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Generierung und Übernahme von Energie-technologien und energiepolitische Förderung in der Schweiz

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English

Abstract

This research project relies on a unique survey of Swiss enterprises in order to provide empirical insights on some relevant issues in energy efficient technology generation and usage. More specifically, the following questions are addressed: What are the determinants of innovation (in the sense of providing previously unavailable new technologies) and of the adoption (the widespread application of such new technologies, once they have reached maturity) in the context of Energy Efficient Technologies (EET)? And what is the effect of public support for the adoption of such technologies in Switzerland?

The present study has been commissioned by the Swiss Federal Office of Energy (SFOE) in order to contribute to a better understanding of processes of diffusion and innovation in the context of new energy technologies. It can be subdivided in two parts: first, a survey has been conducted on a representative sample of Swiss enterprises belonging to the private sector in order to collect information about their activities related to energy efficient technologies (henceforth EET). Second, econometric analysis has subsequently been applied to data obtained by this survey, with respect to three policy relevant issues: the explaining factors of both **adoption** and **innovation** of such technologies, and the effects of **public policies supporting the adoption** of such technologies.

Political and scientific interest in questions related to the availability, production and use of energy in today's modern economies has not ceased to increase in recent years. On the contrary, issues like sustainability (the vast majority of today's energetic needs stems from finite energy carriers, such as fossil and nuclear fuels), global climate change as a consequence of ever increasing worldwide CO_2 emissions resulting from the use of fossil fuels, and the economic risks associated with price fluctuations and potential shortages on energy markets have prompted an increasing awareness of the importance of reliable and sustainable energy supply, and — equally important — improvements in energy efficiency.

Improvements in energy efficiency — loosely defined as improvements in investment goods, processes or patterns of use of energy that allow to produce a given amount of a certain good or to accomplish a certain service using less energy inputs — are essential in order to maintain established standards of living and economic growth, let alone for developing countries to catch up with the economic standards present in the industrialised world. This follows from the simple observation that non-renewable energy carriers might reach depletion in a future not too far from now (or need to be abandoned even before that happens, due to their potentially harmful ecological effects); and that harnessing renewable energy sources in order to fill the resulting gap requires enormous technological efforts of a kind that makes them unlikely to become widely available within a short time span. Moreover, renewable energy sources of the future may very likely be accompanied by other ecological side effects, such as massive land requirements for the production of biofuels or photovoltaic electricity.

Energy efficiency can be improved both as far as production (firms) and consumption (households) of economic output is concerned. This project focuses on firm behaviour, as within-firm use of energy makes up for a considerable share of total energy use; and since in a market economy, private enterprises are expected to be the driving forces of the development (at least partly) and the successful market introduction (mainly) of new technologies. The entire private sector of the Swiss economy is thus the object of this project (with the exclusion of the primary sector). More detailed descriptions of the survey procedure and descriptive results of the indicators obtained are the topic of **chapter 1** of this report, while the three econometric studies based on the survey follow in subsequent chapters.

The first of these studies, presented in **chapter 2** investigates the factors that determine the **adoption of energy saving technologies**, both across (*inter-firm*) and within (*intra-firm*) enterprises. The theoretical literature has postulated the existence of firm-specific (called *rank*) effects, inducement effects, adoption barriers as well as *order, stock and epidemic* effects, the latter of which are related to different kinds of externalities. The data enables us to investigate these effects with regards to four different categories of energy-saving technology applications (electromechanical and electronic applications; applications in motor vehicle and traffic engineering; in building construction; and in power-generating processes) separately. The results show that there are significant differences with respect to rank effects and adoption barriers between inter-and intra-firm diffusion. In practically all cases, positive epidemic and/or network effects outweigh potential negative stock and order effects. Inducement effects, particularly those traced back to intrinsic motivations for environment- friendly technologies, show clearly positive effects on the adoption rates.

The following additional findings emerge: adopting firms do not use more human capital than non-adopting firms. Foreign firms seem to be less inclined than domestic firms to adopt energy-saving technologies in buildings and energy- generating processes. While export activities do not appear to be a specific trait of adopting firms, competitive pressures seem to have some influence on the propensity to adopt energy-saving technologies. As far as externalities are concerned, relevant for the introduction of energy-saving technologies is the experience of first use of such technologies in other firms in similar industries, and in most cases not their intensity of usage. A complicating feature for the formulation of economic policy is the heterogeneity of firms (for example, with respect to firm size or the existence of R&D activities). On the other hand, we find almost the same pattern of diffusion for all four categories of technology applications. Thus, policy has to be specific to firm categories but not to technology types in order to be effective.

A better understanding of **innovative activity related to energy efficient technology** is the aim of the second study of **chapter 3**, which attempts to identify firm-level determinants of innovation and research in these technologies. Applying standard econometric methodology, sizeable differences of the explaining factors of energy efficiency related innovation as compared to overall innovation appear.

In particular, market environment related variables that turn out to be important for overall innovative activity seem to have little explanatory power for EET related innovation, raising the question whether such innovation sufficiently responds to current and potential future demand. On the other hand, two essential productive inputs in the innovation process — funding and human resources — do not seem to be limiting factors in the innovation process with regards to energy efficient technology. Moreover, firms with a positive judgement about their past demand evolution and future demand expectations at various instances turn out to be more likely to engage in R&D as well as innovation activities related to EET. This is substantial (even if not sufficient) microeconomic evidence that demand-induced innovation may constitute an important transmission channel through which both market prices and energy policy can positively affect the pace of technological change. Price signals induced by current or expected scarcity of energy sources, or by CO_2 pricing as a public policy measure, can thus be expected to be effective in promoting innovative activities in energy efficient technologies.

The third study (**chapter 4**) assesses the **effectiveness of policy measures** directed at the diffusion of energy efficient technology among Swiss firms. Data related to whether support has been received from Swiss cantons and municipalities as well as from the Climate Cent Foundation is available and used for this purpose. Three different outcome variables (the number of different technology applications present in a firm, whether they have contributed to reducing CO_2 emissions, and the investment share of EET) are analysed. A *matching* framework has been chosen in an attempt to overcome the important issue of non-random treatment: supported firms that later turn out to be successful in reaching the target variables mentioned above may have done so not as a result of the support they have been granted, but rather because they might — due to their initial capabilities and management strategies — have been more probable to be successful in energy efficient technology adoption (and chosen to receive support specifically because of these favourable initial characteristics). Even when controlling for this concern of non-random treatment, however, diffusion support from the two institutions taken into consideration has indeed been beneficial in spurring adoption of energy saving technology.

While the analysis, due to inherent data limitations, does not bring about any conclusions about the magnitude of success (i.e., what has been the gain in terms of reduced energy consumption by monetary unit of means granted, and whether the funds have been allocated in the most cost-effective manner), it provides tangible evidence that no crowding-out effects emerge as a result of these support schemes, i.e. there have been investments in energy efficiency that would not actually have taken place in the absence of any support. This is an important finding that contributes to justifying ongoing efforts to facilitate diffusion of energy efficient technology, given that reducing our energy systems' reliance on non-sustainable and environmentally costly sources of energy may require decisive and well-coordinated policy intervention.

Swiss enterprises are well aware of the importance of energy issues, something that becomes evident when considering the good response rate to our survey (nearly 40%) or the large proportion of users of energy efficient technology — 50% in manufacturing and 40% in the service sector. Nevertheless, the question remains whether energy efficiency measures so far implemented by entrepreneurs and policy-makers have been adequate and what direction energy policy should take in the future. Providing quantitative answers — how much resources should be put into energy efficiency programs, and how stringently energy efficiency targets should be formulated and enforced — naturally is not possible on the basis of our data; however a few qualitative indications can be made.

A successful policy for energy technology needs to make sure that both the development and the adoption of new, energy efficient technologies (in more familiar economic terms, *supply* and *demand*) are being conducted at an optimum level.

On the **supply side**, unfortunately no impact analysis of support measures was feasible on the data obtained in our survey, due to the limited number of firms in the dataset benefitting from some kind of public support for the development of energy efficient technologies. The analysis of the determinants of innovation in EET of chapter 3 reveals that the incentives and conditions for firms to proceed to such innovative activities are similar to those of innovative activities in other technological fields. The finding of lacking market-orientedness of EET innovations may be interpreted in the sense that more policy emphasis should be given to the demand (technology adoption) side — a hypothesis that, however, would require testing in a more rigorous manner. Of crucial importance for innovation success at the enterprise level is the availability of qualified personnel and funding for such projects. Our findings indicate that no significant shortages of either exist; a hint that institutions of academic and professional training as well as the financial sector in Switzerland work adequately when it comes to the needs of EET innovators. However, the recent financial crisis may have had adverse effects on the latter, which our survey might have been unable to capture due to its reference period, which mostly precedes the latest crisis.

On the **demand side**, the impact analysis of support measures of chapter 4 reveals that as a whole, the measures in place have been effective in stimulating the adoption of new technologies. An important policy instrument that may promote efficient technology indirectly via induced demand — the pricing of fossil energy carriers by means of a CO_2 levy — has not been addressed by our impact analysis, as analytical methods different than the one chosen in our study would be necessary for this. A cautious finding of the analysis in chapter 2 is, however, that induced innovation may constitute an important mechanism, which economic policy can exploit. In the same chapter, we also find evidence of positive reinforcing effects of technology use: first use of a new technology encourages other firms to follow. This justifies efforts to promote first users, by means of supporting pilot and demonstration projects, and this finding universally applies across all sub-fields of energy efficient technology considered here. Additionally, "reputational" incentives appear to be important: firms adopt new, energy efficient technology because there is demand for goods and services that come from environmentally or energetically sound production. Public policy aiming at improving information, transparency and accountability in the context of voluntary energy efficiency improvements by enterprises therefore constitutes another valid option; especially where "hard" policies of the "command-and-control" type or energy pricing only receive (so far) limited political support.

Further research: energy technologies, due to their technological importance and rapid developments, can be expected to interact with the development and implementation of innovations in other types of technology. The "innovation enabling" role of energy technology has not been given thorough attention in the economic literature so far, despite its potential significance for public and corporate policy. Relying on data already collected in the course of the present survey, an interesting question would thus be to analyse if indeed the adoption of new energy technologies positively affects overall innovative performance at the firm level. Of similar interest is the question of how generating and adopting technology in the field of energy, specifically, affects firms' productivity and profitability. Existing empirical literature has found positive productivity effects of overall innovation, and these should be expected to carry over to the specific field of energy, or may even be of greater magnitude there.

Deutsch

Abstract

Diese Forschungsarbeit stützt sich auf eine in ihrer Art einmalige Befragung Schweizer Unternehmungen, um empirische Einsichten zu relevanten Themen im Bezug auf die Nutzung und Generierung energieeffizienter Technologien zu gewinnen. Dabei werden folgende Fragen bearbeitet: welches sind die Bestimmungsfaktoren der Innovation (der Erschaffung zuvor nicht verfügbarer neuer Technologien) sowie des Verbreitung (also des Einsatzes solcher Technologien, die marktreif geworden sind) im Kontext energieeffizienter Technologien (EET)? Und was ist der Effekt von Fördermassnahmen im Bezug auf den Einsatz solcher Technologien in der Schweiz?

Die vorliegende Studie wurde vom Bundesamt für Energie (BFE) in Auftrag gegeben, um einen Beitrag zu liefern für ein besseres Verständnis der Diffusions- und Innovationsprozesse im Kontext neuer Energietechnologien. Sie lässt sich grob wie folgt unterteilen: in einem ersten Teil wurde, basierend auf einer repräsentativen Stichprobe Schweizer Unternehmungen des Privatsektors, eine Befragung durchgeführt, um Informationen zu derer Aktivitäten im Bezug auf Energieeffizienztechnologien (EET) zu sammeln. Ein zweiter Teil umfasst ökonometrische Analysen der damit erhobenen Daten, welche zu folgenden drei politikrelevanten Fragestellungen Aufschlüsse liefern: Bestimmungsfaktoren sowohl des **Einsatzes** als auch der **Innovation** solcher Technologien, sowie Auswirkungen von **politischen Massnahmen zur Förderung des Einsatzes** solcher Technologien.

Das Interesse seitens der Politik und der Wissenschaft für Fragen im Bezug auf Verfügbarkeit, Produktion und Verwendung von Energie in einer modernen Volkswirtschaft hat in den letzten Jahren kaum nachgelassen. Ganz im Gegenteil: Stichworte wie Nachhaltigkeit (zurzeit wird der Löwenanteil der nachgefragten Energie durch nichterneuerbare Energieträger gedeckt, also solche fossilen oder nuklearen Ursprungs), globaler Klimawandel als Resultat der Nutzung fossiler Brenn- und Treibstoffe, sowie ökonomische Risiken verursacht durch Preisschwankungen und potentielle Verknappungen auf den Energiemärkten prägen die Debatte und haben zu einem gestiegenen Bewusstsein der Notwendigkeit eines verlässlichen und nachhaltigen Energieangebots und — nicht weniger bedeutend — von Verbesserungen im Bereich der Energieeffizienz geführt.

