supporting manufacturing firms' competitiveness in the global market. In most cases, developed economies and high income countries have dominated R&D activities in the past two decades. From Table 1, we can see that the EU-15 (Austria, Belgium, Denmark, Finland, France, Germany, Greece, Ireland, Italy, Luxembourg, Netherlands, Portugal, Spain, Sweden, and United Kingdom) generally outperforms emerging countries in terms of innovative output, but the degree of variability among the latter is also large (Bogliacino et al., 2009). Explicitly, the position of Thailand reflects its weakness in terms of product and/or process innovation, especially in the case of extremely low share of innovative firms in Thai manufacturing, compared to those of neighboring countries such as Malaysia and Singapore.

Table 1: Innovative Output in the Manufacturing Sector from Various Countries

	Share of Innovative Firms	Product and Process Innovation (as share of innovative firms)	Product Innovation (as share of innovative firms)	Process Innovation (as share of innovative firms)	Innovative Turnover
EU-15	48.9	45.2	21.3	27.7	10.4
China	30	21.3	3.8	4.8	14.4
Korea	42	18	18	5	54
Malaysia	53.8	N/A	10.6	6.2	42
Singapore	31.7	N/A	24.1	22.4	29
Thailand	**6.4**	**N/A**	**4.1**	**4.3**	**N/A**

Source: Retrieved from Bogliacino et al. (2009)
Notes: The time period is between 2002 and 2006, by utilizing the proper wave of innovation surveys in each country. See Bogliacino et al. (2009) for full details and explanation.

Since the 1980s, the economic performance of Thailand has relied heavily on foreign investment and exports and Thailand's economy has become one of the fast-growing economies in Southeast Asia in the last two decades. However, Thailand has surprisingly one of the lowest levels of R&D spending, R&D workers, and innovation in Southeast Asia and continues to fall behind other countries in the region on most competitiveness indicators, including productivity and innovation (World Bank, 2010). Specifically, Thailand's total domestic expenditure on research is only about 0.25 percent of GDP, significantly less than other countries in Southeast Asia. Additionally, the country has a much lower share of R&D financed by the private sector than other middle-income countries in the region, with just over 40 percent contributed by industry, mostly by large multinationals, compared to over 50 percent in Malaysia and the Philippines (Intarakumnerd, 2010). As can be seen in Table 2, not only is Thailand's overall R&D expenditure low, (amounting to only around 0.25% of GDP), but R&D by the Thai private sector is also especially low (World Bank, 2007). Specifically in the Thai case, R&D expenditure and its growth rate were relatively small compared to other Asian countries. In 2001-2006, R&D expenditure accounted only for 0.25 percent of GDP and gradually decreased to 0.21-0.23 percent in recent years.

Table 2: Low R&D Investment in Thailand

Year	2001	2002	2003	2004	2005	2006	2007	2008	2009
Public R&D (million baht)	8,202	8,138	9,571	10,548	9,988	11,550	10,015	11,887	12,737
Private R&D (million baht)	5,284	5,164	5,928	6,023	6,679	7,998	8,210	7,278	8,174
Total R&D (million baht)	13,486	13,302	15,499	16,571	16,667	19,548	18,225	19,165	20,911
R&D/GDP (%)	**0.25**	**0.24**	**0.26**	**0.25**	**0.24**	**0.25**	**0.21**	**0.21**	**0.23**

Source: Ministry of Science and Technology, Thailand
Notes: Public R&D investments from 2001 to 2007 are collected from the national surveys on R&D expenditure and personnel by the Office of the National Research Council of Thailand. Public R&D investments from 2008 to 2009 are collected from GFMIS, the Comptroller General's Department, Ministry of Finance. Private R&D Investments from 2001 to 2009 are collected from the national surveys on Private R&D Investment by the National Science Technology and Innovation Policy Office (STI Office).

Moreover, according to the Innovation Survey of Thailand in Table 3[1], it is found that only 6 percent of indigenous firms invest in innovation and R&D, primarily to improve production processes rather than to engage in product innovation. The survey also indicates that firms in Thailand are lagging behind in terms of enhancing their technological and innovative capabilities, upgrading learning process, and forging linkages with other actors of its national innovation system (Intarakumnerd and Fujita, 2008). Thai firms in the automotive, electronics, and food processing industries focus mainly on labor-intensive and lower-technology areas and rely more on labor cost advantages and lower overheads to compete in the Southeast Asian region. Very few firms are attempting to move up the

[1] The Innovation Survey of Thailand is commissioned by the National Science and Technology Development Agency (NSTDA) of Thailand, and conducted by the Brooker Group plc. The survey concentrates only on manufacturing companies.

value chain by investing in R&D to stimulate innovation and enhance their technological capability and increase productivity (OECD, 2010). Furthermore, several other survey studies of Thai firms conducted since the 1980s assert that most firms have grown without deepening their technological capabilities in the long run (Intarakumnerd, 2007)[2]. In addition, although there has been a recent increasing trend of innovation patents granted in Thai firms, the level is still low when compared to those of other lower-middle income countries (Jongwanich and Kohpaiboon, 2011). R&D Surveys and Community Innovation Surveys have been carried out periodically in Thailand since 1999 by the Thai National Science and Technology Development Agency (NSTDA). R&D surveys are carried out every year but the innovation surveys were done only in the years 1999, 2001 and 2003.

Table 3: Thailand's Innovation Surveys - Characteristics and Overall Results

	1999	2001	2003
Size of population			
Manufacturing sector	13,450	14,870	16,432
Service sector	Not included	26,162	5,221
Total	**13,450**	**41,032**	**21,653**
Response rate (%)			
Manufacturing sector	47.00%	36.70%	42.30%
Service sector	Not included	37.30%	45.00%
Total	**47.00%**	**36.90%**	**42.80%**
R&D performing firms (%)			
Manufacturing sector	12.70%	4.40%	7.20%
Service sector	Not included	0.20%	2.40%
Total	**12.70%**	**1.70%**	**6.00%**
Innovating firms (%)			
Manufacturing sector	12.90%	4.70%	6.40%
Service sector	Not included	1.40%	4.00%
Total	**12.90%**	**2.60%**	**5.80%**

Source: Retrieved from Intarakumnerd (2007) and data compiled from Reports on R&D/Innovation Surveys Year 1999, 2001, 2003 by National Science and Technology Development Agency (NSTDA).

The survey in 1999 was the first of its kind in Thailand and it covered both R&D and other technological innovation activities only in the manufacturing sector. The second innovation survey in 2001 and the third one in 2003 (with the fourth one currently being

[2] See Intarakumnerd (2007) and Doner et al. (2010) for the main features of the Thai national innovation system and the knowledge of the innovativeness of Thai enterprises.

undertaken) included the service sector in order to gain a better understanding of the nature and differences of R&D and innovation activities in both manufacturing and services sectors. As a result, the scope of the survey has been expanded to be more informative by also including firms in the service and other industries from the year 2001 onwards.

As a result, the main objective of this paper is to empirically examine the relationship between innovation, R&D, and productivity within a single framework using plant-level data from the Thai manufacturing sector. To the best of our knowledge, our paper is one of the first studies for the Thai case to focus on the analysis of the relationship between innovation, R&D, and productivity in detail and provide empirical evidence and policy implications regarding this issue. The main point of why our study is different from those conducted previously is that we are among the first to utilize the plant-level data from the 2007 Industrial Census of Thailand, while previous studies for the Thai case often use the Innovation Survey, which has much less sample coverage. This paper should also help contribute to the body of knowledge on the subject when applying more advanced methods with a newer dataset and a focus on various aspects. Specifically, apart from R&D expenditures (traditional measures of the R&D input) which have been commonly used in many previous studies, we also utilize the number of laboratory units reported in the data as an alternative proxy for the R&D input variable. This is one of the novel contributions of this paper that makes our study different from previous research. In addition, most of the empirical studies on the influences of innovation and R&D on productivity have generally been carried out only in developed countries. However, the R&D and innovation process in developing countries depends on various cultural and economic dimensions such as market structure and business environment. Thus, evidence from Thai manufacturing may provide a good model for other developing countries concerning this topic where there is currently a scarcity of evidence. Since the R&D situation in Thailand has not drastically changed since 2007, although the data employed in this study might be relatively old by the time of this research, results and suggestions are still relevant and important. Moreover, it is very crucial to provide fundamental estimates in developing countries which have less statistical data and fewer empirical studies at the micro level.

This paper is organized as follows. Section 2 describes the related literature. Section 3 presents the econometric model for the analysis and the data used. Next, results from the analysis are discussed in section 4. Finally, section 5 concludes with a summary of our findings and some policy implications and suggestions for future research.

