# Research Paper

## Supply-Side Determinants of Energy Consumption and Efficiency (ECE) Innovations

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This paper empirically analyses the supply-side determinants of eco-innovations related to Energy Consumption or Efficiency (ECE) for electricity and other energy sources. Using preliminary firm-level data from a 2010 survey of innovation activity in Tasmania (a regional economy and state of Australia), a multinomial discrete choice model is employed to test the research hypotheses. The analysis shows the positive association between technological and organisational capabilities and ECE outcomes in electricity and other energy sources, with a specific effect from investment in external R&D. We also find differences in sectoral technological opportunities for ECE innovation and a positive effect for firm structure and size. Our contribution is to show the importance of supply-side factors on ECE innovation outcomes and draw attention to their potential policy relevance.

### 1. Introduction

As climate change and energy security are now top priorities for many OECD governments (OECD, 2009), eco-innovation that reduces firm-level energy consumption or improves energy efficiency – 'Energy Consumption or Efficiency (ECE) Innovation' – will be increasingly required to ensure firm survival, competitiveness, and success. ECE innovations are important from both theoretical and policy perspectives, as they provide a means of reducing greenhouse gas emissions per unit of production output, which can impact on industry competitiveness given the diffusion of climate change policies across countries. The International Energy Agency (IEA 2009, cited in the Australian Productivity Commission, 2011) estimates that 'most of the greenhouse gas-related emission reductions needed to limit the global increase in energy-related emissions by 2020 to 6 percent over 2007 levels, could be attained through improved energy efficiency'. Despite this, there are limited empirical studies that address the role of ECE innovation and its determinants at the firm level or 'supply side'. However, with the wider emergence of firm-level innovation surveys standardised according to the OECD OSLO framework (OECD, 2005), new sources of ECE innovation related data have been delivered, increasing opportunities for empirical study. Using a regional dataset based on the OECD OSLO methodology, this paper aims to contribute to the literature on ECE innovation and to empirical understanding of the main supply-side determinants of ECE innovation.

#### Eco- and ECE Innovations

ECE innovations are normally considered as a subset of eco-innovations. Eco-innovation can be defined as 'new or significantly improved products, processes and business methods that avoid or reduce harmful environmental impacts or which create environmental benefits compared to alternatives' (Arundel and O'Brien, 2009, p. 97). Many researchers (e.g. Frondel, Horbach and Rennings, 2004a; Kesidou and Demirel, 2010) define eco-innovations as either technical– new products or processes– or organisational, and as 'end of pipe' (ancillary to the production process and aimed at compliance with regulatory requirements e.g. waste incineration, waste water treatments or chemical pollution filtering systems) or 'cleaner production' (proactively managing environmental issues e.g. developing new or improved products, processes or organisational methods with positive environmental impacts). In this paper, ECE innovations are defined as eco-innovations (involving the implementation of new equipment, processes or organisational methods) that reduce firm-level energy consumption or improve energy efficiency, thus fall into the 'cleaner production' category. While some definitions of eco-innovation are limited to a specific environmental goods and services sector, this paper is concerned with ECE innovation across all sectors.

## Theoretical and Empirical Background on Determinants of Eco- and ECE Innovations

Much research on eco-innovations is drawn from two perspectives: environmental economics and innovation theory (Kesidou and Demirel, 2010; Cleff and Rennings, 1999). From an environmental economics perspective, eco-innovations present a 'win-win' scenario and double externality issue, as positive spillovers accrue not only from the firm's innovation, but also from its environmental impacts and broader economic modernisation effects (Ziegler and Rennings, 2004; Belin, Horbach and Oltra, 2009; Horbach and Rennings, 2007). As indicated by Porter and van der Linde (1995), policy and regulation can trigger eco-innovations and the associated environmental and economic benefits, creating a regulation or demand-pull effect. Countries can improve their competitiveness by implementing effective policies that stimulate the development of new processes, products and markets, generating early adopter advantage as common environmental standards and regulations diffuse more widely across other countries (Arundel and Kemp, 2009; Kemp and Pearson, 2007). From an innovation theory perspective, a shift from linear to interactive and systems approaches has seen innovation conceptualised as a complex and interactive process (Kline and Rosenberg, 1986; Lundvall, 1992; Mahdjoubi, 1997), and both supply or technology push factors, and market demand or regulatory pull factors can influence firm propensity for eco-innovation (Kesidou and Demirel, 2010; Rennings, 1998).