Verbesserungen der Energieeffizienz — vereinfacht definiert als Verbesserungen in Investitionsgütern, Prozessen oder Vorgehensweisen, welche es ermöglichen, eine gleichbleibende Menge eines gegebenen Gutes oder einer gegebenen Dienstleistung mit einem verminderten Bedarf an Energie bereitzustellen — sind unabdingbar, um gegenwärtige Lebensstandards und Wirtschaftswachstum auch auf weitere Zeit zu gewährleisten, und erst recht, um auch Entwicklungsländern ökonomische Standards nach westlichem Muster zu ermöglichen. Diese Erkenntnis folgt der simplen Tatsache, dass die heute verwendeten nichterneuerbaren Energieträger in nicht allzu ferner Zukunft zur Neige gehen dürften (oder auf deren Nutzung aus ökologischen Gründen bereits zuvor verzichtet werden muss); und dass die Nutzbarmachung alternativer, erneuerbarer Energieträger noch enorme technologische Anstrengungen erfordert, was deren umfassende Einführung auf absehbare Zeit für unrealistisch erscheinen lässt. Zudem werden auch künftige erneuerbare Energiequellen mit grosser Wahrscheinlichkeit nicht ohne Inkaufnahme ökologischer Kosten zu erschliessen sein, etwa in Form eines massiven Landverbrauchs für die Produktion von Biotreibstoffen oder für Photovoltaikanlagen.

Energieeffizienz lässt sich sowohl in der Produktion (in Unternehmungen) als auch beim Konsum (in Haushaltungen) verbessern. Dieses Projekt hat die Entscheidungen auf Unternehmensebene als Gegenstand der Untersuchung, da der Energieverbrauch von Unternehmungen einen bedeutenden Teil des Gesamtenergieverbrauchs ausmacht; und weil es in einer marktwirtschaftlichen Ordnung die privaten Unternehmungen sind, welche einen bedeutenden Beitrag zur Entwicklung und den Hauptbeitrag zur Markteinführung neuer Technologien liefern. Dementsprechend ist der gesamte Privatsektor (unter Ausschluss des primären Sektors) Gegenstand dieses Projekts. Detailliertere Angaben zur Vorgehensweise und den deskriptiven Resultaten der Befragung sind das Thema von **Kapitel 1** dieses Berichts, während die drei ökonometrischen Untersuchungen in den nachfolgenden Kapiteln folgen.

Die erste dieser Untersuchungen, präsentiert in **Kapitel 2** betrifft die Bestimmungsfaktoren des **Einsatzes von Energieeffizienztechnologien**, sowohl auf der *zwischen-* als auch der der *innerbetrieblichen* Ebene. Die theoretische Literatur zur Technologiediffusion unterscheidet dabei zwischen firmenspezifischen ("Rank") Effekten, Induzierungseffekten, Adoptionshemmnissen und externen ("Order", "Stock" und "epidemischen") Effekten, wobei es sich bei letzteren um externe Effekte handelt. Die Datenlage ermöglicht eine Untersuchung dieser Effekte im Bezug auf vier Bereiche energiesparender Technologieanwendungen (Elektrotechnik/Elektronik; Fahrzeuge; Bautechnik; Energie- und Wärmeerzeugung) jeweils separat. In der Gegenüberstellung von zwischen- und innerbetrieblicher Verbreitung zeigen sich bedeutende Unterschiede in der Wirkung firmenspezifischer Effekte; ebenso in derjenigen von Adoptionshemmnissen. Bei den externen Effekten dominieren positive (sprich: "epidemische" und Netzeffekte) die potenziell negativen "Stock"- und "Order"-Effekte durchwegs. Auch der positive Einfluss von Faktoren der induzierten Adoption liess sich bestätigen, insbesondere im Zusammenhang mit dem "intrinsischen" Motiv Umweltbewusstsein.

Zusätzlich lassen sich folgende Schlüsse ziehen: Anwenderfirmen (von energiesparender Technologie) haben keinen grösseren Anteil an höher ausgebildeten Angestellten als Nichtanwender. Ausländische Firmen legen eine geringere Tendenz zum Einsatz energiesparender Technologien an den Tag als einheimische Firmen. Exportaktivitäten scheinen keine ausgeprägte Eigenschaft von Anwenderfirmen zu sein, hingegen ist ein gewisser positiver Einfluss eines hohen Wettbewerbsdrucks auf die Einführung energiesparender Technologien zu beobachten. Im Bezug auf externe Effekte scheint relevant, wie verbreitet die Erfahrung anderer Firmen der gleichen oder ähnlicher Branchen mit der erstmaligen Einführung von Energietechnologien sind; und nicht so sehr, wie intensiv die jeweilige Nutzung in der gleichen Bezugsgruppe ist. Ein verkomplizierender Faktor für die Ausgestaltung energiepolitischer Massnahmen ist die Heterogenität unter den Unternehmungen (etwa im Bezug auf deren Grösse oder auf die Existenz von F&E-Aktivitäten). Andererseits ähneln sich die Verbreitungsmuster zwischen den vier untersuchten Technologieanwendungen stark. Energiepolitische Massnahmen sollten demnach, um zielführend zu sein, spezifisch auf die Diversität in der Unternehmenslandschaft Rücksicht nehmen und weniger auf die Diversität der verschiedenen Technologieanwendungen.

Ein besseres Verständnis der **Innovationsaktivitäten im Bezug auf Energieeffizienztechnologien** ist Gegenstand der zweiten Studie in **Kapitel 3**, wo die firmenspezifischen Bestimmungsfaktoren von Innovations- und Forschungstätigkeiten in solchen Technologien untersucht werden. Die Verwendung ökonometrischer Standardmethoden bringt dabei beträchtliche Unterschiede in den erklärenden Variablen einerseits von energieeffizienzbezogenen Innovationen und andererseits von allgemeinen Innovationstätigkeiten zutage.

Insbesondere stellt sich heraus, dass Variablen im Zusammenhang mit dem Marktumfeld, welche für die allgemeine Innovationstätigkeit von Bedeutung sind, im Bezug auf EET-Innovationen nur geringen Erklärungsgehalt aufweisen. Dies wirft die Frage auf, ob sich letztere Kategorie von Innovationen in einem genügenden Masse an den Anforderungen der gegenwärtigen und künftigen Nachfrage auf dem Markt orientiert. Andererseits lassen sich bei zwei grundlegenden produktiven Ressourcen — nämlich Finanzmittel und Humanressourcen — keine Engpässe in Verbindung mit Innovationsaktivitäten zur Verbesserung von Energieeffizienz ausmachen. Zudem engagieren sich Unternehmungen, welche ihre vergangene und erwartete (künftige) Nachfrageentwicklung als positiv einschätzen, mit einer grösseren Wahrscheinlichkeit und Intensität in Forschungs- und Innovationstätigkeiten im Bezug auf EET. Dies lässt sich als substanzielle (wenn auch nicht ausreichende) mikroökonomische Evidenz auffassen, dass nachfrageinduzierte Innovation ein bedeutender Mechanismus ist, mittels dem sowohl Marktpreise als auch Energiepolitik positiv auf das Tempo technologischer Neuerungen einwirken können. Preissignale, wie sie durch die natürliche Verknappung von Energieträgern oder etwa durch CO_2-Abgaben als Politikmassnahme ausgelöst werden, können deshalb als wirksam in der Stimulation von Innovationsaktivitäten in EET angesehen werden.

Die dritte Studie (**Kapitel 4**) beurteilt die **Wirksamkeit von Fördermassnahmen**, welche auf die Verbreitung von Energieeffizienztechnologien in Schweizer Firmen abzielen. Dabei kommen Angaben zum Einsatz, ob solche Förderung von Kantonen und Gemeinden oder von der Stiftung Klimarappen erhalten wurde. Betrachtet werden drei verschiedene Zielvariablen (die Anzahl der verschiedenen in der Firma eingesetzten Technologieanwendungen, ob diese zu einer Reduktion des CO_2-Ausstosses beigetragen haben, sowie der Anteil an den Totalinvestitionen der Firma von Energieeffizienztechnologien). Zum Einsatz kommt ein *Matching*-Verfahren, mit dem die wichtige Problematik der nichtzufälligen Auswahl überwunden werden soll: bei geförderten Unternehmungen, welche sich später als erfolgreich im Bezug auf die Zielvariablen herausstellen, könnte dieser Erfolg nicht das Resultat der Förderung sein, sondern vielmehr der Tatsache, dass solche Unternehmungen — etwa aufgrund ihrer vielversprechenden Grundvoraussetzungen oder bereits zuvor festgelegten Strategien — von vornherein mit einer grösseren Wahrscheinlichkeit als erfolgreiche Anwender von EET anzusehen waren (und deshalb als förderungswürdig erachtet wurden). Selbst wenn diese Problematik der nichtzufälligen Auswahl berücksichtigt wird, stellt sich jedoch heraus, dass die Fördermassnahmen der erwähnten Institutionen die wünschbaren Auswirkungen im Einsatz von EET entfalten konnten.

Selbst wenn in Anbetracht der verfügbaren Daten keine Aussagen möglich sind zum Umfang des Förderungserfolgs (etwa des erzielten Nutzens in Form eingesparter Energieäquivalente pro eingesetztem Förderungsfranken, und ob die Mittel auf die kosteneffizienteste Art und Weise eingesetzt wurden), liefert die Untersuchung dennoch substanzielle Hinweise, dass allenfalls befürchtete Mitnahmeeffekte der Fördermassnahmen nicht zutage treten: es lassen sich also Investitionen in EET ausmachen, welche ohne Förderung nicht stattgefunden hätten. Dieses bedeutende Resultat kann weiterführende Anstrengungen zur Förderung der Verbreitung von Energieeffizienztechnologien stützen; in Anbetracht der Tatsache, dass eine Abkehr von der Abhängigkeit unseres Energiesystems von nicht nachhaltigen und ökologisch problematischen Energieträgern von der Einführung energischer und sorgfältig koordinierter politische Massnahmen abhängen könnte.

Das Thema Energiefragen ist im Bewusstsein der Schweizer Unternehmungen sehr präsent, was sich sowohl an den guten Rücklaufquoten unserer Erhebung zeigt (nahezu 40%), als auch an den hohen Quoten von Nutzern energieeffizienter Technologien — 50% in der Industrie und 40% im Dienstleistungssektor. Die Frage steht allerdings im Raum, ob die gegenwärtig seitens der Unternehmen und der Politik umgesetzten Massnahmen sinnvoller Natur sind, und welche Richtung die Energiepolitik künftig einschlagen soll. Unsere Datengrundlagen erlauben es naturgemäss leider nicht, zu diesen Fragen quantitative Antworten zu liefern — wieviele Aufwendungen für Energieeffizienzmassnahmen bereitzustellen, bzw. wie streng Energieeffizienzziele zu formulieren und umzusetzen sind. Dennoch sind einige qualitative Aussagen möglich.

Eine erfolgversprechende Energieeffizienzpolitik sollte dafür sorgen, dass sowohl die Entwicklung als auch die Anwendung neuer, energieeffizienter Technologien (also deren *Angebot* und *Nachfrage*, um ökonomische Begriffe zu verwenden) in optimalem Ausmass getätigt werden.

Was die **Angebotsseite** betrifft, war im Rahmen der hier verfügbaren Daten bedauerlicherweise keine Wirkungsanalyse möglich, da zuwenige der erhobenen Firmen von

Fördermassnahmen im Zusammenhang mit der Entwicklung energieeffizienter Technologien erhielten. Die Analyse der Bestimmungsfaktoren der EET-Innovationen von Kapitel 3 offenbart, dass sich die Anreize und Umstände für solcherart Innovationen kaum von jenen für Innovationstätigkeiten in anderen technologischen Feldern unterscheiden. Die Hinweise einer mangelnden Marktorientierung von EET-Innovationen kann dahingehend interpretiert werden, dass die Politik der Nachfrageseite (Technologieübernahme) mehr Beachtung schenken sollte — allerdings ist dies eine Hypothese, welche durch rigorosere Untersuchungen noch zu erhärten wäre. Eine fundamentale Rolle für den Innovationserfolg auf Unternehmensstufe spielt weiter das Vorhandensein ausreichend qualifizierter Arbeitskräfte sowie Finanzmittel für solche Projekte. In unseren Resultaten lassen sich keinerlei Indizien finden, dass hier ein Mangel bestehen würde; ein Hinweis, dass sowohl Bildungs- als auch Finanzinstitutionen hierzulande ihre Funktion aus der Sichtweise der Energie-Innovationspolitik in ausreichendem Masse wahrnehmen. Allerdings ist nicht auszuschliessen, dass dieser Befund im Bezug auf den Finanzsektor im Zuge der jüngsten Finanzkrise heute anders ausfallen würde; ein Effekt, welcher unsere Befragung wegen ihres früher gelegenen Referenzzeitraums nicht zu erfassen in der Lage wäre.