2. Related Literature

One of the earliest studies which examine the relationship between innovation, R&D and productivity using firm-level data is the empirical study developed by Crépon et al. (1998), also known as the *CDM (Crépon, Duguet, and Mairesse) model*[3]. In their paper,

[3] See Crepon et al. (1998) for the full explanation of the CDM Model, and Johansson and Lööf (2009) for alternative specifications of CDM models.

the authors use a structural model to analyze the link between R&D, innovation output and productivity. They explain productivity by innovation output and innovation output by R&D expenditure using a cross-section of French firm data from the European Community Innovation Survey (CIS). The results reveal that the propensity of a firm to conduct R&D increases with firm size, market share and diversification as well as with demand pull and technology push indicators. Research effort (R&D capital intensity) depends on the same set of variables, excluding firm size. Innovation output (either measured as number of patents or innovative sales) increases with R&D input and with demand and technology variables. In addition, innovation output correlates positively with productivity.

Subsequently, Griffith et al. (2006) extend the work of Crépon et al. (1998) and estimate a variation of the CDM model for France, Germany, Spain, and the United Kingdom. They find that the innovation output is significantly determined by the innovation effort, while a significant productivity effect of product innovations can only be confirmed for France, Spain and the UK, but not for Germany. The results also depict some interesting heterogeneity across the four countries. Masso and Vahter (2008) apply a structural model that involves a system of equations on innovation expenditure, innovation outcome and productivity. Their results from the data from innovation surveys show that both product innovation and process innovation can increase productivity in post-transition Estonia. Furthermore, Crespi and Zuniga (2012) examine the determinants of innovation and its impact on firm labor productivity across Latin American countries and find the importance of innovation in enabling firms to improve economic performance.

In addition, Lee (2008) estimates a CDM model based on firm-level data from the Malaysian manufacturing sector. The results suggest that the decision to conduct R&D activities is significantly determined by firm size, exports and the technology intensity of a firm’s sector. Furthermore, the level of R&D expenditure is significantly correlated with firm size. Output (product and process innovations) is positively and significantly determined by R&D expenditure, firm size, exports and local ownership. The author concludes that investment intensity and labor quality appear to be important determinants of productivity, but not innovation or firm size for the Malaysian case.

For the Thai case, recent studies regarding R&D and innovation can be found in Intarakumnerd (2005; 2010) and Intarakumnerd and Chairatana (2008). However, these papers mainly deal with elements of the national innovation system, capabilities and firm competitiveness in terms of qualitative aspects. The authors mostly examine the situation and evaluate Innovation Surveys of Thailand and investigate the state of innovation of firms in developing countries using Thailand, a less successful country in catching up economies, as a case study. Moreover, Berger (2010) applies a CDM model to firm-level data from innovation surveys in order to establish the relationship between innovation activities and labor productivity in 18 OECD countries. Berger (2010) extends the analysis to Thailand by estimating an identical econometric model for data from the R&D and Innovation Surveys of Thailand, and compares the results with those of the OECD project. The results confirm that large and international firms that belong to an enterprise group have a higher probability of being innovative, and tend to invest more resources in innovation activities.

Firms receiving public financial support and participating in innovation cooperation show higher innovation expenditure. Innovation input positively correlates with innovation output, which in turn increases labor productivity.

More recently for the Thai manufacturing sector, Jongwanich and Kohpaiboon (2011) investigates the role of multinational enterprises (MNEs) and exporting on R&D activity using the 2007 Industrial Census with an emphasis on providing suggestions for the promotion of R&D activities in Thailand. The key finding is that the determinants of each type of R&D are not straightforward, suggesting that it is necessary to distinguish between the types of R&D when examining their determinants. The statistical significance of firm-specific factors found in their study suggests that the decision to carry out R&D largely depends on the firm's profitability. Firms exposed to global competition through either exporting or involving in global production networks are more likely to make R&D investments. Nevertheless, our study differs from the mentioned and existing literature and that of Jongwanich and Kohpaiboon (2011) in two ways. First, we try to utilize the number of laboratory units as an alternative for the R&D input variable, and also provide various estimation techniques in order to confirm results with previous studies. Second, this is one of the few studies for the Thai case to consider possible heterogeneity in firms' decision regarding R&D and innovation at the micro level analysis.

Despite the importance of this topic, concerning the direct relationship between innovation, R&D and productivity in the full view, there has been little empirical evidence so far regarding this relationship for the Thai case. For this reason, there is a need to create a concrete research design for this matter in order to empirically examine the relationship between innovation, R&D and productivity within a single and understandable framework. The findings from this study should add to the literature and provide some insight for policy makers in Thailand by shedding light on the puzzle between these variables and their impact on the productivity of domestic firms and the overall economy.

3. Econometric Model and Data

3.1 Model Specification

For the empirical analysis of innovation, R&D and productivity for the Thai case, we use the structural model developed by Crepon et al. (1998) and Griffith et al. (2006). Our analysis here follows the research style from Lee (2008) for the Malaysian case, but adapts the context to the Thai case. Essentially, there are two components in the model. First, research activity influences innovation output. Second, innovation output influences productivity. The standard framework for the structural model comprises four equations that can be estimated in three stages. The details are as follows.

Research Activity Function

The first two sets of equations are related to research activities of a plant and can be estimated using the ordinal probit model and Heckman selection model. In the model, the regression equation for research activity - R&D (r_i) can be modeled as follows:

$$r_i^* = x_i\beta + e_{1i} \tag{1}$$

where x_i is the set of explanatory variables (a vector of determinants of innovation effort), r_i^* is an unobserved latent variable. Since this is the plant-level analysis, for r_i^*, we use R&D expenditure and the number of laboratory units reported in a plant for our analysis. It is important to note that we do not have the exact amount of R&D expenditure from the Industrial Census data and R&D laboratory expenditure is reported instead as a categorical unit ranging from 1 to 5[4]. Specifically, there are two main sources of R&D expenditure from the 2007 Industrial Census of Thailand that can be used. First, R&D expenditure in a plant (research cost) is reported as a proportion of expenses (in percentage unit). Second, R&D expenditure is also reported as laboratory expense (in categorical unit and total number of laboratory units). Since we are trying to analyze innovation effort, the number of laboratory units in a given plant and the R&D expenditure from a plant's laboratory (categorical unit) is the appropriate choice in our study given that the Census data do not provide the exact monetary amount of R&D expenditure (the census only provides research cost and budget in percentage unit). Also, other suitable measures of innovation expenditure are not available to fully utilize. Therefore, we mainly use the number of laboratory units (in nominal unit) as a core R&D proxy in our analysis and only use R&D expenditure (categorical unit) in the ordinal probit (and ordinal logit) model.

Next, β is the coefficient vector and e_{1i} is an error term. As mentioned earlier, we mainly measure (or proxy) plants' innovative effort r_i^* by their number of laboratory units, denoted by r_i only if plants have (and/or report) their laboratory unit, thus we could only directly estimate equation (1) at the risk of selection bias. However, not all plants are observed to have or report the number of their laboratory units. Utilizing the Heckman selection model, the selection equation provides the condition under which a plant *i* is observed to undertake R&D proxied by the number of laboratory units reported in the plant, namely when:

$$z_i\gamma + e_{2i} > 0 \tag{2}$$

where z_i is the set of explanatory variables, γ is is the coefficient vector and e_{2i} is an error term. For equation (1), assuming that the error terms e_{1i} and e_{2i} are bivariate normal with zero mean, we estimate the system of equations (1) and (2) as a generalized Tobit model by maximum likelihood (Heckman selection model by Heckman, 1979) when the dependent variable is the number of laboratory units reported in a plant. This will be our benchmark specification for the first step in the estimation procedure. Moreover, we also estimate

[4] The R&D laboratory expenditure in the 2007 Industrial Census is categorized as follows. 1 = less than 500,000 baht, 2 = 500,001 – 1,000,000 baht, 3 = 1,000,001 – 5,000,000 baht, 4 = 5,000,001 – 10,000,000 baht, and 5 = more than 10,000,000 baht.

equation (1) separately by first using the ordinal (categorical) probit (and logit) model for the case of the dependent variable being a categorical R&D expenditure (ranging from 1 to 5) to provide more evidence and compare our estimated results.