The empirical literature on firm level eco-innovation generally separates determinants into supply-side factors (firm innovation strategies, cost savings, productivity, R&D and collaboration activities) verses demand-side determinants (consumer demand, public image or regulatory factors) (Oltra, 2008). Existing studies of supply side determinants focus on determinants of broader eco-innovation rather than ECE innovations only. In a firm-level panel study of German firms classified as producing products with environmental impacts, Horbach (2006) finds that technological capabilities, measured by skills, R&D and knowledge capital are important for firm eco-innovation performance, and that organisational changes and cost savings are important drivers of eco-innovation. Studies by Ziegler and Rennings (2004) and Ziegler (2005), using firm-level data on the German manufacturing industry, find that R&D activities, technological opportunities and organisational measures are positively correlated with both product and process based eco-innovations, while a panel study of Italian manufacturing firms by Mazzanti and Zoboli (2006) reveals a positive influence of R&D and collaboration activities on eco-innovation. Other firm-level studies have indicated a correlation between cost reduction and management strategies and eco-innovation (e.g. Frondel, Horbach and Rennings, 2004b). Connections between firm size, enterprise structure and eco-innovation, however, are inconclusive overall; some studies find significant effects (e.g. Ziegler, 2005; Ziegler and Rennings, 2004) while others do not (e.g. Horbach, 2006; Wagner, 2008; Mazzanti and Zoboli, 2006).

However, despite these findings, there remain few firm-level studies relating to supply-side determinants of eco-innovations (Belin, Horbach and Oltra, 2009; Oltra, 2008), and very few on the determinants of innovations related to energy and material efficiency (e.g. Rennings and Rammer, 2009). One relevant study by Rennings and Rammer (2009) suggests that supply-side determinants of efficiency based eco-innovations are correlated with broader innovation strategies, with R&D and collaboration related to energy and resource efficiency innovations. In addition, most of the studies above focus on a censored sample consisting of eco-innovators only, and questions remain regarding the interplay between ECE innovation outcomes and firm characteristics and capabilities, innovation strategies and sectoral technological opportunities across wider economic populations of innovative firms.

Due to a clear gap in the research, our study considers the central research question: what are the main supply side determinants of Energy Consumption or Efficiency (ECE) innovation? Drawing on the broader eco-innovation literature above, we extract the following four hypotheses to address our research question:

*Hypothesis 1 Firm-level technological capabilities influence the likelihood of ECE innovation.*

*Hypothesis 2 Firms following cost savings or productivity oriented innovation strategies are more likely to have ECE innovation.*

*Hypothesis 3 Firm-level organisational capabilities influence the likelihood of ECE innovation*

*Hypothesis 4 Sectoral technological opportunities influence the propensity for firm level ECE innovation*

## 2. Methods

This study is based on cross-sectional data from a 2010 survey of innovation activity in Tasmania, a regional economy and state of Australia. The survey instrument was developed based on the OECD OSLO manual, and administered via telephone interviews. The survey covered firms in all sectors with 5 or more employees, achieving a 61% response rate with 1446 respondent firms. A non-response analysis showed no statistically significant difference between respondents and non-respondents in terms of product or process innovations. Our sample population for this study consists of 1104 technological (product or process) innovators. Table 1 shows the sample characteristics by industry and firm size. The sample was skewed towards small firms, with around 90% of responding firms having less than 100 employees. Data were aggregated into six sectors, and three of these sectors – 'retail wholesale, accommodation and food services', 'knowledge intensive business services' and 'manufacturing' accounted for around 70% of the sample population.

All firms were asked if they 'implemented' or 'planned' to implement 'any new or improved equipment, processes or organisational methods', to reduce consumption of electricity or other energy sources e.g. natural gas, coal, wood, or petrol– providing our definition of ECE innovations (dependent variables).