Auf der **Nachfrageseite** konnte unsere Wirkungsanalyse in Kapitel 4 bestätigen, dass die bestehenden Fördermassnahmen in ihrer Gesamtheit wirksam sind, um die Adoption neuer Technologien voranzutreiben. Ein weiteres bedeutendes Instrument der Förderpolitik, mit welchem sich Energieeffizienztechnologien indirekt über den Wirkungskanal der induzierten Nachfrage unterstützen lassen — die Bepreisung fossiler Energieträger mittels einer CO_2-Abgabe — konnten wir nicht in unsere Wirkungsanalyse miteinbeziehen, da hierfür offenkundig ein anderer analytischer Ansatz nötig wäre. Mit der angebrachten Zurückhaltung lässt sich jedoch aus Kapitel 2 der Schluss ziehen, dass induzierte Innovation ein wichtiger Wirkungsmechanismus darstellt, von welchem auch die Förderpolitik Gebrauch machen kann. Im selben Kapitel finden wir auch Hinweise auf positive Rückkopplungseffekte der Technologieübernahme: der erstmalige Einsatz einer Technologie ermutigt andere Firmen zum weiteren Einsatz. Dies rechtfertigt eine Unterstützung von Erstanwendern, etwa mittels Pilot- und Demonstrationsprojekten; eine Feststellung, die gleichermassen gilt für sämtliche Untergruppen von Energieeffizienztechnologien, die in Betracht gezogen worden sind. Zusätzlich scheinen "Reputationsanreize" von Bedeutung zu sein: Unternehmen setzen neue, energieeffiziente Technologien ein, weil eine Nachfrage besteht nach Gütern und Dienstleistungen aus umweltschonender oder energiesparender Produktion. Massnahmen, welche zu verbesserter Information, Transparenz und Nachvollziehbarkeit im Kontext freiwilliger Energieeffizienzverbesserungen von Unternehmungen beitragen, stellen somit eine weitere sinnvolle Politikoption dar; insbesondere wo "harte" Politikmassnahmen wie Vorschriften oder Energiebesteuerung (bislang) nur eine begrenzte politische Unterstützung erfahren.

Weitere Forschung: Energietechnologien, bedingt durch deren technische Bedeutung und rasche Entwicklung, interagieren potentiell stark mit Entwicklung und Verbreitung von Neuerungen in anderen Technologiezweigen. Einer allfälligen "Innovationsermöglichender" Funktion von Energietechnologien wurde in der ökonomischen Literatur bislang wenig Beachtung geschenkt, trotz deren potentiell wichtigen Bedeutung für Politik und Unternehmungen. Eine interessante Fragestellung wäre demnach, inwiefern die Übernahme neuer Energietechnologien die gesamte Innovationsleistung auf Firmenebene positiv zu beeinflussen vermag; was mittels der Verwendung der bereits im Rahmen der vorliegenden Befragung erhobenen Daten möglich wäre. Gleichermassen interessant wäre die Frage, welche Auswirkungen die Generierung und Übernahme von Energietechnologien im Spezifischen auf Produktivität und Profitabilität auf Firmenebene haben. Die bestehende empirische Literatur hat für Innovationen allgemeiner Art hier zumeist positive Effekte gefunden, was auch im Falle des Unterbereichs von Energieinnovationen gleichermassen, wenn nicht sogar in noch grösserem Masse, der Fall sein sollte.

Chapter 1

The 2009 Energy Technology Survey

The Energy Technology Survey, conducted in the spring of 2009 on the basis of the KOF Enterprise Panel[1], constitutes the empirical foundation of the present research project. Data resulting from this exercise allows for a descriptive overview of technology use in relation with energy efficiency among Swiss enterprises, to be presented in more depth in this chapter; as well as for the three econometric studies, which are the topic of the subsequent chapters.

1.1 Definitions and Structure

An analysis of technological change in an economy, regardless of whether it is specifically concerned with a technology subfield such as energy technologies, may conveniently distinguish between the two phenomena of technological *innovation* (i.e. the introduction on the market or within the bounds of the enterprise of products and processes with somehow improved characteristics by an enterprise) and technology *diffusion* (the application of such new products and processes by firms and households, which might also involve the replacement of obsolete investment goods by improved ones).

Energy is an essential productive input in nearly all economic activity. In certain manufacturing activities, such as metallurgy, cement and in most processes of the chemical industries, energy input is inevitably required for chemical transformations of materials. In other industries as diverse as food, textiles, paper and processing of metals, heat energy is indispensable for changing product characteristics or shape. And the remaining manufacturing activities, which are not characterised by such chemical or thermal energy requirements, typically require some degree of mechanical working of materials and products, which again requires energy. Similarly, most economic activities belonging to the service sector cannot be imagined without significant energetic inputs, as they in-

[1]See http://www.kof.ethz.ch/surveys/structural/panel/ for more details on the KOF Enterprise Panel.

evitably depend on transportation (wholesale and retail trade, logistics and transport), information technology (banking, telecommunications, many business services) or rely on infrastructure whose maintenance in turn requires energy (such as heating, cooling and lighting for buildings). Consequently, no economic branch can a priori be thought as not relevant for the question of how technologies related to the use of energy *diffuse* in an economy.

Changing and, if possible, improving the patterns of use of energy by implementing new technology, in turn, is essentially the result of some *innovative effort*, which may be embodied in investment goods provided by specialised firms (in which case the actual innovation takes place at a location different from the place of its use), or which may be carried out at the place of its application ("in-house" development). In either case, dedicated engineering skills are an essential input in this innovative process, unless we are interested in innovations of the non-technological kind, which is not the case in this study, even if this constitutes an interesting topic in itself.[2] This means that *innovation* in energy technology — carrying out R&D, and successfully putting into place new such products and processes either in order to market them or for in-house use — is an economic activity that only occurs in some dedicated firms, belonging to a narrow set of economic branches.

In order to distinguish between *innovation* and *application* of energy technology in our survey, separate sections on the questionnaire are concerned with each respective phenomenon, so that participants were asked to provide information for both activities separately. For organisational purposes, however, one single version of the questionnaire, featuring respective sections dedicated to both phenomena, was sent to all enterprises in the sample, regardless of their economic activity. The questionnaire, in its German version, is included at the end of this report for reference.

Keeping in mind the research project's goal — to better understand *processes of diffusion and innovation in the context of new energy technologies*, namely those of interest for a *successful energy and climate policy* and *growth and international competitiveness* — the need for a more precise definition or delimitation of technologies relevant for the survey emerges. It was decided that providing a list of readily identifiable, narrowly defined *technology applications* on the questionnaire best suits this requirement, for the following reasons:

- Letting each survey respondents not only specify *that* they were users or innovators of energy technologies of interest, but also more precisely *what* kind of such technologies were the object of their use or innovation efforts, allows to collect information at a more detailed level and, subsequently, carrying out more targeted analysis.

[2]Such non-technical innovations can be of the organisational kind (training programmes for employees that help reduce energy consumption, e.g. destined to improve ecologically sound driving skills) or of the management kind (e.g. developing advertising strategies to specifically promote household appliances that are energy efficient).

- An explicit listing of various kinds of concretely identifiable technology applications can be expected to be easier to understand by respondents (especially those with limited technical background) than a definition of technologies fulfilling some possibly abstract criteria (such as *improved energy efficiency*, or substitution of *depletable energy carriers* by *renewable* ones).

Nevertheless, the questionnaire intentionally delimits the group of users of the various technology applications in question by stating that firms should declare themselves as adopters (or innovators) of the respective technologies only if the latter are *energy-saving*, so that the simple fact of e.g. purchasing technical equipment that consumes electricity, without having contributed to an improvement of the firms' *energy efficiency* (in the sense that less energy input is required for a given output), does not qualify a survey participant as an adopter of new energy technology. Likewise, those questions concerning technology applications related to the generation of electricity and heat distinguished between different energy carriers and featured specific items for efficiency features (such as combined heat and power, heat pumps and heat recovery systems).

1.2 Sample, Response Rates and Weights

Table 1.1 provides an overview of the structure of both the final sample (enterprises that were contacted and ultimately found to be potential respondents) and actual response turnout, each in absolute numbers. The response rate — defined as the quotient of the two — is shown in table 1.2. A number of 2306 firms submitted valid questionnaires, resulting in an average response rate of 39.7%, which is fairly good result for surveys of this kind. Both the actual number of responses and the response rates are higher for manufacturing in comparison to services, probably reflecting a higher degree of awareness and economic importance of energy technology and usage among managers of manufacturing firms. In the course of the survey, we attempted to avoid large differences in response rates across different branches and size classes by conducting a targeted telephonic recall action.

Individual observations in the respondent set have been assigned statistical weights according to their probabilities *(a)* of being sampled and *(b)* of actually responding, once contacted. The first parameter is easily computable, since both the KOF Enterprise Panel's reference population and its actual composition are known.[3] With regards to *(b)*, a statistical (Probit) model has been estimated to predict response probabilities, in accordance to standard practice with surveys from the KOF Enterprise Panel. The descriptive statistics of this chapter that follow have been calculated using these weights

[3]Essentially, private sector enterprises with more than five full-time equivalent employees, with the exclusion of the primary sector (agriculture, forestry, fishing and mining), make up the reference population. Enterprise Census data provided by the Swiss Federal Office of Statistics has been used to determine both the composition of the reference population and to randomly draw enterprises in order to construct and keep up to date the KOF Enterprise Panel.

Table 1.1: Energy Technology Survey — Composition of Sample and Returned Questionnaires

	Sample				Returned			
	S	M	L	Total	S	M	L	Total
Manufacturing	1355	1073	270	2698	586	442	136	1164
Food, Beverage, Tobacco	84	109	21	214	35	51	12	98
Textiles	25	19	14	58	10	5	9	24
Clothing, Leather	11	9	3	23	7	3	0	10
Wood Processing	48	39	5	92	20	14	3	37
Paper	22	18	15	55	11	7	7	25
Printing	65	75	23	163	26	27	15	68
Chemicals	154	53	9	216	64	17	4	85
Plastics, Rubber	41	45	16	102	20	23	9	52
Glass, Stone, Clay	39	38	17	94	20	14	7	41
Metal	29	31	7	67	11	17	3	31
Metal Working	158	136	63	357	73	62	32	167
Machinery	226	187	28	441	101	79	14	194
Electrical Machinery	79	60	7	146	30	23	5	58
Electronics, Instruments	191	95	4	290	87	39	0	126
Watches	66	59	5	130	20	20	0	40
Vehicles	37	21	4	62	9	11	2	22
Other Manufacturing	37	44	20	101	13	15	9	37
Energy, Water	43	35	9	87	29	15	5	49
Construction	240	244	87	571	69	101	33	203
Services	1436	884	220	2540	522	332	85	939
Wholesale Trade	195	204	67	466	72	75	25	172
Retail Trade	380	92	5	477	120	27	2	149
Hotels, Catering	137	142	51	330	35	55	15	105
Transport	234	103	2	339	99	42	1	142
Banks, Insurance	221	83	4	308	94	32	3	129
Real Estate, Leasing	12	18	10	40	7	6	5	18
Computer Services	43	48	33	124	18	19	13	50
Business Services	185	173	24	382	70	70	9	149
Personal Services	7	8	22	37	2	2	10	14
Telecommunication	22	13	2	37	5	4	2	11
Total	3031	2201	577	5809	1177	875	254	2306

Notes: S/M/L stand for Small/Medium/Large enterprises. Definitions for size classes vary across the different branches according to criteria of optimum sample stratification. See the subsequent chapters for descriptive tables of composition of respective samples relying on constant definitions of size classes.

taking into account disproportionate sampling and varying response probabilities across different strata. A specific survey among non-respondents, which might contribute to alleviate the potential bias incurred by *unit nonresponse*, has not been conducted, given the inherent complexity of the topic and the difficulties this would have caused to obtain meaningful information from non-respondents. However, comparable surveys conducted on the basis of the KOF Enterprise Panel in recent years, where such a non-response survey had been undertaken, have generally not given rise to dramatic changes in either qualitative or quantitative findings, even in those cases where there was evidence for some bias attributable to unit non-response.

Table 1.2: Energy Technology Survey — Response Rates (%)

	S	M	L	Total
Manufacturing	43.2	41.2	50.4	43.1
Food, Beverage, Tobacco	41.7	46.8	57.1	45.8
Textiles	40.0	26.3	64.3	41.4
Clothing, Leather	63.6	33.3	0.0	43.5
Wood Processing	41.7	35.9	60.0	40.2
Paper	50.0	38.9	46.7	45.5
Printing	40.0	36.0	65.2	41.7
Chemicals	41.6	32.1	44.4	39.4
Plastics, Rubber	48.8	51.1	56.2	51.0
Glass, Stone, Clay	51.3	36.8	41.2	43.6
Metal	37.9	54.8	42.9	46.3
Metal Working	46.2	45.6	50.8	46.8
Machinery	44.7	42.2	50.0	44.0
Electrical Machinery	38.0	38.3	71.4	39.7
Electronics, Instruments	45.5	41.1	0.0	43.4
Watches	30.3	33.9	0.0	30.8
Vehicles	24.3	52.4	50.0	35.5
Other Manufacturing	35.1	34.1	45.0	36.6
Energy, Water	67.4	42.9	55.6	56.3
Construction	28.7	41.4	37.9	35.6
Services	36.4	37.6	38.6	37.0
Wholesale Trade	36.9	36.8	37.3	36.9
Retail Trade	31.6	29.3	40.0	31.2
Hotels, Catering	25.5	38.7	29.4	31.8
Transport	42.3	40.8	50.0	41.9
Banks, Insurance	42.5	38.6	75.0	41.9
Real Estate, Leasing	58.3	33.3	50.0	45.0
Computer Services	41.9	39.6	39.4	40.3
Business Services	37.8	40.5	37.5	39.0
Personal Services	28.6	25.0	45.5	37.8
Telecommunication	22.7	30.8	100.0	29.7
Total	38.8	39.8	44.0	39.7

Notes: S/M/L stand for Small/Medium/Large enterprises. Definitions for size classes vary across the different branches according to criteria of optimum sample stratification. See the subsequent chapters for descriptive tables of composition of respective samples relying on constant definitions of size classes.