Importantly, there are some variations in the literature in terms of the set of explanatory variables included in the regression equation (1) and selection equation (2). In Crépon et al. (1998), it is assumed that $x_i = z_i$. This implies that the set of explanatory variables with the propensity to undertake R&D (having reported the use of laboratory units) is the same as those regarding R&D intensity (the number of laboratory units). The explanatory variables used in their study include market share, equivalent number of activities (degree of diversification), number of employees (size), and dummy variables for demand pull factors, supply push factors and industry factors. Griffith et al. (2006) adopts a different approach where there are some differences in the explanatory variables used to explain R&D intensity (regression equation) and R&D propensity (selection equation). In their study, the explanatory variables included in both the regression and selection equations include international competition, dummies for formal and strategic protection, dummies for funding, and dummies for industries. Dummies for plant size are included in the selection equation. In our study, the set of explanatory variables x_i for the regression equation includes the dummy variable for foreign ownership, the dummy variable for plant export status, plant technological characteristics (namely, the use of energy saving systems and waste management systems), the central region dummy variable, the BOI (Thai Board of Investment) dummy – investment promotion status of a plant, the dummy variable for government aid status, the dummy variable for the form of organization of the plant, and the dummy variable for selected industries. Lastly, dummies for plant size are included in the selection equation in our study to cope with the issue of exclusion restriction.

Innovation Function

Next, we model the innovation production function, following Lee (2008), as:

$$g_i^* = r_i^* \beta_2 + x_{2i} \beta_3 + e_{2i} \tag{3}$$

where g_i^* is the latent binary innovation indicator proxied by both product innovation and process innovation (taking the value of 1 if a plant reports the innovation indicator, and zero otherwise), r_i^* is the latent innovation effort and enters as an explanatory variable, x_{2i} represents other explanatory variables (a vector of other determinants of innovation function) which include the dummy variable for foreign ownership, the dummy variable for plant export status, plant technological characteristics (namely, the use of energy saving systems and waste management systems), the central region dummy, the BOI (Thai Board of Investment) dummy, the dummy variable for the form of organization of the plant, the dummy variable for selected industries, and dummies for plant size. Finally, β_2 and β_3 are coefficient vectors and e_{2i} is an error term.

We estimate the innovation equation (3) as two separate univariate probit and bivariate probit equations for the process and product innovation indicators. For the plants' innovative effort (r_i^*), we use the predicted value from the estimated generalized tobit equations (1) and (2). That is, we estimate (3) for the sample of all firms, not only for the sub-sample of those reporting R&D activities (the number of laboratory units). By using its predicted value, we calculate the innovative effort r_i^* and take caution that it is possibly endogenous to the innovation function. As mentioned in Griffith et al. (2006), it seems likely that firm characteristics unobservable to us (and thus omitted) can make firms both increase their innovative effort and also their productivity in producing innovations.

As a result, the estimation of equation (3) is realized by performing univariate probit and bivariate probit estimations using the predicted value of R&D intensity (r_i). Following Griffith et al. (2006), separate estimates are carried out for product and process innovations. In short, the bivariate probit model is a joint model for two binary outcomes (product innovation and process innovation). These binary outcomes may be correlated and if the correlation turns out insignificant, then we can estimate two separate probit models, otherwise it is more appropriate to utilize and consider the bivariate probit model.

Production Function

The final component of the model involves the use of an augmented Cobb-Douglas production function to measure plant productivity:

$$q_i = \alpha_1 k_i + \alpha_2 l_i + \alpha_3 g_i^* + \alpha_4 w_i + \alpha_5 X_i + \varepsilon_i \qquad (4)$$

where q_i is labor productivity (natural log of value-added per worker). k_i is the capital intensity (proxied by fixed assets per worker). l_i is labor quality (proxied by the share of skilled workers in the total workforce of each plant). g_i^* is the predicted innovation input. w_i is the plant size and ε_i is an error term. X_i is the vector of other control variables which affect labor productivity. We take care of the endogeneity of g_i (respective binary variable) in this equation by using the predicted values from the innovation function equations (3).

In summary, our model consists of the four equations, (1), (2), (3), and (4). Since we assume a recursive model structure and do not allow for feedback effects, we follow a three-step estimation procedure as a simplified CDM model. In the first step, we estimate the generalized tobit model (equations (1) and (2)) by Heckman selection model (we also perform ordinal probit/logit regressions and univariate probit/logit regressions separately in the first step to compare the results, however, the estimated results, other than those of the Heckman selection model in the first step, are not related to the further steps of the analysis). In the second step, we separately estimate the two innovation production functions for product and process innovations as two univariate probit and bivariate probit equations using the predicted value of innovative effort from the first step to take care of both selectivity and endogeneity of r_i^* in equation (3). In the last step, we estimate the productivity equation using the predicted values from the second step to take care of the endogeneity of g_i in equation (4). Finally, it should be noted again that we perform many estimations side-by-side in the first and second step to compare and cross-check our estimated results. We will discuss the details for estimated results later in section 4.

3.2 Data and Variable Construction

Concerning the Thai data, there are three types of data sets which can be used in the micro-level analysis regarding the relationship between innovation, R&D and productivity for the manufacturing sector. First, comprehensive datasets and samples are available in the National Statistical Office's (NSO) Industrial Census for 1997 and 2007 (data collected in 1996 and 2006, respectively). To date, the 1997 and 2007 censuses are by far the most comprehensive data available in Thai manufacturing. However, the main disadvantage of this census data is that it is cross-sectional data, which limits its use for sophisticated research such as panel data and dynamic analysis. Second, another micro-level data set in Thai manufacturing can be found in the Manufacturing Industry Survey by the NSO. However, the Manufacturing Industry Survey does not provide enough information and variables necessary for our innovation analysis. Third, there is also the Innovation Survey conducted by the National Science and Technology Development Agency (NSTDA) of Thailand. However, these innovation surveys include relatively little information on firm characteristics, especially for non-innovative firms. This causes some problematic variable definitions and model specifications for empirical studies (Berger, 2010).

In our econometric investigation into the relationship between innovation, R&D, and productivity, we use the detailed data set at plant level from the 2007 Industrial Census of Thailand. This data set was collected by Thailand's National Statistical Office (NSO) which surveyed all establishments in 2006. The information is one of the most current plant-level data sets in Thailand. The original sample size consists of 73,931 observations, of which 71,154 observations are domestic plants (plants owned by domestic firms), and 2,777 observations are foreign plants (plants owned by foreign-owned firms)[5]. The census covers 34,625 establishments belonging to 127 four-digit industries of the International Standard Industrial Classification of All Economic Activities (ISIC Rev3.0). Due to missing information on some key variables, the census was cleaned up by deleting plants which had not responded to one or more of the key questions and those which had provided seemingly unrealistic information, such as negative value added and inputs used or total employment being less than one. As described in more detail in Kohpaiboon and Ramstetter (2008), there are some duplicated records in both the data from Manufacturing Surveys and the Industrial Census of Thailand, presumably because plants belonging to the same firm filled the questionnaire using the same records. The procedure followed to address this problem was to treat the records that report the same value of the seven key variables of interest in this study as one record[6]. Industries that are either to serve niches in the domestic market in

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[5] In this study, if the foreign investment in a plant is reported, we consider the plant as foreign plant and if there is no report of foreign equity participation, we consider the plant to be domestic plant.

[6] See details in Ramstetter (2004). In addition, there are the near-duplicate records. A careful treatment to maximize the coverage of the sample is used as described in full detail in Ramstetter (2004).

the service sector or explicitly preserved for local enterprises are excluded[7]. As a result, the final dataset contains 49,432 observations as shown in Table 4. Additionally, the pairwise correlation matrix of the key variables can be found in Table 5 as shown below.

Table 4: Statistical Summary of the Key Variables

Variable	Unit	Obs	Mean	Std. Dev.	Min	Max
R&D Expense	categorical (1 to 5)	1702	1.7086	0.9942	1.0000	5.0000
Lab Number	number of laboratory units	1731	1.7163	1.5499	1.0000	20.0000
Value-added per worker	(ln) baht	49432	11.1916	1.6783	2.5621	19.2820
Capital Intensity	(ln) baht	49432	11.5081	1.8936	1.2217	20.2177
Material Intensity	(ln) baht	49432	10.7221	2.1947	-5.4972	20.1004
Labor Quality	(ln) share of skilled workers	49432	0.5970	0.1908	0.0000	0.6931
Lab (Status)	zero-one dummy	49432	0.0350	0.1838	0.0000	1.0000
Process Innovation	zero-one dummy	49432	0.0277	0.1640	0.0000	1.0000
Product Innovation	zero-one dummy	49432	0.0314	0.1743	0.0000	1.0000
Foreign	zero-one dummy	49432	0.0391	0.1937	0.0000	1.0000
Exporting	zero-one dummy	49432	0.0781	0.2684	0.0000	1.0000
Energy	zero-one dummy	49432	0.0206	0.1419	0.0000	1.0000
Waste	zero-one dummy	49432	0.0197	0.1391	0.0000	1.0000
Gov Aid	zero-one dummy	49432	0.0460	0.2095	0.0000	1.0000
BOI	zero-one dummy	49432	0.0678	0.2514	0.0000	1.0000
Central	zero-one dummy	49432	0.4388	0.4962	0.0000	1.0000
State-Owned	zero-one dummy	49432	0.1605	0.3671	0.0000	1.0000
Head Branch	zero-one dummy	49432	0.0703	0.2557	0.0000	1.0000
Size 2-50	zero-one dummy	49432	0.8716	0.3345	0.0000	1.0000
Size 51-100	zero-one dummy	49432	0.0511	0.2202	0.0000	1.0000
Size 101-200	zero-one dummy	49432	0.0348	0.1832	0.0000	1.0000
Size 201-500	zero-one dummy	49432	0.0268	0.1615	0.0000	1.0000
Size 501-1000	zero-one dummy	49432	0.0095	0.0972	0.0000	1.0000

Source: Author's calculation

[7] See details in Kohpaiboon and Ramstetter (2008).