Firms' ECE innovation decisions (electricity or other energy resources) fall into three mutually exclusive categories: either they did not implement or plan to implement ECE innovation (NoECE), or they did not implement

**Table 1 Sample characteristics by industry and firm size**

| Industry | Firm Size (%) | | | | |
|---|---|---|---|---|---|
| | *N* | *5-19* | *20-99* | *100+* | *Total* |
| Natural resources[1] | 70 | 60.3 | 30.9 | 8.8 | 6.3 |
| Manufacturing | 231 | 61.0 | 30.5 | 8.5 | 20.9 |
| *-Chemical & chemical related manufacturing*[2] | *98* | *60.6* | *29.8* | *9.6* | *42.4** |
| *-Other manufacturing*[3] | *133* | *61.2* | *31.0* | *7.8* | *57.6** |
| Infrastructure[4] | 140 | 46.3 | 41.8 | 11.9 | 12.7 |
| Knowledge intensive business services[5] | 260 | 64.2 | 30.4 | 5.4 | 11.8 |
| Health, education, public administration and safety and other services | 130 | 69.0 | 25.6 | 5.4 | 11.8 |
| Retail, wholesale, accommodation and food services | 273 | 69.5 | 24.9 | 5.6 | 24.7 |
| Total | 1104 | 62.9 | 29.9 | 7.2 | 100 |

*Calculated as a percentage of the manufacturing sector

1)Natural resources' includes agriculture and mining sectors; 2)Chemical and chemical related manufacturing' includes basic chemical and chemical products, food and beverage, printing, textiles, and polymer and rubber products manufacturing sectors; 3)Other manufacturing' includes machinery and equipment, and furniture manufacturing sectors; 4) Infrastructure' includes electricity, construction and transport sectors; 5) Knowledge intensive business services' includes telecommunications, professional and scientific services, financial and real estate services sectors.

ECE innovation but plan to implement in the next two years (PlanECE), or they implemented ECE innovation (ImpECE). Therefore, a multinomial logit model was chosen for hypothesis testing. We estimate the following model of ECE Innovations:

$$\text{Prob}(Y = j) = e^{\beta jXi} / \sum_{k=0} e^{\beta kXi}, \; j = \{\text{NoECE}(0) \mid \text{PlanECE}(1) \mid \text{ImpECE}(2)\}$$

where Y is the probability that firm i makes the choice j; Xi is a vector of independent variables of firm i; β is the vector of coefficients. NoECE is used as the base category (k=0).

Independent variables are categorised into four groups according to proposed hypotheses. To measure technological capabilities (Hypothesis 1), we include dummy variables for conduct of R&D (D_ConductRD) and collaboration with the knowledge infrastructure (universities or public research institutes - D_CoKnow), and continuous variables for the share of skilled employees (SkillsEmploy), and for the intensity of expenditure on internal R&D (InRDIntent) and external R&D (ExRDIntent). To measure cost savings or productivity based innovation strategies (Hypothesis 2), a dummy variable for process innovation (D_ProcInn) is included. To measure firm-level organisational capabilities (Hypothesis 3), a dummy variable for organisational innovation (D_OrgInn) is included. Finally, to measure sectoral technological opportunities (Hypothesis 4), sector dummies for natural resources (D_Natural), manufacturing (D_Manuf), infrastructure (D_Infra), knowledge-intensive business services (D_Knowledge) and health, education, public administration and safety and other services (D_HealthOthSer) are included, with retail, wholesale, accommodation and food services as the reference category. Although there was insufficient evidence in previous studies to justify a specific hypothesis on firm structure or size, we include dummy variables for firms being part an enterprise group (D_Group) and a continuous variable for natural-log of firm's employees (Ln_Employees) to measure their effect. Descriptive statistics for all variables are shown in Table 2.

## 3. Results

Table 3 shows the distribution of firms by ECE innovation status. For electricity, 36.9% of firms implemented ECE innovations while 20.9% planned ECE innovations. Of those implementing ECE innovation in electricity, 76.9% were also planning ECE innovation. This can be explained by the fact that approximately 80% of all electricity in Tasmania is generated from hydropower, and substantial future price rises are expected to fund upgrading of existing infrastructure. In these conditions we would expect the share of firms with no ECE innovation to further decrease over time as more firms are forced to improve efficiency. For other energy sources, 22% of firms implemented ECE innovations and 12% planned ECE innovations. Of those implementing ECE innovation, 80.2% were also planning ECE innovation.