1.3 Descriptive Results

Figures 1.1 and 1.2 visualise the respective shares of firms in different branches of manufacturing and construction/services that have applied at least one of the energy efficient technologies listed on the questionnaire within the five years up to the time of the survey. Technology application tends to be higher in the manufacturing (roughly 50%) than in the construction and service (40%) sector. Besides the energy sector which, little surprisingly, exhibits the largest proportion of technology users, plastics/rubber, vehicles and food/beverages/tobacco are branches where energy efficient technologies are extensively used. Among the service branches, telecommunications and transport rank highest.

As far as the different technology applications featured on the questionnaire are con-

Figure 1.1: Share of Users of EET (%) — Manufacturing

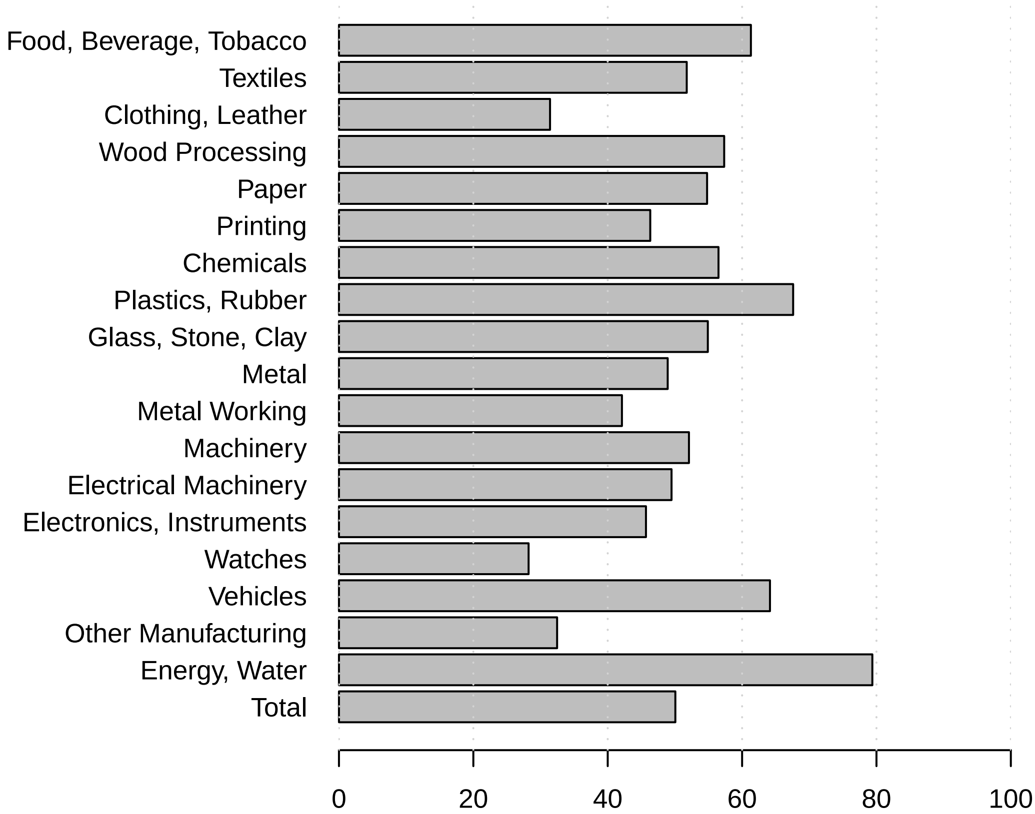
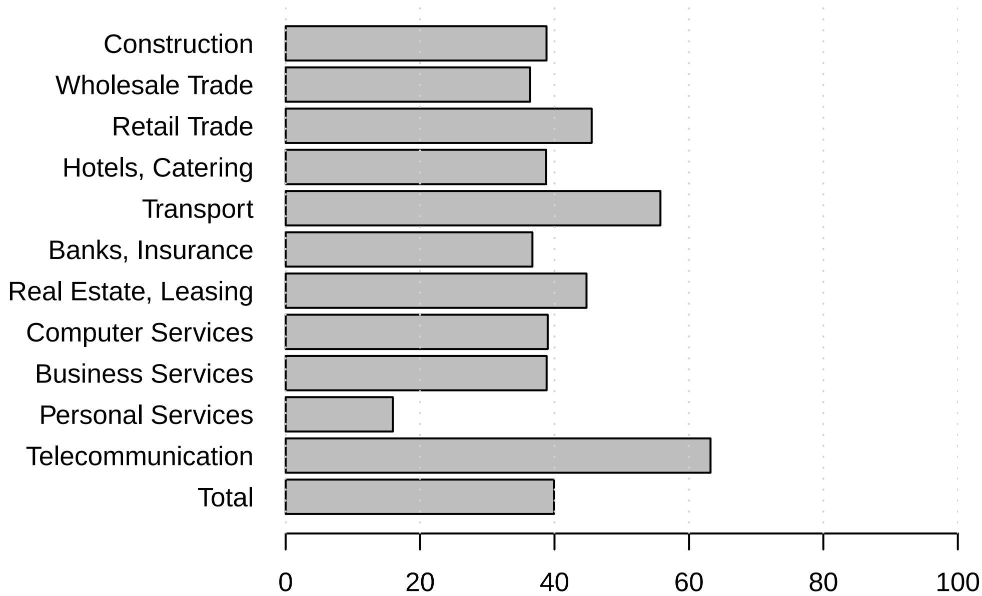


Figure 1.2: Share of Users of EET (%) — Construction and Services



cerned, the degree of use varies considerably, as figure 1.3 reveals. Among the technology applications in energy use, those loosely related to the maintenance of built-up surfaces

Figure 1.3: Share of Users of EET in Energy Use (%) — By Technological Application

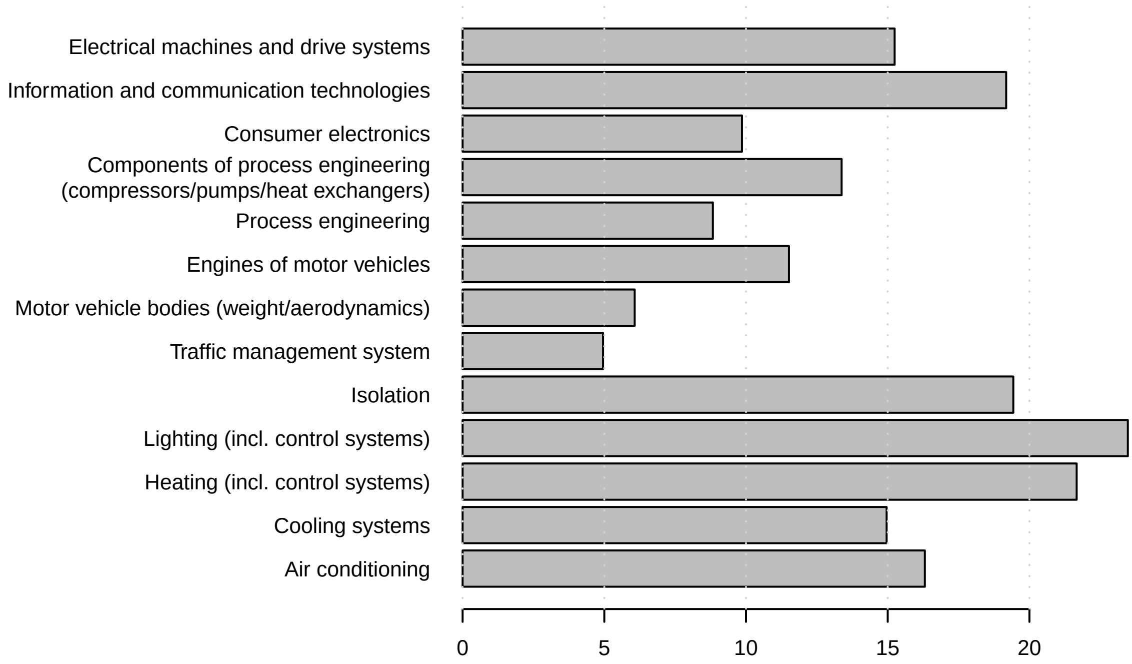
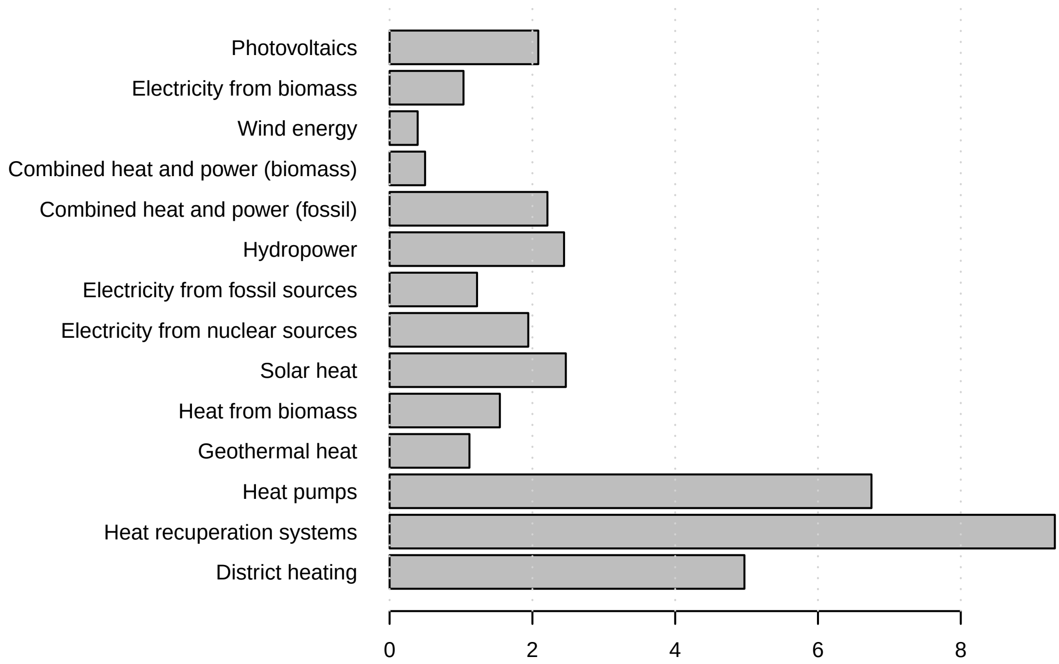


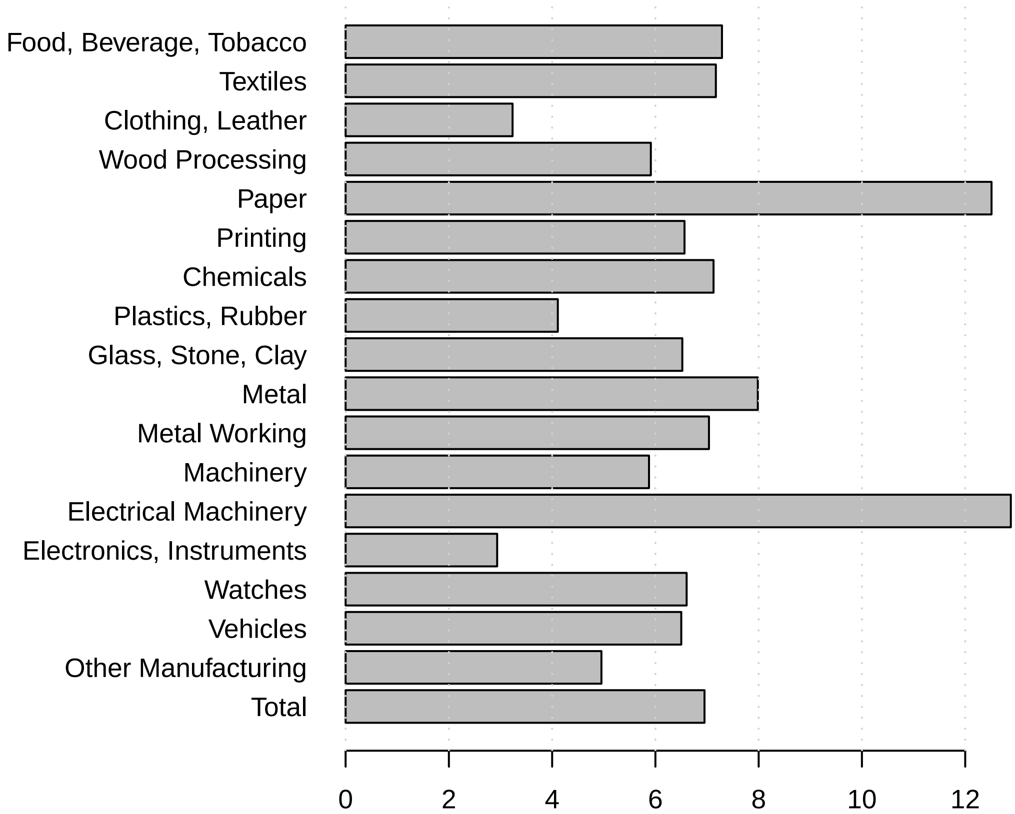
Figure 1.4: Share of Users of EET in Energy/Heat Production (%) — By Technological Application



(comprising isolation, lighting and everything associated with temperature regulation in buildings and/or production spaces) are the highest ranking, each application being present among at least 15% of all enterprises. Technologies used for mechanical, electronic and more generally in industrial process purposes, all appearing at the top of table 1.3, are still fairly widely used, whereas technologies related to efficient energy use in vehicles are present in fewer firms. As an overall impression, the most widespread technology applications are those that are feasible at a small scale and where the number of potential users is large; such as lighting, which can be expected to be relevant to all firms in some place, and where a quarter of firms are found to have implemented energy efficient technology.