Table 5: Pairwise Correlation Matrix of the Key Variables (Observations are 1,702)

Correlation	R&DExpense	Lab Number	LnVAL	LnKI	LnMI	LnLQ	Process	Product	Foreign	Exporting	Energy	Waste	Gov Aid	BOI
R&DExpense	1													
Lab Number	0.249*	1												
LnVAL	0.257*	0.078*	1											
LnKI	0.223*	0.063*	0.551*	1										
LnMI	0.217*	0.055*	0.740*	0.434*	1									
LnLQ	0.028	0.021	-0.069*	0.119*	-0.102*	1								
Process	0.088*	0.076*	0.191*	0.121*	0.164*	-0.041*	1							
Product	0.090*	0.049*	0.200*	0.124*	0.175*	-0.052*	0.678*	1						
Foreign	0.050*	0.045	0.257*	0.163*	0.228*	-0.040*	0.154*	0.164*	1					
Exporting	0.135*	0.054*	0.323*	0.180*	0.295*	-0.074*	0.246*	0.263*	0.447*	1				
Energy	0.068*	0.072*	0.170*	0.110*	0.145*	-0.039*	0.646*	0.661*	0.152*	0.219*	1			
Waste	0.037	0.064*	0.165*	0.108*	0.143*	-0.040*	0.648*	0.662*	0.148*	0.209*	0.798*	1		
GovAid	0.112*	0.047	0.222*	0.112*	0.207*	-0.093*	0.247*	0.287*	0.198*	0.317*	0.234*	0.233*	1	
BOI	0.151*	0.050*	0.310*	0.180*	0.284*	-0.073*	0.242*	0.251*	0.458*	0.913*	0.216*	0.202*	0.321*	1

Notes: All correlation coefficients are significant at the 5% level or better (VAL=Value-Added per worker, KI=Capital Intensity, MI=Material Intensity, LQ=Labor Quality).

Given the nature of data availability in this study, although the more preferred panel data choice is desirable, the two industrial censuses (1997 and 2007) provide inconsistent establishment identification numbers. As a result, it is difficult to utilize both data sets and leads to difficulties in creating complete panel data. This lack of complete panel data in many developing countries, including Thailand, is one of the main reasons there have been so few comprehensive studies using firm-level analysis.

Next, the explanation of key variables used in our analysis can be described in detail as follows (see Table 4 for the statistical summary of key variables used in the analysis).

Knowledge/Innovation

R&D Intensity: R&D laboratory expenditure (as a categorical unit ranging from 1 to 5) and the number of laboratory units in a plant (in nominal unit)

Process Innovation: Dummy variable, which takes the value 1 if a plant reports having introduced new or significantly improved its production technology

Product Innovation: Dummy variable, which takes the value 1 if a plant reports having introduced new or significantly developed its product

Labor Productivity: Value added per worker of a plant

Capital Intensity: The ratio of fixed assets to total number of employees in each plant (average physical capital stock per worker)

Material Intensity: Material input intensity, defined as the ratio of raw material input purchases of each plant to total number of workers in that plant

Labor Quality: The share of skilled workers in the total workforce of each plant (both male and female skilled operatives and non-production workers). The actual number of supervisors and management workers are not available in the census. Therefore, the number of non-production workers reported would also include administrative staff.

Public Support

Government Aid: Dummy variable, which takes the value 1 if a plant receives or demands financial support or aid from government agencies for innovation projects.

BOI: Dummy variable for the Thai Board of Investment - the investment promotion status of a plant (equal to 1 if a plant is investment-promoted, and zero otherwise). The plant receives tax incentives or non-tax incentives or other investment benefits from BOI under the Investment Promotion Act of Thailand. Recent policies to promote R&D activity in Thailand are principally implemented through the Broad of Investment.

Demand Pull

Energy Saving: Dummy variable, which takes the value 1 if a plant reports having implemented an energy saving system

Waste Management: Dummy variable, which takes the value 1 if a plant reports having implemented an improved waste management system

Region and Form of Organization

Central: Central area dummy (equal to 1 if plants are in the central area - Bangkok and the central region of Thailand, and zero otherwise)

Head Branch: Form of economic organization dummy (equal to 1 if these are plants belonging to multiple-unit plants, and zero if they are Single Unit type - plants belonging to single-unit or stand-alone plants)

State-Owned: Form of legal organization dummy (equal to 1 if plants are state-owned, and zero if they are private enterprises)

Other

Foreign Ownership: Dummy variable, which takes the value 1 if a plant is a foreign plant, and zero if the plant is a domestic plant

Size: Set of size dummy variables according to a plant's number of employees. Categories are 2-50, 51-100, 101–200, 201–500, and 501-1,000 employees.

Industry: Set of industry dummies according to the plant's main business activity

4. Empirical Results

Before reviewing and interpreting the estimated results, we point to an important caveat of our study in that we only have cross-sectional data for the analysis and that most of the factors we consider may be simultaneously determined. Therefore, we need to take great care in interpreting our results. Although the panel data analysis is more preferred, it is impossible to obtain the complete set of data at the time of this study. In addition, the data on innovation and innovative indicators is rather scarce for the Thai case, making it even harder to utilize the data from other sources. Additionally, since the analysis from the Innovation Survey of Thailand has already been explored in previous studies, our estimation here would better contribute to the literature on the subject when applying other methods with a newer dataset from the Industrial Census, which has a direct focus on the relationship between innovation, R&D, and productivity in Thai manufacturing. The results of our analysis can be divided into three sections as shown below.

4.1 Research Activity and R&D Intensity Function

We start this section by considering estimates of the determinants of whether or not plants undertake R&D and if so, how much R&D they conduct. As noted before, we use both R&D expenditure (in categorical unit) and the number of laboratory units (in nominal unit) as the dependent variable in equation (1) and (2). The estimated results of the research equation for the case of R&D expenditure (dependent variable) being a categorical unit are shown in Table 6 to provide initial evidence. Later, the main results in our analysis will be thoroughly explained from Table 7.

Table 6: Research Equation - R&D Expenditure (Coefficients)

R&D Expenditure	Ordinal Probit		Ordinal Logit	
(Categorical Unit: 1 to 5)	(1)	(2)	(3)	(4)
Foreign	-0.0128	0.0515	-0.0164	0.0928
	(-0.19)	(0.72)	(-0.14)	(0.75)
Exporting	-0.134	-0.197	-0.204	-0.340
	(-0.88)	(-1.24)	(-0.75)	(-1.17)
Energy	0.135	0.184*	0.247	0.328*
	(1.51)	(2.08)	(1.55)	(2.08)
R&D Expenditure	Ordinal Probit		Ordinal Logit	
(Categorical Unit: 1 to 5)	(1)	(2)	(3)	(4)
Waste	-0.0702	-0.149	-0.124	-0.249
	(-0.78)	(-1.65)	(-0.77)	(-1.53)
Gov Aid	0.237***	0.206***	0.392***	0.347***
	(4.00)	(3.44)	(3.85)	(3.34)
BOI	0.262	0.293	0.408	0.487
	(1.71)	(1.84)	(1.49)	(1.68)
Central	0.293***	0.275***	0.476***	0.478**
	(3.84)	(3.29)	(3.61)	(3.29)
State-Owned	0.418	0.461	0.733	0.793
	(1.46)	(1.55)	(1.44)	(1.49)
Head Branch	0.193**	0.154*	0.328**	0.254*
	(3.28)	(2.53)	(3.22)	(2.42)
Size 2-50	-1.100***	-1.407***	-1.801***	-2.376***
	(-7.89)	(-9.51)	(-7.31)	(-9.09)
Size 51-100	-0.936***	-1.138***	-1.538***	-1.904***
	(-7.38)	(-8.68)	(-6.79)	(-8.19)
Size 101-200	-0.751***	-0.926***	-1.228***	-1.537***
	(-6.27)	(-7.58)	(-5.76)	(-7.04)
Size 201-500	-0.513***	-0.617***	-0.837***	-1.021***
	(-4.40)	(-5.27)	(-4.03)	(-4.92)
Food		0.302***		0.584***
		(3.36)		(3.70)

Textiles		-0.101		-0.197
		(-0.66)		(-0.74)
Apparel		-0.199		-0.392
		(-0.64)		(-0.74)
Wood		0.770*		1.340
		(2.06)		(1.83)
Chemicals		0.681***		1.214***
		(7.14)		(7.21)
Rubber and Plastics		-0.107		-0.171
		(-0.92)		(-0.86)
Non-metallic		0.00475		0.0328
		(0.03)		(0.13)
Basic metals		-0.152		-0.305
		(-0.80)		(-0.91)
Observations	1702	1702	1702	1702
Pseudo R2	0.0514	0.0759	0.0472	0.0742

Source: Author's calculation
Notes: Robust t-statistics in parentheses and ***, **, * indicates a statistical significance at 1, 5, 10 percent, respectively.