Table 4 presents results of the multinomial logit regressions for ECE innovations in electricity and in other energy sources. For the electricity model, conduct of R&D (*D_ConductRD*) has a significant positive effect on decisions for both planning and implementing ECE innovation ($p<0.001$). For the other energy sources model, however, a positive effect of conduct of R&D is observed only for implementing ECE innovation ($p<0.01$). In both models, the intensity of expenditure on external R&D (*ExRDIntent*) positively affects decisions for both planning and implementing ECE innovation ($p<0.05$), whilst no effect of internal R&D expenditure (*InRDIntent*) is detected. This finding suggests that investment in the import of external knowledge and technology (or absorptive capacity) plays a more significant role in stimulating ECE innovations. Collaboration with the knowledge infrastructure (*D_CoKnow*) is found to positively affect the propensity for implementing electricity-based ECE innovation ($p<0.05$), while no effect of our skills measure (*SkillsEmploy*) is detected.

These findings partially support Hypothesis 1, and confirm the notion that technological capabilities are important factors for ECE innovations. They also raise questions about the nature of policy support for access to external knowledge and capabilities, while much of the existing policy focus is on supporting internal R&D.

For cost savings driven innovation strategies proxied by process innovation (*D_ProcInn*), we find no support for Hypothesis 2 for electricity nor for other energy sources. Despite no observed effect of organisational capability (*D_OrgInn*) on planned ECE innovation, such capability is found to positively influence the propensity for implementing ECE innovation in both models ($p<0.05$), thus partially supporting Hypothesis 3.

In terms of sector effects, manufacturing (*D_Manuf*) firms are less likely (than firms in the retail, wholesale, accommodation and food services sector) to implement other energy

Table 2 Descriptive statistics for all variables

| Variables | Description | N | Mean | S.D. |
|---|---|---|---|---|
| PlanECE (Electricity) | Firms that did not implement, but plan to implement, ECE for electricity (with no ECE for electricity as the reference category). | 1104 | 0.21 | 0.41 |
| ImpECE (Electricity)[1] | Firms that implemented ECE for electricity (with no ECE for electricity as the reference category) | 1104 | 0.37 | 0.48 |
| PlanECE (Energy) | Firms that did not implement, but plan to implement, ECE for other energy sources (with no ECE for other energy sources as the reference category). | 1104 | 0.12 | 0.33 |
| ImpECE (Energy)[2] | Firms that implemented ECE for other energy sources (with no ECE for other energy sources as the reference category). | 1104 | 0.22 | 0.46 |
| D_ConductRD | Dummy identifying firm conducting internal R&D activities (with no R&D activity as the reference category) | 1104 | 0.58 | 0.50 |
| D_CoKnow | Dummy identifying firms collaborating with consultants, universities or public research institutes (with no collaboration partner as the reference categories). | 1104 | 0.16 | 0.37 |
| SkillsEmploy | The percentage of skilled employees in total employment (Continuous variable). | 1067 | 9.08 | 20.0 |
| InRDIntent | Internal R&D expenditure as a percentage of sales (Continuous variable). | 991 | 1.70 | 7.29 |
| ExRDIntent | External R&D expenditure as a percentage of sales (Continuous variable). | 1050 | 0.25 | 2.28 |
| D_ProcInn | Dummy identifying firms introducing process innovation (with no process innovation as the reference category). | 1104 | 0.85 | 0.36 |
| D_OrgInn | Dummy identifying firms introducing organisational innovation (with no organisational innovation as the reference category). | 1104 | 0.85 | 0.43 |
| D_Natural[3] | Dummy identifying firms in the natural resources sector. | 1104 | 0.06 | 0.24 |
| D_Manuf[3] | Dummy identifying firms in the manufacturing sector. | 1104 | 0.21 | 0.41 |
| D_Infra[3] | Dummy identifying firms in the infrastructure sector. | 1104 | 0.13 | 0.33 |
| D_Knowledge[3] | Dummy identifying firms in the knowledge intensive business services sector. | 1104 | 0.24 | 0.43 |
| D_HealthOthSer[3] | Dummy identifying firms in the health, education, public administration and safety sector. | 1104 | 0.12 | 0.32 |
| D_Group | Dummy identifying firms being part of an enterprise group. | 1104 | 0.35 | 0.48 |
| Ln_Employees | Natural logarithm of the firm's employees (Continuous variable). | 1089 | 2.86 | 1.01 |