Technology applications for production of energy and heat are less widely used — none of the individual applications exhibits a user base of more than 10% here, as figure 1.4 shows. The wider used items here are those allowing for more efficient or distributed use of heat, namely heat pumps, heat recuperation systems and district heating. No discrimination has been made here between the possible end uses of heat (process heat or heating of buildings). It comes as no surprise that only a small number of enterprises report to be users of the typical large-scale electricity generating technologies.

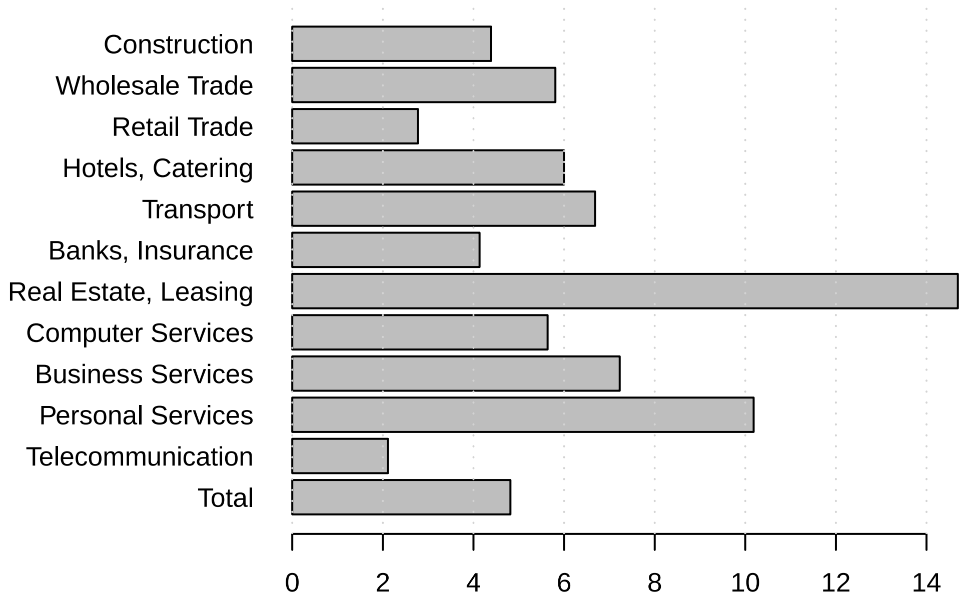
Figure 1.5: Share of Investments Dedicated to EET (%) — Manufacturing, Excluding Electricity Providers



The industry of electricity providers is not featured in the figure, as its extraordinary value of 48% would have made the visualisation more difficult.

An impression of the *quantitative* economic importance of the application of energy

Figure 1.6: Share of Investments Dedicated to EET (%) — Construction and Services

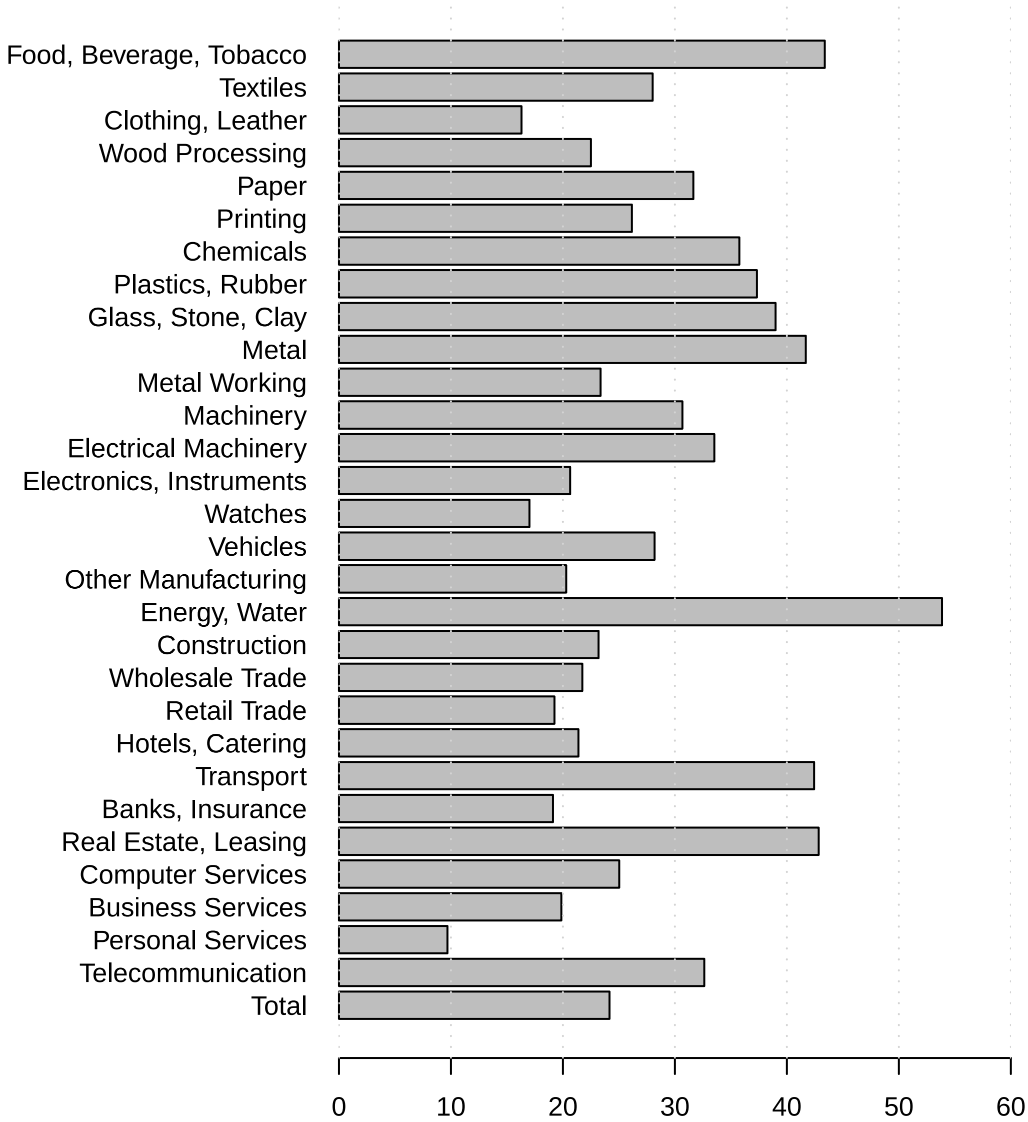


Real Estate and Telecommunications: Estimated values are imprecise due to small number of observations.

efficient technology can be obtained by looking at the mean share of firms' total investments dedicated to acquiring such technology. Figures 1.5 and 1.6 plot these shares for the manufacturing and construction/service sectors respectively. The high value for paper (an energy intensive industry) seems plausible, for electrical machinery a little less so. Plastics and rubber turns out to be less inclined to adopt energy efficient technologies in this figure than the (qualitative) indicator used in figure 1.1 would suggest. Otherwise, the variation across industries follows a fairly similar pattern between figures 1.5 and 1.1; which is encouraging news, given that the econometric analysis of the subsequent chapter mainly relies on qualitative indicators (whether firms have adopted EET or not) to measure firms' and industries' inclination towards such technologies. This is a little less the case in the construction/services sector (comparing figures 1.6 and 1.2). However, part of the variability in the latter figure is due to measurement imprecisions resulting from the low number of observations where quantitative values for EET investments are actually available from respondents.

The effect on CO_2 emissions of applications of energy efficient technologies, despite not being the main focus of this project, is of vital ecological and political importance. When asked whether energy efficient has been introduced and at the same time contributed to a reduction of CO_2 emissions within the firm, roughly a quarter within the total population responded affirmatively, with some considerable variation across industries, according to figure 1.7. Naturally, shares are high in industries that are important users of fossil fuels or release CO_2 as a result of their typical chemical pro-

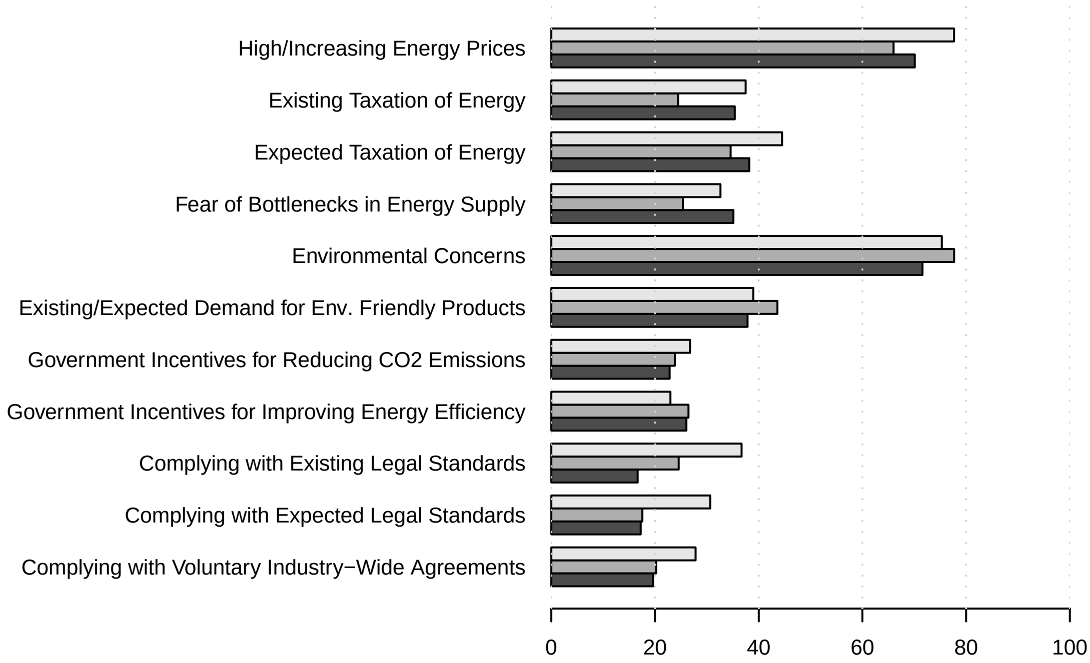
Figure 1.7: Share of Firms Having Reduced their CO_2-Emissions Following the Introduction of EET (%)



cesses — glass/stone/clay, metal, transport, real estate and lending (the high value for food/beverage/tobacco being a slight oddity). In industries where this is less the case, lower mean values appear, in accordance with the formulation chosen on the questionnaire that only CO_2 emission reductions *within* the firm should be reported.