First, the results of our research equation, estimated by using the ordinal probit (and ordinal logit) model provide first insight regarding the relationship between R&D expenditure and determinant variables. From Table 6, the positive coefficients of *Gov Aid* (government aid) mean that the likelihood of plants' R&D expenditure increases with public financial support from the government. Moreover, plants in the central region of the country and plants, categorized as Head Branch type, have higher propensity to engage in R&D. Plant size is positively correlated with R&D expenditure and indicates a significant positive effect on the probability to perform R&D. The majority of plants in Thailand are small in terms of employees. As a result, for the Thai manufacturing sector, smaller plants have lower propensity to engage in R&D. In addition, plants in the food production industry (Industry division 15) and the chemical production industry (Industry division 24) are also more likely to invest in R&D. Importantly, from Table 6, we can conclude that being large plants, plants in the central region, and plants demanding government funding increases the probability of engaging in R&D.

Table 7: Research Equation: Laboratory Unit (Marginal Effects)

Lab/Lab Number	Probit	Logit	Heckman	
	(1)	(2)	(3) Main	(4) Select
Foreign	0.000765	0.000412	0.134	0.00130
	(1.45)	(0.93)	(1.35)	(1.72)
Exporting	0.00201	0.00185	0.0304	0.00277
	(1.61)	(1.66)	(0.15)	(1.44)
Energy	0.0116**	0.00826***	0.0373	0.0173**
	(3.28)	(3.45)	(0.32)	(2.93)
Waste	0.0108**	0.00789***	-0.146	0.0134**
	(3.17)	(3.37)	(-1.24)	(2.66)
Gov Aid	0.0431***	0.0262***	-0.216**	0.0594***
	(9.23)	(9.08)	(-2.58)	(6.58)
BOI	0.00233	0.00198	-0.0807	0.00252
	(1.71)	(1.72)	(-0.41)	(1.34)
Central	0.00182***	0.00173***	0.0156	0.00234***
	(4.63)	(4.40)	(0.19)	(4.27)
State-Owned	-0.00325***	-0.00413***	1.679*	-0.00263***
	(-9.48)	(-10.58)	(2.17)	(-5.16)
Head Branch	0.00338***	0.00274***	0.0450	0.00458***
	(4.64)	(4.99)	(0.59)	(4.14)
Food	0.00639***	0.00640***	-0.0839	0.00809***
	(6.82)	(7.69)	(-0.84)	(4.90)
Textiles	0.000702	0.000601	0.193	0.00139
	(0.93)	(0.84)	(1.22)	(1.27)
Apparel	-0.00256***	-0.00317***	0.0217	-0.00299***
	(-8.88)	(-9.58)	(0.08)	(-5.39)
Wood	-0.00223***	-0.00300***	0.212	-0.00252***
	(-6.61)	(-7.02)	(0.98)	(-4.45)
Lab/Lab Number	Probit	Logit	Heckman	
	(1)	(2)	(3) Main	(4) Select
Chemicals	0.0330***	0.0248***	0.312*	0.0634***
	(6.59)	(6.65)	(2.21)	(5.42)
Rubber and Plastics	0.00261**	0.00273**	-0.0714	0.00317*
	(2.72)	(3.26)	(-0.60)	(2.34)

Non-metallic	0.00347**	0.00347***	0.0300	0.00488*
	(3.24)	(3.52)	(0.18)	(2.51)
Basic metals	-0.00127**	-0.00153**	-0.121	-0.00170**
	(-2.99)	(-3.15)	(-0.82)	(-3.16)
Furniture	-0.00234***	-0.00295***	0.311	-0.00257***
	(-7.76)	(-8.38)	(1.40)	(-4.63)
Size 2-50	-0.0535***	-0.0451***		-0.102***
	(-5.25)	(-5.58)		(-4.40)
Size 51-100	-0.00195***	-0.00224***		-0.00252***
	(-6.29)	(-6.11)		(-5.21)
Size 101-200	-0.00151***	-0.00170***		-0.00207***
	(-4.18)	(-4.07)		(-4.46)
Size 201-500	-0.000690	-0.000835		-0.00125*
	(-1.25)	(-1.53)		(-2.14)
Observations	49432	49432	49432	

Source: Author's calculation
Notes: Robust t-statistics in parentheses and ***, **, * indicates a statistical significance at 1, 5, 10 percent, respectively.

Second, the results from the research equation using the Heckman selection method provide further insight on both the decision to undertake R&D (by having laboratory units in a plant) and the intensity of R&D. In Table 7, we estimate the research equation by probit, logit, and Heckman selection models to compare our results. We can observe that the sign of the estimates (marginal effects) is the same with the results only differing in magnitude. However, we will only consider the results from the Heckman selection model for our research equation, with the dependent variable being the number of laboratory units, as our benchmark results. The estimated results suggest that the plant's decision to undertake R&D is positively influenced by energy saving status, waste management status, government aid, and central region status. Specifically, the marginal effect for government aid (*Gov Aid*) is relatively large. Plant size appears to positively affect the decision to undertake R&D, with bigger plants having more and smaller plants having less probability to engage in R&D activities. Larger plants, which may have more stable funding access, are likely to afford R&D investment as opposed to smaller plants (Jongwanich and Kohpaiboon, 2011). For this reason, as confirmed by our estimated results in Table 6 and Table 7, smaller plants are less likely to engage in R&D (the magnitude of coefficients is larger as the firm size is smaller). It is interesting to note that state-owned plants (in terms of legal organization) are less likely to invest in R&D while plants that are Head Branch type (in terms of economic organization) are more likely to engage in R&D. Furthermore, the BOI and export status of a plant appears to weakly affect the propensity of a plant in conducting R&D. Finally, we find that being a foreign plant is not related to greater engagement in R&D activities. Moreover, the estimated results from Table 7 reveal that plants in some industries are more likely to engage in R&D activities; namely, plants in the food production (Industry division 15), chemical production (Industry division 24), rubber and plastic production (Industry division 25), and non-metallic mineral production industries (Industry division 26). Conversely, plants in the following industries have less probability to undertake R&D: apparel (Industry division 18), wood production (Industry division 20), metal production (Industry division 28), and furniture (Industry division 36). In summary, from Table 6 and Table 7, in terms of industry, it is found that almost all industries are more likely to carry out R&D than the textiles industry; especially the chemical industry which has a relatively high marginal effect. These results are in line with the previous study by Berger (2010).

4.2 Innovation Function

We next consider the results of the innovation equation in Table 8 and Table 9. These empirical results provide us with an idea of important determinants for the propensity to innovate in both product innovation and process innovation.