1 76.9% of implementing firms also planned to implement new ECE (electricity) innovation in the next two years.
2 80.2% of implementing firms also planned to implement new ECE (other energy sources) innovation in the next two years.
3 The retail, wholesale, accommodation and food services sector is used as the reference category.

 

**Table 3 ECE innovation in electricity and other energy sources.**

| ECE innovation | Electricity | | Other energy sources | |
|---|---|---|---|---|
| | *N* | % | *N* | % |
| NoECE | 466 | 42,2 | 729 | 66 |
| Plan ECE | 231 | 20,9 | 132 | 12 |
| IMP ECE | 407 | 36,9 | 243 | 22 |
| Total | 1104 | 100 | 1104 | 100 |

source based ECE innovation ($p<0.01$). This finding may be explained by a reliance on electricity over other energy sources in manufacturing. Infrastructure (*D_Infra*) firms, however, are more likely to plan to implement other energy sources based ECE innovation ($p<0.05$). This finding might be explained by planned equipment upgrades (that embody new technological innovations) to improve efficiency and reduce costs, as infrastructure, (which includes energy production, transport and construction) is largely fossil fuel intensive and subject to energy prices rises and policy uncertainty. The finding of a significant negative effect for knowledge-intensive business services sector (D_Knowledge) on both planning ($p<0.05$) and implementing ($p<0.01$) electricity-based ECE innovation, may be explained by the prevalence of office-based work and could be a function of the structure of this sector in Tasmania which is less innovative and much smaller in terms of output and sophistication than in the national economy. Reliance on electricity as the main energy source may also be the reason for a negative effect of this sector on implementing ECE innovation for other energy sources. Therefore, sectoral differences suggest partial support for Hypothesis 4.

Belonging to an enterprise group (*D_Group*) shows a significant positive effect on planning (for electricity and other energy) and implementing ECE innovation (for electricity), while a positive influence of firm's employees (*Ln_Employees*) is observed on implementing other energy source based ECE innovation ($p<0.001$). Greater access to internal knowledge networks and resources could explain these findings, drawing attention to a need for policy support of ECE innovation in smaller firms (OECD, 2010).

Of note, for this paper, we initially tested for correlations between ECE innovation decisions and firm performance in terms of firm growth and productivity improvements (we lack data on profitability), though found no significant results. ECE innovation might be expected to have some effect on performance through improved efficiency or profitability, and there is a need for future theoretical and empirical research in this area (see Antonioli and Mazzanti, 2009).

## 4. Discussion, Conclusions and Future Research

This paper queried the role of supply-side determinants of ECE innovations for electricity and other energy sources, using a firm-level innovation dataset covering all sectors in a regional Australian economy. We derived four hypotheses from the theoretical and empirical literature on eco-innovations, testing them with a multinomial logit model. Our findings confirmed the importance of technological capabilities for ECE innovation outcomes, and highlight the need for policy to facilitate greater access to and investment in new external knowledge and technologies in order to stimulate ECE innovations. Our analysis implicates the significance of organisational capabilities for implementing ECE innovation for electricity and other energy sources, suggesting that improving such capabilities from a policy and firm perspective may support longer term ECE innovation outcomes. Significant size and structure effects also indicate a need for policy support to improve ECE innovation performance in smaller firms, whereas sector effects implied differing sectoral technological opportunities for ECE innovation as expected.