The questionnaire also asked firms to report their motives for the introduction of energy efficient technologies (only EET adopters) as well as any obstacles that discouraged them from or significantly complicated the process of employing any of these technologies. Motives are displayed in figure 1.8, distinguishing between small, medium and large sized firms. Two motives present in a large majority of all firms — nearly three quarters of them — are *energy prices* and *environmental concerns*. All of the remaining motives on the list are mentioned far less frequently. There seems to be a slight tendency

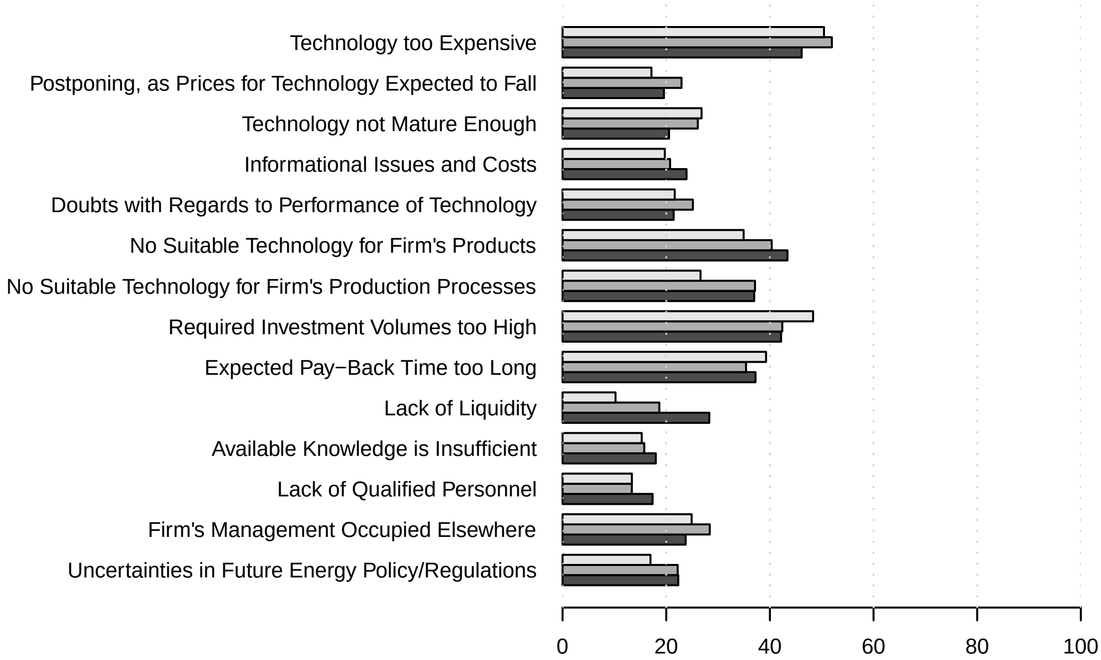
Figure 1.8: Motives for the Introduction of EET: Respective Share of Firms Expressing a High Priority Rating (%)



Different shades of gray for size classes: less than 50 full time equivalent (FTE) employees (dark); 50-250 FTE employees; more than 250 FTE employees (bright).

of smaller firms to respond to "government incentives" for reducing CO_2 emissions or improving energy efficiency more readily, whereas larger firms report "complying with legal standards" (and industry agreements) more often. As far as obstacles are concerned (see figure 1.9), financial considerations seem to dominate ("technology too expensive", "investment volumes too high", "expected pay-back too long"); besides the responses that "no suitable technology" fits the firms products and processes, a response that can be mostly expected for firms that use little energy to begin with and see it as a small concern to further reduce their energetic requirements. The largest discrepancies between small and large firms can be found for the item "lack of liquidity", where small firms seem affected disproportionally.

Figure 1.9: Obstacles Encountered During Introduction of EET: Respective Share of Firms Expressing a High Priority Rating (%)



Different shades of gray for size classes: less than 50 full time equivalent (FTE) employees (dark); 50-250 FTE employees; more than 250 FTE employees (bright).

Chapter 2

Factors Determining the Adoption of Energy-saving Technologies in Swiss Firms — An Analysis based on Micro Data

2.1 Introduction

Energy efficiency and energy policy have been high on the agenda of economic research in recent years. Moving towards an economy that uses energy in a more sustainable manner will remain a major challenge to enterprises and policymakers for the near and future and beyond, despite the obvious difficulties encountered by international politics to agree on binding reduction targets for greenhouse gas emissions. It is clear that the implementation of technologies and practices that increase firms' and households' energy efficiency – that is to say, which enable to produce or provide given amounts of goods or services using less energy inputs – are of crucial importance to meet this challenge. Only then can we expect to maintain the high level of standard of living industrialised countries enjoy today and developing countries are striving to catch up with.

This paper attempts to shed light on the driving forces of the diffusion of ready-to-use energy efficient technologies among firms. As remarked by Battisti (2008), much of the existing literature on new technology (and, specifically, green technology) solely focuses on the R&D and innovation stage, rather than the actual diffusion of such technology among final users. This seems odd, given the observed fact that "the diffusion of a technology is a very slow and heterogeneous process and this is true (...) for green technologies that are notoriously slower than traditional technologies at diffusing within and across firms" (Battisti 2008, p. S29). In the same survey, the author raises concern that empirical research so far has mostly neglected the patterns of intra-firm diffusion of new technologies, largely due to data restrictions.[1]

Moreover, several academics (Popp et al. 2009 provide a survey) and practitioners (most prominently, McKinsey & Company with their "Greenhouse gas abatement cost curves" initiative[2]) have pointed to the fact that adoption of energy-saving technologies among firms takes place slowly or not at all even in cases where the potential private gains (through lower energy input requirements or related cost savings) outweigh the associated costs. In a more long-term and macro-oriented setting, some narrative and empirical findings likewise suggest that increased involvement in green technology (or, specifically, energy efficiency) may have noticeable welfare-enhancing effects rather than causing net costs or decreasing a country's competitiveness (see, for instance, Cadot et al. 2009 for a cross-country, cross-industry survey on the topic).

However, we deem it important to better understand the patterns of diffusion of energy efficient technologies; given that potential market failures (the existence of which many of these studies suggest) might encourage stronger policy measures for technology adoption in the future.

A remarkable body of literature related to the adoption of cleaner technologies has been accumulated over the past fifteen years, yet many open questions remain. In a broad survey of studies dealing with the subject, Montalvo (2008) has identified several difficulties such analyses are confronted with: the multitude of factors potentially affecting the adoption decision at the firm level, and the limited availability of longitudinal data which severely restricts the possibility to investigate the dynamics of diffusion processes. In addition, findings of industry-specific surveys often cannot be generalised to the whole economy, and for some time research of technology diffusion has been divided in different streams that are difficult to reconcile with each other.

A further branch of literature focuses on the slowness of the dissemination of technologies that enhance energy efficiency and analyzes the reasons for the "energy-efficiency gap" that presumably exists between actual and optimal level of energy efficiency (see, e.g., Jaffe and Stavins 1994 and DeCanio 1993). As a consequence empirical research in some papers concentrates on the potential barriers of the diffusion of energy-saving technologies, thus neglecting other important factors that may impact the adoption rate (see, e.g., De Groot et al. 2001; DeCanio 1998; and Reddy and Painuly 2004).

We attempt to relieve some of these difficulties by drawing on a new dataset of Swiss firms that has been collected by means of a survey specifically designed to this task, covering a broad range of particular energy efficient technologies as well as stemming from a wide spectrum of enterprises covering the industrial (including energy and water) as well as the construction and service sectors. Despite the cross-sectional nature of our data, which evidently limits the possibilities to conduct truly dynamic analysis, we are

[1] However, the fact that The Journal of Cleaner Production dedicated a special issue to the diffusion of cleaner technologies (Volume 16, Issue 1, Supplement 1, pp. S1–S184) shows that there is an increasing interest for this subject.

[2] http://www.mckinsey.com/clientservice/ccsi/costcurves.asp

capable of implementing an econometric approach that allows some inference about market and non- market intermediated externalities as well as differentiating between the inter-firm and intra- firm aspects of technology diffusion.

The paper is structured as follows. In section 2 the theoretical background and the model specification are presented. In section 3 the data used in this study are described. Section 4 contains descriptive information about the inter-firm and intra-firm adoption rates of the energy-saving technology applications analyzed in this study. In section 5 the empirical results are presented and discussed. Section 6 contains a summary and some conclusions.

2.2 Framework of Analysis

2.2.1 Theoretical Background

In a recent paper Battisti et al. (2009) presented an integrated model of diffusion that integrates the analysis of inter-firm and intra-firm diffusion, mostly modelled separately, in an encompassing framework, in which inter- and intra-diffusion are treated simultaneously.[3] This study is an extension of Karshenas and Stoneman (1993) and subsequent work of Battisti (2000). This model builds the main base for our conceptual framework. According to equation (3a) in Battisti et al. (2009, p. 136) $A_i^*(t)$, the firm's desired or optimal level use of new technology in time t, i.e. the desired extent of both inter- and intra-firm diffusion, is a function of the following factors:

1. Characteristics of a firm i (a vector $F_i(t)$ of variables that have to be specified) and its environment (a vector $F_j(t)$ of variables for industry j that have also to be specified) reflecting rank effects. The cause for rank effects is firms' heterogeneity leading to differing returns to adoption and thus differing reservation prices (see, e.g., Davies 1979 and Ireland and Stoneman 1986). In this case the inter-firm concept of rank effects is extended to intra-firm technology use. These effects are expected in general to be positive.

2. The extent of industry usage of new technology $SO_j(t)$ capturing inter-firm stock and order effects (i.e. market-mediated externalities[4]). Stock effects are based on the assumption that the returns to technology adoption decrease with the number of firms utilizing this technology (see, e.g., Reinganum 1981). Order effects depend also on the number of adopters but specifically at the time of adoption. For a certain level of adoption costs at a certain point in time, it is profitable to be the first adopter; as costs decrease with time, adoption becomes profitable also for a

[3]For recent reviews of the literature on the theory of technology diffusion in general see Sarkar (1998) and Geroski (2000).

[4]External effects mediated by the market are so-called "pecuniary externalities" that arise from direct pecuniary benefits to users; external effects that are not mediated by the market are so-called "technological externalities" and encompass indirect benefits through learning effects (see Battisti et al. 2009, p. 141 and further literature cited there).

second firm, then a third, and so on (see, e.g., Fudenberg and Tirole 1985). In general, these effects are expected to be negative, unless positive network effects are strong enough to outweigh them.

3. Positive epidemic effects (i.e. learning and network non-market intermediated externalities) reflecting either the firm's own experience with the new technology $E_i(t)$, often proxied by the time since the firm's first adoption, or the experience gained from observing other firms $E_j(t)$ (often proxied by the extent of technology diffusion in time t).

4. The expected adoption cost of a unit technology $P_i(t)$ constituting of two parts, one common to all firms, e.g., the price of machines, and a second one reflecting firm-specific adjustment and installation costs.

In accordance to the particular conditions of the introduction of energy-saving technologies in Switzerland (as in many other countries) also elements of the literature on induced innovation and technology diffusion (see, e.g., Binswanger 1974) are taken into consideration. The diffusion of energy-saving technologies can be positively influenced (a) through increases of energy prices and/or taxes (see, e.g., Linn 2008 and Jacobs et al. 2009) and (b) through public regulation and/or public incentives to use energy-saving technologies (see, e.g., Popp et al 2009). We consider a vector $IA_i(t)$ of variables that capture the influence of such factors (inducement effects). These variables are reflecting both firm-specific (e.g., due to high share of energy costs; due to value-oriented "intrinsic" effects) and industry-specific or economy- wide effects (e.g., due to high energy prices).

A formal expression of the relation of between the optimal level of use of new technology and the factors presented above is as follows:

$$A_i^*(t) = G[F_i(t), F_j(t), SO_j(t), E_i, E_j, P_i(t), IA(t)] \tag{2.1}$$

As expressed in the above equation, the adoption of new technology as well as the more intensive use of it build a dynamic process. However, since we dispose of data only for a single cross-section, is not possible to specify a dynamic model. Instead, we apply a static version of the model to investigate the determinants of the diffusion of energy-saving technologies in the Swiss business sector in the year 2008. As a consequence, the variable $E_i(t)$ reflecting the firms' individual experience of the new technology cannot be measured in single cross-section and has to be ignored.[5] The finally operative expression of equation (2.1) after dropping the time subscripts is as follows:

$$A_i^* = G[F_i, F_j, SO_j, E_j, P_i, IA] \tag{2.2}$$

[5]However, it would be possible to control for $E_i(t)$ for those firms in the sample that reported the adoption of single technology applications in both periods, before and after 2004.

2.2.2 Model Specification

We specified an empirical model that contains the same determinants for both inter- and intra- firm diffusion. Table 2.1 describes the adoption variables used in this study. Table 2.2 gives an overview of the variables used as determinants of adoption.

We used the following variables to measure firm-specific rank effects F_i:

Factor endowment. A firm's factor endowment, especially its endowment with human capital and know-how, is an important factor determining the firm's ability to adequately utilize new technologies. Capital intensity is measured by gross investment per employee (LN_INVEST/L), human capital intensity is measured by the share of employees with tertiary-level education (HQUAL), know-how intensity is measured by the ability to generate new knowledge as reflected in the existence of permanent R&D activities (R&D). We expect positive effects for all three variables.

Firm size. Here measured by the number of employees in full-time equivalents (LN_EMPL) firm size may capture firm-specific characteristics relevant for the technology adoption that are not specified in this model, such as management abilities, scale economies etc. This variable has been widely used as a determinant of technology diffusion in earlier studies; most of these studies have found, at least for the case of inter-firm diffusion, a positive effect of firm size on diffusion (see, e.g., Karshenas and Stoneman 1995 for a survey of this literature). There is a further line of argumentation stating that due, e.g., to managerial diseconomies of scale larger firms, once they have adopted a new technology, tend to use it less intensively than smaller ones; in this case a negative effect of firm size on intra-firm technology adoption is expected (see, e.g., Fuentelsaz et al. 2003).

Export activities. Here measured by a dummy variable (export activities yes/no; EXPORT) may indicate an above-average propensity to adopt new technology in order to keep high its international competitiveness. A positive effect on diffusion is expected. Foreign-ownership. Here measured by a dummy variable (foreign-owned firm yes/no; FOREIGN) indicates whether a firm is controlled by a foreign parent company. We expect in general a higher than average propensity of foreign-owned firms to adopt new technologies. However, depending on the conditions in home country foreign-owned firms may react differently as domestic firms to public regulation and/or incentives with respect to energy- saving in the host country. As a consequence, the sign of this variable is not a priori clear.

To measure rank effects as to the firm's market environment F_j we considered the following variables:

Demand prospects: Positive demand expectations (DEMAND) as perceived by the firms themselves may enhance the propensity to adopt new technologies because firms expect to distribute acquisition costs on a larger volume of products.