Table 8: Innovation Equation (Marginal Effects)

	Univariate Probit		Bivariate Probit	
	(1) Process	(2) Product	(3) Process	(4) Product
	Innovation	Innovation	Innovation	Innovation
Lab Number	-0.0145**	-0.00164	0.007**	0.067***
	(-3.25)	(-0.40)	(3.20)	(6.69)
Foreign	0.00172	0.000274	0.001	0.001
	(1.04)	(0.20)	(-0.04)	(-0.07)
Exporting	0.0101*	0.0176***	0.004	0.014***
	(2.43)	(3.52)	(1.57)	(3.49)
Energy	0.148***	0.173***	0.054***	0.079***
	(7.69)	(7.83)	(6.03)	(6.03)
Waste	0.119***	0.159***	0.055***	0.071***
	(6.48)	(6.98)	(5.84)	(5.68)
GovAid	0.00284	0.0154***	0.001	0.001*
	(1.43)	(4.19)	(1.15)	(1.83)
BOI	-0.000211	-0.00289*	0.001	-0.003***
	(-0.10)	(-2.31)	(0.69)	(-4.21)

Central	0.00291***	0.00665***	0.001	0.004***
	(3.47)	(7.78)	(1.42)	(6.71)
State-Owned	0.0312	-0.00488	-0.004***	-0.004***
	(1.16)	(-1.19)	(-6.22)	(-5.88)
Head Branch	0.0103***	0.00463**	0.006***	0.001
	(5.09)	(3.23)	(4.48)	(0.96)
Food	-0.000657	0.00350*	-0.001	0.001
	(-0.56)	(2.38)	(-0.79)	(1.23)
	Univariate Probit		Bivariate Probit	
	(1) Process	(2) Product	(3) Process	(4) Product
	Innovation	Innovation	Innovation	Innovation
Textiles	-0.00102	0.000565	-0.003**	0.000
	(-0.67)	(0.36)	(-3.51)	(0.27)
Apparel	-0.00533***	-0.00356***	-0.004***	-0.001
	(-6.67)	(-3.63)	(-6.24)	(-0.72)
Wood	-0.000988	-0.00433***	-0.002*	-0.003***
	(-0.60)	(-3.96)	(-1.8)	(-3.22)
Chemicals	0.0230***	0.0362***	0.003	0.014***
	(4.19)	(5.50)	(1.75)	(4.41)
Rubber and Plastics	-0.00118	0.000839	-0.001	0.000
	(-0.84)	(0.50)	(-1.27)	(0.28)
Non-metallics	0.000312	0.00315*	-0.002*	0.002
	(0.24)	(1.96)	(-2.92)	(1.29)
Basic metals	-0.00435***	-0.00340**	-0.003***	-0.002**
	(-4.59)	(-3.19)	(-4.25)	(-2.67)
Size 2-50	-0.00776	-0.0123*	-0.002	-0.001
	(-1.71)	(-2.11)	(-0.96)	(-0.49)
Size 51-100	0.00203	0.000890	0.003	0.004
	(0.63)	(0.30)	(1.06)	(1.18)
Observations	49432	49432	49432	49432

Source: Author's calculation
Notes: Robust t-statistics in parentheses and ***, **, * indicates a statistical significance at 1, 5, 10 percent, respectively. Dummy variables: Size 101-200 and Size 201-500 are statistically insignificant and omitted to save space.

Table 9: Innovation Equation (Coefficients)

	Univariate Probit		Bivariate Probit	
	(1) Process	(2) Product	(3) Process	(4) Product
	Innovation	Innovation	Innovation	Innovation
Lab Number	-0.730**	-0.0882	0.530**	1.104***
	(-3.27)	(-0.40)	(3.40)	(9.43)
Other	Omitted	Omitted	Omitted	Omitted
Independent	(Same with	(Same with	(Same with	(Same with
Variables	Table 8)	Table 8)	Table 8)	Table 8)
Observations	49432	49432	rho	0.875***
Pseudo R2	0.5222	0.5567		(24.73)

Source: Author's calculation
Notes: Robust t-statistics in parentheses and ***, **, * indicates a statistical significance at 1, 5, 10 percent, respectively.

From Table 8, most of independent variables are statistically significant. We can see that exporting plants, plants with energy saving and waste management systems, plants that receive or demand public financial support, plants in the central region, and plants which are categorized in terms of economic organization as Head Branch type are more likely to be innovative. More importantly, comparing Table 8 and Table 9, the variable *Lab Number* (the number of labs reported in a plant), which is a proxy for R&D expenditure, negatively relates to process innovation in the univariate probit model. As stated in Berger (2010), international competitive advantage for Thai plants is based on (labor) cost advantages and not (as in most of OECD countries) on innovative products. For this reason, it is not surprising that we might observe a negative and/or insignificant relationship between innovation indicators (process and product innovation) and the number of laboratory units (R&D expenditure), especially for process innovation, where we find a strong and negative relationship. However, if we consider the bivariate probit model instead, we find that *Lab Number* is positively related with both process and product innovation. Because the bivariate model estimates decisions that are interrelated, and the estimated results may differ if the two decisions (process and product innovation) are indeed interrelated. Another explanation for the negative sign for *Lab Number* might be that the number of labs may be not suitable for R&D input proxy for the Thai case. However, we can see in the correlation matrix in Table 5 that *Lab Number* has a positive correlation with both product innovation and process innovation (and also categorical R&D expense). As a result, from this section on, we will compare the estimated results from both the univariate probit model and the bivariate model. Although the correlation coefficient of binary outcomes in the bivariate model (rho) in Table 9 is statistically significant and the bivariate model might be more appropriate, we will compare the estimated results side-by-side since our paper is one of the first studies trying to proxy *Lab Number* as one of the key R&D inputs.

We clearly observe that the marginal effects for product innovation are generally larger than those of process innovation. For the innovation equation, we also find that being a foreign plant or BOI-promoted plant is not related to being more innovative both in terms of process or product innovation. The negative and insignificant results for BOI are in line with Jongwanich and Kohpaiboon (2011). We also find a positive and statistically significant relationship between exports and a firm's decision to invest in product development. This reflects the idea that exporters tend to learn more about competing products and customer preferences in international markets. For selected industries, plants in the food production (Industry division 15), chemical production (Industry division 24), and non-metallic mineral production industries (Industry division 26) are more likely to innovate, especially in the aspect of product innovation. In contrast, plants in the apparel (Industry division 18), wood production (Industry division 20), and metal production industries (Industry division 28) are less likely to innovate both for process and product innovation. Our results confirm the positive role of exports in R&D decision found by Jongwanich and Kohpaiboon (2011), and uncover additional determinants of innovation such as energy saving status and waste management status. The use of *Lab Number* is also to show the qualitative differences between the natures of innovation activity undertaken in smaller firms, which may have few or have no formal R&D units, and those of larger firms, which may have formal R&D laboratories (Schumpeter, 1942).

From Table 7 and Table 8, in contrast to some previous studies, we find that government funding or aid plays an important role for a plant to engage in R&D activities and to be innovative, especially in terms of product innovation. On one hand, the demand-pull aspect of a plant such as energy saving and waste management systems is a crucial determinant of innovative effort. On the other hand, the economic organization of a plant (Head Branch type) and location (the central region) also affects the probability of a plant being more innovative. According to the literature in this field, plant size may affect innovative effort. However, from our estimated results, we find that it is not the first or an important determinant since we only observe a weak relationship between plant size and innovative indicators. In short, plants operating in exports markets, relatively larger plants, and plants belonging to the chemical sector have a higher likelihood to innovate, especially in product innovation. In contrast to Jongwanich and Kohpaiboon (2011) and Berger (2010) which find relatively unimportant role of public financial support in stimulating R&D and innovation expenditure in Thailand, we find a positive relationship between government support (*Gov Aid*) and product innovation. Nevertheless, we confirm the same results for a negative relationship between BOI and product innovation. One explanation for previous negative signs for BOI is that, with weak national innovation system and surrounded by firms and public organizations that lack innovation capabilities, innovative firms might prefer to stay away from innovation collaboration since the perceived costs (knowledge losses) may be higher than the benefits (knowledge gains). In contrast, less capable firms (need to) seek cooperation in order to pool scarce resources and knowledge to enhance their innovative capabilities (Intarakumnerd et al. 2002; Berger 2010).

4.3 Productivity Function

Finally, we consider our results for the productivity equation shown in Table 10 with various OLS estimators to compare and check the robustness of our estimated results. The results are shown for both univariate probit model and bivariate probit model. The details of the OLS estimators employed in Table 10 can be described as follows; *reg* is the OLS estimator with robust standard errors, *rreg* is robust regression and this estimator yields a highly efficient M-estimator (an alternative to least squares regression used for the purpose of detecting influential observations), *qreg* is median (quantile) regression and this estimator protects against vertical outliers but not against bad leverage points, and *mmreg* is the estimator which yields a MM-estimator that combines high breakdown points and high efficiency[8]. Industry dummies are included but not reported in the table to save space. It is clear from Table 10 that the results from various OLS estimators yield the same direction and sign of estimated coefficients and only differ in magnitude.