Our contribution is to show the importance of firm-level supply side factors on ECE innovation outcomes, supporting the theoretical notion

**Table 4 Multinomial logit regressions for ECE innovations.**

| | Electricity | | | | Other Energy Sources | | | |
|---|---|---|---|---|---|---|---|---|
| | PlanECE | | ImpECE | | PlanECE | | ImpECE | |
| | B | S.E. | B | S.E. | B | S.E. | B | S.E. |
| Intercept | -1,454*** | 0,372 | -1,595*** | 0,340 | -2,417*** | 0,430 | -3,162*** | 0,408 |
| D_ConductRD | 0,856*** | 0,203 | 0,604*** | 0,169 | 0,422 | 0,237 | 0,657*** | 0,193 |
| D_CoKnow | 0,506 | 0,273 | 0,489* | 0,240 | 0,505 | 0,286 | 0,142 | 0,245 |
| SkillsEmploy | 0,008 | 0,005 | 0,007 | 0,004 | 0,004 | 0,006 | 0,001 | 0,005 |
| InRDIntent | -0,026 | 0,017 | -0,015 | 0,011 | -0,002 | 0,016 | 0,003 | 0,012 |
| ExRDIntent | 0,354* | 0,158 | 0,362* | 0,156 | 0,206* | 0,090 | 0,209* | 0,088 |
| D_ProcInn | -0,111 | 0,246 | 0,409 | 0,233 | -0,090 | 0,288 | 0,476 | 0,286 |
| D_OrgInn | 0,027 | 0,212 | 0,495* | 0,1941 | -0,099 | 0,249 | 0,570* | 0,236 |
| D_Natural | -0,356 | 0,409 | -0,521 | 0,351 | -0,318 | 0,512 | 0,156 | 0,346 |
| D_Manuf | 0,332 | 0,262 | -0,298 | 0,237 | -0,056 | 0,308 | -0,923** | 0,270 |
| D_Infra | -0,042 | 0,309 | -0,528 | 0,272 | 0,838* | 0,334 | 0,374 | 0,277 |
| D_Knowledge | -0,738* | 0,285 | -0,619** | 0,223 | -0,535 | 0,330 | -0,950*** | 0,268 |
| D_HealthOthSer | -0,529 | 0,349 | -0,414 | 0,276 | -0,647 | 0,455 | -0,269 | 0,302 |
| D_Group | 0,478* | 0,203 | 0,504** | 0,174 | 0,538* | 0,225 | 0,239 | 0,191 |
| Ln_Employees | 0,069 | 0,100 | 0,140 | 0,087 | 0,125 | 0,112 | 0,329*** | 0,091 |
| N (Observations) | 1104 | | | | 1104 | | | |
| -2 Log likelihood | 1847,755 | | | | 1467,784 | | | |
| Model $X^2$ (df) | 123,258 | | | | 127,965 | | | |
| Pseudo $R^2$ | 0,139 | | | | 0,155 | | | |

*p<0,05; **p<0,01; ***p<0,001

of a technology or supply push influence on firm level ECE and eco-innovation outcomes, adding to the very limited empirical work on this topic and drawing further attention to the policy relevance of firm level capabilities and absorptive capacities for ECE innovation outcomes. In particular, the results suggest that enhancing organisational capabilities may be one means of obtaining further efficiencies in energy use in sectors facing technological constraints, and that acquisition of external knowledge and technology is an important factor. As unrealised innovations in energy efficiency are estimated to have significant potential for reducing global greenhouse gas emissions and improving firm and industry competitiveness, this paper contributes to the limited empirical work that may inform the debate around emission abatement policies. In addition, the findings of this paper raise questions regarding the complementarities of innovation and energy policies, particularly whether there is scope for further integration between the two to maximise environmental spillovers.

However, we note that this study is limited by its preliminary nature and the use of cross-sectional data, which prevents us from inferring causality. Coupled with the fact that other unknown intervening factors could lead to errors in the analysis, the interpretation and generalisation of these findings needs to be done with caution. A key area for future research is the extent of ECE innovation and its effects on firm performance, which are not measured in this paper. On the demand side, future research might consider particular policy effects on ECE innovation outcomes, for instance whether there are negative policy effects for some firms or sectors from policy bias towards pre-defined technologies, or the level of positive net effects from particular policies, such as those that mandate energy efficiency reporting requirements for larger firms.

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