Competitive pressures: A well-known line of argument argues that it is the elasticity of demand faced by a firm in its specific market that induces innovative or imitative activity (see Kamien and Schwartz 1970 for the original argument). In those markets where competition pressure is greater, demand elasticity can be expected to be higher because of the existence of close substitutes, thus driving firms to innovative activity or rapid new technology adoption (see, e.g., Majumdar and Venkataaman 1993). In accordance to this line of reasoning, we proxied competitive pressures through the intensity of price (IPC) and non-price competition (INPC) on the product market (as perceived by the firms themselves) and expect a positive relationship to the propensity to adopt new technology.

In order to control for *epidemic effects* E_j we use two variables, one measure for inter-firm effects (share of firms having adopted new technology in the industry subsector the firm is affiliated (INTER_...), and a second one for intra-firm effects (mean of the firms' adopted technology applications in the industry sub-sector the firm is affiliated (INTRA_...) (see table 2.2 for more details about the variable construction).[6]

In a cross-section analysis, inter-firm epidemic effects E_j cannot be distinguished from inter- firm order and stock effects SO_i. Therefore, the estimated coefficients of these two variables measure the net effects, which may be positive (dominance of positive non-market intermediated epidemic effects and market intermediated network effects) or negative (dominance of the stock and order effects) or insignificant (the two opposite effects are equally strong), although it is not possible to say to which type of positive network effects the net positive effect is traced back.

To measure (indirectly) firm-specific adoption costs P_i we used a group of variables indicating various barriers to the adoption of energy-saving technologies that would postpone or even hinder completely the adoption of new technology because of different types of costs. We identified four groups of such barriers based on principal component factor analysis of 14 single obstacles of adoption, the importance of which has been assessed by firms on a five- point Likert scale (see table 2.2 and table 2.14 in the appendix for more details): (a) lack of compatibility with current product programme or current production technology (high adjustment costs due to high sunk costs) (COMPAT); (b) too high investment expenditures, too low liquidity (high financing costs) (FIN); (c) information and knowledge barriers (information costs) (INFO); and (d) organizational and managerial barriers (ORGAN). We expect such barriers to be negatively correlated with adoption.

In order to measure inducement factors IA_i, we add the following variables to the model: (a) the sales share of energy costs as indicator of high reactivity to energy prices and/or taxes; (b) a variable indicating the a firm's willingness to take environmental criteria into consideration for procurement of intermediate inputs and reflecting its "intrinsic" motivation; and (c) a group of variables indicating various motives that would induce the adoption of energy-saving technologies. We identified four groups of such

[6] It could be argued that such a variable is possibly only weakly exogenous or even endogenous because it is contemporaneous to the dependent variable. Unfortunately data limitations do not allow the construction of a lagged variable.

motives based on principal component factor analysis of 11 single motives for adoption, the relevance of which has been assessed by firms on a five-point Likert scale (see table 2.2 and table 2.15 in the appendix for more details): (i) (expected) increases of energy prices and/or taxes that would enhance the propensity of the adoption of energy-saving technologies; (ii) (expected) public incentives for energy efficiency and / or CO_2 reduction (PUBLIC_ INCENT); (iii) (expected) public regulations and/or agreements between firms and government agencies with respect to energy efficiency (PUBLIC_REGUL); and (iv) other motives such as the (expected) increase of demand for environment-friendly products, expected energy bottlenecks or the "intrinsic" motivation for environment-friendly behaviour. We expect positive effects for the four motive variables.[7]

2.3 Data

The data used in this study were collected in the course of a survey among Swiss enterprises in the year 2009 using a questionnaire specifically designed for this survey that included besides questions on some basic firm characteristics (sales, exports, employment, investment and employees' vocational education), questions on energy-saving activities as well as on motives and obstacles of such activities.[8] The survey was based on a (with respect to firm size) disproportionately stratified random sample of firms with at least 5 employees covering all relevant industries of the manufacturing sector, the construction sector and selected service industries (on the whole 29 industries and within each industry three industry-specific firm size classes with full coverage of large firms). The final data set includes 2324 enterprises from all fields of activity and size classes (see table 2.10 in the appendix for the structure of the used data set by industry and firm size respectively)[9].

2.4 Descriptive Analysis

2.4.1 Preliminary Remarks

Based on information of the International Energy Agency (see IEA 2008) we distinguished four groups of energy-saving technology applications (see table 2.3 and table 2.4): (a) electromechanical and electronic applications (e.g., energy-saving in machines either by substitution for more energy efficient machines or by modification of already installed machines towards more energy efficiency); (b) applications specific to motor vehicles and traffic engineering; (c) applications in building construction; and (d) applications in power- generating processes. Each of these four main groups of energy-saving technology applications were further divided to more specific categories of applications,

[7]These variables are available for adopting firms only.

[8]Versions of the questionnaire in German, French and Italian are available at www.kof.ethz.ch.

[9]Table 2.11 in the appendix shows the descriptive statistics for all variables used in this study; table 2.12 shows the respective correlations matrix.

e.g., we distinguish under the heading applications of type (d) heat pumps, heat recuperation systems and combined heat-and-power generation based on biomass or gas/ carbon. We measure inter- firm diffusion by the binary variable “adoption of at least one energy-saving technology application in one of the technology fields defined in table 2.3 in a certain point of time: yes/no” (see also table 2.1). Intra-firm diffusion is measured by the number of technology applications of a certain technology field defined in table 2.3 adopted by the firm in a certain point of time (see also table 2.1).

2.4.2 Inter-Firm Diffusion

On the whole more than 50% of all responding firms reported at least one of the energy-saving technology application defined in table 2.3 and table 2.4. About half of them (51.1%, i.e. 27.3% of all firms) have introduced such technologies already before 2004. 92.3% of technology adopting firms, i.e. 49.3% of all firms, have either introduced such technologies for the first time or expanded the use of them in the year 2004 and later. A similar pattern is found also for most of single technology applications. In sum, according to these data the adoption of energy-saving technologies is a rather new phenomenon. Inter-firm diffusion has been intensified in the last five years.

The most frequently reported applications were related to building construction (type (b); 45.0% of all firms). 70.5% of such applications (i.e. 31.7% of all firms) referred to building lighting; building heating (69.1%, i.e. 31.1% of all firms) has been an equally important domain for energy-saving. The high percentage of such technology applications can be explained by the fact that building-related energy-saving is widely applicable in all sectors of the economy.

39.6% of all firms used energy-saving technology applications of category (a), primarily in components of process engineering (compressors, pumps, heat exchangers, etc.), electrical machines and drive systems as well as in information and communication technologies (about 62% of them in each sub-group, i.e. about 25% of all firms).

Energy-saving technology applications in transport (category (b); 18.3% of all firms) or power-generating processes (category (d); 21.7% of all firms) have been much less frequently introduced than energy-saving technologies in the categories (a) and (c). For category (d) is obvious that only for larger firms can be efficient to generate their own power and not buy it. It is remarkable that power-generating technologies based on non-fossil energy sources that also reduce CO_2-immissions are rather rare: only 5.0% of firms with applications of category (d) (i.e. 2.0 of all firms) reported the use of combined heat-and-power generation based on biomass.

The fact that many firms reported the use of energy-saving technology applications in more than one of the four technology categories considered in this study shows that a parallel use of such technology applications is a frequent firm practice that indicates a kind of complementarity of the different technology categories with respect to a total firm energy- saving goal.

All these technology applications reflect energy-saving in production processes as well as in products. Process applications are presumably dominant in the service industries and in manufacturing industries such as food, clothing and textile, wood processing, chemicals, plastics, metals and glass, stone and clay. Both types of applications are used in the industries producing primarily capital goods (machinery, electrical machinery, electronics and instruments and vehicles).

2.4.3 Intra-Firm Diffusion

In this study intra-firm diffusion cannot be measured as in studies referring to a single technology (for example, IT for E-commerce) by an intensity measure (for example, sales share by E-commerce). Thus, we apply a wider concept of intra-diffusion based on the number of technology applications (belonging to one of the four categories distinguished here) used in the firm.[10]

55.5% of the firms using technology applications of category (a) reported only 1 or 2 such applications, 44.5% of them 3, 4 or 5 such applications. The shares of firms with only 1 application for the other categories are: 58.5% (type (b)); 42.0% (type (c); and 63.6% for type (d)). These figures show that with the exception of technology applications for construction the intra-firm extent of usage of energy-saving technologies either in production processes or in products is rather limited. A possible explanation for this could be that most firms do not have integrated strategies of energy-saving (see, e.g., Santos da Silva and Amaral 2009) but invest occasionally in the one or the other application field. However, it is a common characteristic to many technologies after their early years that intra-firm diffusion is limited (see Canepa and Stoneman 2004).

2.5 Estimation Method and Empirical Results

2.5.1 Inter-Firm Diffusion

Basic Estimates

In a first step, we estimated a probit model for each of the four groups of energy-saving technology applications that were presented in section 4 (see table 2.5; table 2.16 in the appendix shows the respective marginal effects). Table 2.1 shows the construction of the respective four binary variables, table 2.2 contains the explanatory variables in accordance with the model specification in section 2. Information on adoption motives was available only for adopting firms, therefore the probit estimates in table 2.5 that are based on all firms do not include the adoption motives as variables that measure adoption inducements.

Firm-Specific Rank Effects.

[10] Of course one could define other measures, e.g. number of technology categories or total number of technology applications. In this paper we restrict the analysis to this measure that we think has the larger information content.

We find to a large extent the same pattern with respect to the variables reflecting firm-specific rank effects for all four groups of energy-saving technology applications. Obviously the likelihood that at least one of the technology applications is adopted is driven by the same firm characteristics independent from the specific type of technology applications. Not all firm characteristics included in our variable vector are equally important for technology adoption. With respect to factor endowment the variable for gross investment per employee[11] and the dummy variable for R&D show the expected positive signs and the respective coefficients are statistically significant at the 10% test level. It is not astonishing that R&D activities are more important for electromechanical and electronic applications (group (a)) than for the other three types of technology applications (see the marginal effects in table 2.16 in the appendix). Contrary to our expectations, adopting firms do not use more human capital than non-adopting firms. The insignificant coefficients of the variable HQUAL in table 2.5 indicate that in the case of energy-saving technologies not the percentage of employees with tertiary-level education but rather the existence of R&D activities constitutes a crucial precondition for adopting such new technologies.[12]

Firm size shows the expected (non-linear) positive effect. There are some differences among the various technology types with respect to foreign-owned firms. Foreign firms seem to be less inclined than domestic firms to adopt energy-saving technologies in buildings and energy-generating processes. A possible explanation for this effect is that foreign firms more often than domestic firms do not use own buildings or own energy-generation processes, thus they are not responsible for this kind of investment in energy-saving technologies.[13] Finally, export activities do not appear to be a specific trait of adopting firms.

Most of the studies with a similar theoretical background known to us investigate the diffusion of advanced manufacturing technologies or of information and communication technologies (ICT). For this reason we discuss in the next paragraph the similarities or differences of our results with respect to these studies, in the sense of a test of the range of the validity of the underlying common theoretical approach. In section 5.1.2 we discuss then some studies that deal specifically with the diffusion of energy-saving technologies but not use, at least explicitly, our theoretical approach.

[11]The equations in table 2.5 contain also the dummy variable INVEST/L_0 as control for firms with null gross investment in 2008.

[12]The possibility that multicollinearity effects due to the correlation between the variables R&D and HQUAL ($r = 0.17$) could be responsible for the insignificant coefficient for HQUAl was examined in estimates of all four equations without the variable R&D. The coefficient for R&D remained also in this case statistically insignificant at the 10% test-level. The slightly negative sign of the variable HQUAL in the estimates for the technology applications in group (d) (variable ENERGY) in table 2.5 is not robust, as the estimates of the multivariate probit model in column 4 in table 2.6 (as well as probit estimates without the variable R&D) showed.

[13]We tested the hypothesis that diffusion obstacles, particularly compatibility impediments, may restrain foreign firms stronger than domestic firms. To this end, we inserted in the equation for ENERGY interaction terms of the obstacle variables with the the dumy variable for foreign firms. Estimates not presented here showed no significant effect for the interaction terms.

Most empirical studies on advanced manufacturing technologies – this is one of the fields that have been most intensively investigated in empirical research on technology diffusion – also find positive effects of firm size on inter-firm diffusion (see Karshenas and Stoneman 1995 and Canepa and Stoneman 2004 for surveys of this literature). Recently, also studies on ICT diffusion show similar positive effects (see, e.g., Hollenstein 2004 and Bertschek and Fryges 2002). The evidence for the effect of human capital intensity shows also positive effects on inter-firm diffusion: for example, Battisti et al. (2007) and Battisti et al. (2009) found a positive effect on inter-firm diffusion of ICT for both Swiss and UK firms; Arvanitis and Hollenstein (2001) reported a positive effect on inter-firm diffusion of advanced manufacturing technologies. Less clear is the evidence for in-house R&D and/or innovative activities: these are found to be important by Battisti et al. (2007) for UK firms (but not for Swiss firms), Battisti et al. (2009) for UK firms, Hollenstein and Woerter (2008) and Arvanitis and Hollenstein (2001) for Swiss firms, Arundel and Sonntag 1999 for Canadian firms but not by Colombo and Mosconi (1995) for Italian firms. In sum, the firm-specific rank effects in this study are on the terms explained above in accordance to existing empirical literature.