In terms of general sources of productivity, exporting plants, foreign plants, plants with high capital and material intensity are more likely to be productive. The negative values of the coefficients for labor quality indicate that lower labor quality is associated with higher levels of productivity. This is surprising but the reason may be that the majority of manufacturing plants in Thailand are still in labor-intensive industries and these industries do not require highly skilled workers. Moreover, the education system in Thailand is not highly ranked and there are also some deficiencies in the training of workers in both the private and manufacturing sectors (World Bank, 2007). Foreign plants usually tend to have higher productivity and use more modern equipment than domestic enterprises in Thailand. Specifically, having foreign equity participation and involving in export markets is associated with approximately 10 to 20 percent increase in labor productivity. The plant size, measured by number of employees, also plays a crucial role in determining the level of productivity with larger plants being more productive on average.

The results for product innovation are conclusive. Product innovation increases productivity by 3 to 4.7 times in productivity equation in the univariate probit model, and increases productivity by 1.4 to 2.2 times in productivity equation in the bivariate probit model. However, the results for process innovation are mixed. On one hand, if we consider findings in the univariate probit case, process innovation decreases productivity by 3 to 4.5 times. The negative results are in line with previous studies from Berger (2010) and Jongwanich and Kohpaiboon (2011). This may imply a lack of efficiency in the innovation

[8] A discussion of these methods is beyond the scope of this paper; see Verardi and Croux (2009) for an introduction with a view on applications (plus Stata code) and for references to the theoretical literature.

process of Thai plants and/or process innovation may have a time lag before they can fully enhance labor productivity and/or process innovation may not be related with the number of lab units in our study. On the other hand, findings in the bivariate probit case indicate that process innovation enhance productivity by 2.4 to 4.4 times. This may conversely imply an aim of the process innovation could be to reduce production costs and that we expect that process innovation is more relevant in the Thai context than the product innovation. Overall, if we consider the univariate probit model, we observe from the estimated results that there is a negative impact of process innovation on productivity. Instead, if we consider the case for the bivariate model, we find that there is a positive relationship between process innovation and productivity.

Particularly, if we consider only for the bivariate probit model, two puzzling findings in the univariate probit case (the negative relationship between the number of laboratory units (as the proxy measure of R&D) and innovation, and the negative relationship between process innovation and productivity), would be resolved. In fact, we can look at the estimated rho (r is the correlation coefficient between the bivariate outcomes). If rho is statistically and significantly different from zero, we should use the estimated results from the bivariate probit model as our benchmark results since the decisions (regarding process innovation and product innovation) are interrelated in modeling of process innovation and product innovation (rho is shown in Table 9 to be statistically significant). However, since this is cross-sectional analysis for one year, it is possible that we may obtain some surprising results (i.e. the above two puzzling findings). Therefore, both the estimated results from the univariate and bivariate probit models are provided side-by-side for comparison. Nevertheless, it is obvious from the estimated results that, in any case, there is a positive relationship between product innovation and productivity. This indicates that product innovation is likely to be an important and promising source of the productivity improvement of plants in the Thai manufacturing sector. In contrast, depending on research methodology and the nature of data, process innovation might exhibit unexpected signs. The wrong sign could also be caused by the usage of cross sectional data (Berger, 2010). Another explanation for negative process innovation could be that process and product innovations are closely linked and hard to separate from one another. Panel data would be more ideal for future analysis. Nevertheless, product innovation can be an important driver of productivity growth in Thai manufacturing apart from exporting and foreign direct investment. For the Thai case, Innovation might also be a condition for the transformation process from being traditional production-oriented industries to becoming more oriented towards knowledge intensive production (Dilling-Hansen and Jensen, 2011).

Table 10: Productivity Equation

LnVAL	Productivity Equation (after Univariate Probit)				Productivity Equation (after Bivariate Probit)			
	(1) OLS	(2) Robust OLS	(3) Median Reg.	(4) Robust MM Reg.	(1) OLS	(2) Robust OLS	(3) Median Reg.	(4) Robust MM Reg.
Capital Intensity	0.224***	0.160***	0.169***	0.146***	0.222***	0.222***	0.168***	0.146***
	(57.75)	(66.06)	(58.83)	(49.16)	(57.69)	(57.69)	(58.78)	(49.05)
Material Intensity	0.417***	0.560***	0.523***	0.574***	0.416***	0.416***	0.522***	0.573***
	(62.65)	(262.36)	(207.12)	(138.95)	(62.53)	(62.53)	(207.31)	(138.36)
Labor Quality	-0.331***	-0.179***	-0.204***	-0.144***	-0.329***	-0.329***	-0.196***	-0.144***
	(-13.50)	(-8.40)	(-8.10)	(-6.74)	(-13.45)	(-13.45)	(-7.84)	(-6.73)
Foreign	0.203***	0.118***	0.126***	0.0974***	0.209***	0.209***	0.142***	0.101***
	(8.29)	(5.07)	(4.59)	(4.63)	(8.45)	(8.45)	(5.21)	(4.78)
Exporting	0.289***	0.214***	0.229***	0.207***	0.238***	0.238***	0.203***	0.178***
	(15.89)	(11.35)	(10.27)	(12.35)	(12.54)	(12.54)	(8.85)	(10.25)
Process Innovation	**-4.582*****	**-3.401*****	**-3.433*****	**-2.904*****	**4.435*****	**4.435*****	**2.862*****	**2.407*****
	(-15.60)	(-10.79)	(-9.22)	(-10.82)	(8.39)	(8.39)	(4.94)	(5.05)
Product Innovation	**4.734*****	**3.518*****	**3.521*****	**2.995*****	**2.195*****	**2.195*****	**1.498*****	**1.378*****
	(17.23)	(12.00)	(10.16)	(11.90)	(13.87)	(13.87)	(7.26)	(9.60)
Size 2-50	-0.00594	0.0959	0.0857	0.0717	-0.0257	-0.0257	0.0587	0.0457
	(-0.12)	(1.81)	(1.37)	(1.73)	(-0.53)	(-0.53)	(0.95)	(1.10)
Size 51-100	0.257***	0.233***	0.257***	0.199***	0.224***	0.224***	0.222***	0.167***
	(5.31)	(4.31)	(4.03)	(4.70)	(4.54)	(4.54)	(3.51)	(3.92)
Size 101-200	0.282***	0.251***	0.247***	0.219***	0.241***	0.241***	0.228***	0.187***
	(5.79)	(4.59)	(3.83)	(5.25)	(4.85)	(4.85)	(3.56)	(4.43)
Size 201-500	0.281***	0.243***	0.273***	0.217***	0.167***	0.167***	0.182**	0.140***
	(5.80)	(4.37)	(4.15)	(5.19)	(3.35)	(3.35)	(2.79)	(3.30)
Size 501-1000	0.360***	0.291***	0.302***	0.254***	0.146**	0.146**	0.154*	0.116*
	(6.59)	(4.50)	(3.96)	(5.32)	(2.60)	(2.60)	(2.03)	(2.38)
Observations	49432	49432	49432	49432	49432	49432	49432	49432
Adjusted R2	0.642	0.751			0.643	0.643		

Source: Author's calculation **Notes:** Robust t-statistics in parentheses. Industry dummies are included and ***, **, * indicate a significance at 1, 5, 10 percent, respectively.

Table 11: Percentage Difference in Labor Productivity (VAL) among Plants

Average Labor Productivity of Plants with and without Innovation in the Sample						Percentage Difference in VAL
Type of Plant	Observation	Mean	Std. Dev.	Min	Max	Compared to non-innovative plants
Process Innovation	1367	1056925	3245375	1225	8.79E+07	127.23%
Product Innovation	1550	991695.4	3058226	2500	8.79E+07	123.36%
Process & Product	1001	1137167	3723510	2500	8.79E+07	131.49%
No Innovation	47516	235032.1	1484607	12.96296	2.37E+08	0

Source: Author's calculation

In addition, we can see in Table 11 that the percentage difference in average productivity of the innovative and non-innovative plants is approximately 120 to 130 percent in our sample. This indicates that both process and product innovation may play a crucial role in determining plant productivity. Lastly, with more available data in the future, it is noteworthy that this issue should be closely re-investigated to provide more solid evidence for the Thai case.

5. Summary and Conclusions

Innovation, R&D and productivity have long been considered as the main sources of economic growth for many countries. The recent poor productivity and firm performance of Thailand compared to other countries in Southeast Asia has been a key focus for government policy in recent years. In response to current concerns regarding lagging productivity and poor innovative performance in Thailand, this paper empirically investigates the relationship between innovation, R&D, and productivity in the Thai manufacturing sector. This study is among one of the first studies for the Thai case to estimate a structural model that describes the link between R&D input, innovation output, and productivity empirically using the enriched Industrial Census data of Thailand. Importantly, our econometric model is aware of the fact that some plants may engage in innovation efforts, but do not explicitly report them as R&D in the data since we apply the CDM model to the case of Thai manufacturing.

Specifically, the main contribution of Crépon et al. (1998) and Griffith et al. (2006) is their design of the structural model appropriate for empirical studies based on information regarding non-innovative firms and innovative firms (Johansson and Lööf, 2009). However, it should be noted that the CDM model is accounting for relatively strong assumptions and potential endogeneity problems. As we emphasize in presenting our results, a major drawback of our data is that it is cross-sectional, so we do not observe many of the same plants repeatedly over time. This means that we need to take great care in interpreting our results. On the whole, our major finding is that government aid or funding and plant characteristics play an important role regarding the decision for a plant to engage in R&D and to be innovative both in terms of process innovation and product innovation. Exporting plants, plants in the central region, and plants that are categorized as Head Branch type are more likely to engage in R&D. Specifically, our results reveal that plants in the food production industry (Industry division 15) and the chemical production industry (Industry division 24) are more likely to invest in R&D and are more innovative compared to plants in other industries.

More importantly, our results from the structural model also provide further insights into the complex relationship between innovation, R&D and productivity. The type of industry and specific technological characteristics of plants are shown to influence the decision to undertake R&D. Interestingly, while the sign of the coefficients for product innovation is consistently positive, the sign of the coefficients for process innovation can be either negative or positive depending on research design (and possibly the nature of data). Explicitly, capital and material intensity, exporting status, plant size, and product innovation appear to be important determinants of productivity in the Thai manufacturing sector. In general, firms in Thailand tend to lag behind firms in other Southeast Asian countries in innovative performance whether they are multinational enterprises, state-owned enterprises, or small-medium enterprises (World Bank, 2010). The majority of Thai firms do not invest in R&D, but rather in technological learning through acquisition of existing technology, reverse engineering, testing, and quality control. Only a small minority of large subsidiaries of transnational corporations (TNCs), large domestic firms and SMEs have capability in R&D and innovation. Most SMEs are concerned mainly with building up basic operational capabilities, and using technicians to obtain and gradually improve fairly standard technology (Intarakumnerd, 2007).

In addition, government efforts have generally done little to strengthen the innovative or absorptive capabilities of Thai suppliers as most firms do not avail themselves of government programs including R&D tax incentives, subsidies and grants, and technical and consulting services (OECD, 2010). Moreover, fragile and sporadic links between government agencies and firms have contributed to the government's poor record in helping to detect, support, and aid the growth of local technological capacities (Doner et al, 2010). It is obvious that Thailand is placed at a relatively low rank in the context of R&D and innovation at both the aggregate and firm levels. The stage of development towards knowledge economy is underway in Thailand, but still not in a favorable condition due to the lack of firm incentives and full support from government. Based on our findings, the main issue will be initiating new knowledge for firms through basic research and R&D spending and developing strong linkages in universities, research and government institutions as a foundation for knowledge creation and technology catching-up (OECD, 2008).

Last but not least, despite some initiatives and policy attempts, innovation effort in Thai manufacturing has been limited due to a failure to coordinate agencies and policies. Further improvements are needed, specifically in the institutional arrangements for the coordination of national science and technology policies (Intarakumnerd, 2010). It is hoped that there will be future research on this issue to help clarify solid conclusion for the Thai case.

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References

Berger, M., 2010, 'The Innovation- Productivity Link – Comparing Thailand with a Sample of OECD Countries', *InTeReg Working Paper*, 55, Wien.

Bogliacino, F., Perani, G., Pianta, M., and Supino, S., 2009, 'Innovation in Developing Countries: The Evidence from Innovation Surveys', *FIRB Conference Research and Entrepreneurship in the Knowledge-Based Economy*, Universita L. Bocconi, Milano.

Crépon, B., Duguet, E., and Mairesse, J., 1998, 'Research, Innovation and Productivity: An Econometric Analysis at the Firm Level', *Economics of Innovation and New Technology*, 7, 2, pp. 115-158.

Crespi, G. and Zuniga, P., 2012, 'Innovation and Productivity: Evidence from Six Latin American Countries', *World Development*, 40, 2, pp. 273-290.

Doner, R.F., Intarakumnerd, P., and Ritchie, B.K., 2010, 'Higher Education and Thailand's National Innovation System', World Bank, New York, USA.

Dilling-Hansen, M., and Jensen, S., 2011, 'Lifestyle Production: Transformation from Manufacturing to Knowledge Based Production Using Innovation', *International Journal of Economic Sciences and Applied Research*, 4, 1, pp. 35-54.

Greene, W., 2003, *Econometric Analysis*, New Jersey, Prentice Hall.

Griffth, R., Huergo, E., Mairesse, J., and Peters, B., 2006, 'Innovation and Productivity Across Four European Countries', *Oxford Review of Economic Policy*, 2, 4, pp. 483-498.

Heckman, J.J., 1979, 'Sample Selection Bias as a Specification Error', *Econometrica: Journal of the Econometric Society*, pp. 153-161.

Intarakumnerd, P., 2005, 'Government Mediation and Transformation of Thailand's National Innovation System', *Science, Technology and Society*, 10, 1, pp. 87-104.

Intarakumnerd, P., 2007, 'Measuring Innovation in Catching-up Economies: An Experience from Thailand', NSTDA Document, Thailand.

Intarakumnerd, P., 2010, 'Country Profile of Thailand for OECD Review of Innovation in South-East Asia', College of Innovation, Thammasat University, Thailand.

Intarakumnerd, P., Chairatana, P. and Tangchitpiboon, T., 2002, 'National Innovation System in Less Successful Developing Countries: the Case of Thailand', *Research Policy*, 31, 8, pp. 1445-1457.

Intarakumnerd, P. and Chairatana, P., 2008, 'Shifting S&T Policy Paradigm. An Experience of an RTO in Thailand', *International Journal of Technology and Globalization*, 4, 2, pp. 121-138.

Intarakumnerd, P. and Fujita, M., 2008, 'Coping with a Giant Challenges and Opportunities for Thai and Vietnamese Motorcycle Industry from China', *Science Technology & Society*, 13, 1, pp. 35-60.

Johansson, B. and Lööf, H., 2009, 'Innovation, R&D and Productivity - Assessing Alternative Specifications of CDM-models', *Working Paper Series in Economics and Institutions of Innovation 159*, Royal Institute of Technology, CESIS- Centre of Excellence for Science and Innovation Studies.

Jongwanich, J. and Kohpaiboon, A., 2011, 'Multinational Enterprises, Exporting and R&D Activities in Thailand', in Hahn, C. H. and Narjoko, D. (eds.), *Globalization and Innovation in East Asia*, *ERIA Research Project Report*, 4, pp. 141-192.

Kohpaiboon, A. and Ramstetter, E. D., 2008, 'Producer Concentration, Conglomerates, Foreign Ownership, and Import Protection: Thai Manufacturing Firms a Decade after the Crisis', *The International Center for the Study of East Asian Development (ICSEAD) Working Paper*, 5, pp. 1-51.

Lee, C. (2008), 'Innovation, Productivity and Exports: Firm-Level Evidence from Malaysia'. *Nottingham University Business School University of Nottingham-Malaysia Campus*, *Working Paper Series*, 6.

Lundvall, B., 2003, 'National Innovation System: History and Theory', Aalborg University, Aalborg, Denmark.

Masso, J. and Vahter, P., 2008, 'Technological Innovation and Productivity in Late-Transition Estonia: Econometric Evidence from Innovation Surveys', *The European Journal of Development Research*, 20, 2, pp. 240-261.

OECD, 1996, 'The Knowledge-Based Economy', OECD, Paris.

OECD, 2008, 'Innovation in Firms: Findings from a Comparative Analysis of Innovation Surveys Microdata: Background and Highlights', OECD, Paris.

OECD, 2010, 'Review of SME and Entrepreneurship Issues and Policies in Thailand at National and Local Levels', Centre for Entrepreneurship, SMEs and Local Development.

Porter, M.E., 1985, *Competitive Advantage*, Free Press, New York, USA.

Ramstetter, E.D., 2004, 'Labor Productivity, Wages, Nationality, and Foreign Ownership Shares in Thai Manufacturing, 1996-2000', *Journal of Asian Economics*, 14, 6, pp. 861-884.

Schumpeter, J.A. 1942, 'Capitalism, Socialism and Democracy', Harper, New York, USA.

Verardi, V. and Croux, C., 2009, 'Robust Regression in Stata', *The Stata Journal,* 9, 3, pp. 439-453.

World Bank, 2007, 'Towards a Knowledge Economy in Thailand', Washington, D.C., USA.

World Bank, 2010, 'Thailand Economic Monitor', Washington, D.C., USA.