Rank Effects of Market Environment

Competitive pressures as measured by the intensity of price competition (IPC) are relevant for at least two technology groups, electromechanical and electronic applications (variable MACHINE) and energy-generating processes (ENERGY), also for transport applications (TRANSPORT) (in the estimates in column 2 in table 2.6) but not for building applications (BUILDING). On the whole, competitive pressures seem to have some influence on the propensity to adopt energy-saving technologies, particularly for firms with substantial energy costs that use machinery intensively and/or generate their own power (electricity or heat). Competitive pressures show positive effects on inter-firm diffusion partly in Hollenstein and Woerter (2008) (only for E-purchasing of Swiss firms), also partly in Dholakia and Kshetrei (2004) for US firms and in Arvanitis and Hollenstein (2001) (only for the intensity of non- price competition for Swiss firms) but not in Karshenas and Stoneman (1993) for the UK and Colombo and Mosconi (1995) for Italy.

The third variable that refers to influences of the market environment, the indicator for expected demand DEMAND, seems to be of minor importance (except for building-related technologies).

Stock, order and epidemic effects. The variables for inter-firm diffusion on industry level show positive and significant coefficients in all four equations. Similar effects were found also in earlier studies (see, e.g., Battisti et al. 2009; Hollenstein and Woerter 2008 (only for E- selling); Arvanitis and Hollenstein 2001; Colombo and Mosconi 1995). In contrast to this result, the coefficients for intra-firm diffusion on industry level ("cross-effect") are positive but statistical insignificant at the 10% test-level in three out of four equations in table 2.5, but significantly negative in the equation for adoption of technology applications in power- generating processes (ENERGY). This negative effect means that more intensive use of such technologies by other firms has a downward impact on the likelihood of such technologies being adopted. Existing similar literature has yielded mixed evidence: for example, Battisti et al. (2009) found a positive effect; Hollenstein and Woerter (2008) could not find any significant effect.

In sum, inter-firm epidemic (learning) and network effects seem to outweigh negative effects of stock and order effects leading to positive net effects that enhance the inter-firm adoption rate of energy-saving technologies. This is not the case for intra-firm epidemic (and/or eventually network effects), with the exception of the ENERGY technology applications. Thus, for the introduction of energy-saving technologies relevant is the experience of first use of such technologies in other firms and in most cases not the intensity of usage (for example, the number and width of used technology applications).

Adoption costs. Adoption cots are only indirectly modelled in this study. Our model contains variables for four potential barriers that could increase adoption costs. Lack of compatibility with current product programme or current production technology seems to be the main barrier for firms that hinder them from adopting any kind of energy-saving technologies. The respective variable COMPT has a significantly negative coefficient in all four equations in table 2.5. Contrary to our expectations, we obtained significant but positive coefficients for the variables for financing obstacles (FIN) and for information and knowledge barriers (INFO) also in all four estimates. These findings mean that non-adopting firms seem to anticipate these two types of obstacles less as a problem than adopting firms. This is because technology adoption involves a learning process. Technology users face problems that they assessed to be less severe before the adoption and have to be solved during the adjustment process. We conclude that information on impediments in surveys should not be interpreted as impenetrable barriers. Rather, they often reflect a problem awareness that increases with experience in technology use (see Baldwin and Lin 2001 for a similar line of argumentation based on evidence for technology adoption in Canadian firms). Finally, the fourth group of potential barriers, organizational and managerial impediments, does not seem to have an influence on the adoption rate.[14]

Inducement effects. The level of the sales share of energy costs is positively correlated only with the propensity to adopt energy-saving technologies in power-generating processes. Further, we obtain a positive effect for the second variable for inducement effects ENV_AWARE (reflecting "intrinsic" motivation) in all four equations in table 2.5. Both results can be interpreted as hints that inducement effects are relevant for explaining the adoption rate of such technologies.

[14]Earlier studies using also variables for adoption impediments brought out rather heterogeneous results due to the heterogeneity of the impediments that were considered; see, e.g., Hollenstein and Woerter (2008); Dholakia and Kshetri (2004); Baldwin and Lin (2002); Arvanitis and Hollenstein (2001).

2.5.2 Empirical Studies of Adoption of Energy-Saving Technologies

There are relatively few empirical studies dealing with the diffusion of energy-saving at firm level. Many of these studies do not use the theoretical background of this study (and of other similar studies) but concentrate on the investigation of barriers of diffusion of energy-saving technologies. We discuss here four of them that use firm data for more than one industry. In a study based on data for 285 larger US companies in three energy-intensive industries (plastics; petroleum; and steel) Pizer et al. (2002) investigated the determinants of the adoption of energy-saving technologies in the period 1991-1994. The factors that were found to enhance the adoption rate were firm size, profits and – to a smaller extent – energy prices, De Groot et al. (2001) found in a study for 135 Dutch firms for the year 1998 positive effects on the adoption rate for the energy intensity and the investment ratio in the horticulture industry, the investment ratio and mixed positive and negative effects for competitive pressures in the horticulture and the metal industry as well as the sub-sector of machinery, textiles and construction materials industry. Rather astonishingly, a positive firm size effect could be found only for the industry for basic metals. The most important barriers have been quite heterogeneous among industries: lack of compatibility with existing technologies (industry for basic metals; horticulture industry); organizational problems (horticulture industry); lack of internal financing (sub-sector of machinery, textiles and construction materials industry); lack of public subsidies (paper industry); and no need for further increase of energy efficiency (basic metals and food industry). In a further study for 110 Dutch firms Velthuijsen (1993) found that the following factors have been significant reasons for not implementing energy efficiency improvement opportunities: limited financial means; lack of information; no need to renew existing equipment; and lack of interest due to the fact that energy-saving do not belong to firms' core business. A study based on data for 50 Greek firms in 2004/2005 found that out of six industries primarily the metal industry suffered under a series of impediments such as lack of fund; high investment costs; high transaction costs; managerial deficiencies and uncertainty with respect to the development of energy prices (Sardianou 2008).

2.5.3 Extensions and Robustness Checks

In a second step, we took into consideration the interdependence among the adoption variables. To this end, we estimated a multivariate probit model, i.e. a simultaneous system of four adoption equations for the four different types of technology applications, instead of four separate probits. We applied the procedure implemented in STATA, which is based on the so- called GHK-simulator for multivariate distributions.[15] The

[15] The STATA procedure 'mprobit' estimates M-equation probit models by the method of simulated maximum likelihood. The Geweke-Hajivassiliou-Keane (GHK)-simulator is applied to evaluate the M-dimensional Normal integrals in the likelihood function (for a description of the GHK-simulator see Greene 2003).

results are presented in table 2.6. We found significant positive correlations between any pair of part-adoption equations. Thus, there is considerable empirical justification for estimating a multivariate probit model, even if the estimates in table 2.6 do not differ much from those in table 2.5. Small differences exist primarily with respect to the statistical significance of the dummy variables for the industrial sub-sectors. A further interesting point is that the positive correlations among the various categories of technology applications can be interpreted as a hint for the existence of complementarities among these technologies. This means that the different categories of technology applications are used parallel because they refer to different domains of enterprise functions and activities.[16]

In a third step, we took into account also the information about the point in time of the introduction of technology applications. Firms reported in our survey whether they introduced an energy-saving technology application before or after 2004. Based on this information, we constructed an ordinal variable for each of the four categories of energy-saving technology applications for non-adopting firms, "early" adopters and "late" adopters (3-level variable; see table 2.1). Table 2.7 contains the ordered probit estimates for these variables. Distinguishing early and late adopters did not bring any new insights and the pattern of explanatory factors remains the same.

Data limitations do not allow tests of the potential endogeneity of some of the right-hand variables. However, in order to test model stability and potential bias we have estimated the model omitting the potentially endogenous variables (R&D; LN_INVEST/L; LN_ENEXP). We found that dropping the variables R&D and LN_ENEXP does not affect the other parameter estimates in any of the four equations. This is not the case for the variable LN_INVEST/L, the omission of which causes a significant increase of the coefficient of the variable DEMAND that cannot be traced back to multicollinearity because of the low correlation between these two variables ($r = -0.121$). Thus, the suspicion of endogeneity for the variable LN_INVEST/L cannot be removed.

2.5.4 Intra-Firm Diffusion

We estimated a multinomial logit model for each of the four groups of energy-saving technology applications that were presented in section 4 (see table 2.8).[17] [18] Table

[16] Complementarities between various advanced manufacturing technologies were found, for example, also in Colombo and Mosconi (1995); Stoneman and Toivanen (1997); and Arvanitis and Hollenstein (2001).

[17] We used a multinomial logit estimator after testing for the "Independence from Irrelevant Alternatives" (IIA assumption) (Hausman and McFadden 1984). We conducted Hausman tests for each of the eight coefficient vectors reported in table 2.8, and none of the associated chi-quadrate statistics hinted to a violation of the IIA assumption at any conventional level of statistical significance.

[18] We also estimated ordered probit models for 3 levels (and 3 to 5 levels dependent on the maximum number of single technology applications reported as adopted by a firm in one of the four categories of energy-saving technology applications; see table 2.17 and table 2.18 in the appendix). There are no differences between these estimates and the estimates for inter-firm adoption because the differences between adopting and non-adopting behaviour dominate the results in both cases, so that the intra-firm differences are not discernible.

2.11a shows the construction of the respective four dependent variables that contain three mutually exclusive groups of firms' states (non-adopting; "low-level" adopting; "high-level" adopting firms). We chose level 1 as base level, so that the estimates reflect the comparison of "low-level" adopting behaviour either with non-adopting behaviour or "high-level" adopting behaviour. Table 2.2 contains the explanatory variables in accordance with the model specification in section 2. The columns 1, 3, 5 and 7 in table 2.8 contain the estimates for the comparison between non-adopting and "low-level" adopting behaviour. These estimates are qualitatively the same as those in the probit estimates in table 2.5 with the exception of the variables for intra-firm epidemic effects in the estimates for MACHINE and BILDING that have now rather unexpectedly positive signs, hinting to negative effects.

We concentrate here to the intra-firm effects ("high-level"-adopting versus "low-level" adopting behaviour) that are found in the columns 2, 4, 6 and 8 in table 2.8. There are significant differences from the pattern of relevant explanatory factors for inter-firm adoption found in table 2.5. Some of the factors that were important for the inter-firm adoption rate lost their importance for explaining the extent of usage of energy-saving technologies (see table 2.8). Factor endowment in the form of gross investment per employee and R&D showed no effect on the rate of intra-firm adoption, with the exception of rather weak positive effect of gross investment in the case of building-related technologies (BUILDING; column 3 in table 2.8). Firm size showed a positive effect in all four equations in table 2.8 also on intra-firm adoption. Foreign firms are less inclined than domestic firms to more intensive use of energy- saving technologies (with the exception of transport-related technologies). Competitive pressures remained also relevant but non-price competition appears to be more effective than price competition in the case of intra-firm adoption. It seems that more intensive usage of new technologies requests higher technological capabilities that are available mostly to firms that are stronger exposed to non-price competition with respect to qualitative and technological product characteristics.

The results with respect to the variables for inter-firm and intra-firm external effects are symmetrical to those for inter-firm diffusion. The intra-firm effects (direct effects) are significantly positive in three out of four types of technology applications, positive but statistically insignificant in the case of the fourth category (d) of power-generating technology applications (ENERGY). All four cross-effects (inter-firm) are insignificant. Therefore, also in the case of intra-firm adoption the direct epidemic (and/or eventually network effects) seem to outweigh stock and order effects, with the exception of power-generating technology applications. In the latter case no influence of external effects could be found. As to adoption barriers, information and knowledge obstacles showed positive coefficients only for machinery-related technology applications. Financial and organizational barriers were of no relevance. Finally, compatibility barriers that appeared to be "proper" impediments of adoption in case of inter-firm diffusion changed the sign to positive in the equation for transport-related equation (column 4 in table 2.8) indicating now a problem awareness that increases with more intensive technology use (see the discussion of such effects in section 5.1.1).

The sales share of energy costs is positively correlated with the rate of intra-firm adoption only in the equation for ENERGY, as it was the case also in the inter-firm estimates. The second variable for inducement effects reflecting the "intrinsic" motivation for adopting environment-friendly technologies (ENV_AWARE) has again a significantly positive coefficient throughout the estimates in the columns 2, 4, 6 and 8.

The evidence from comparable earlier studies[19] that investigated intra-firm diffusion is mixed. In general, most studies found that the firm-specific factors that explain inter-firm adoption and intra-firm adoption are not the same. For example, firm size can be positively, negatively or not correlated with the intra-firm adoption rate, while most studies find a positive correlation of firm size and inter-firm adoption rate. Further, the significance of the external effects differ from study to study substantially: For example Battisti et al. (2009) found negative effects of the inter-firm diffusion variable (on industry level) and positive effects of the intra-firm diffusion variables (on industry level) and Hollenstein and Woerter (2008) estimated significant positive coefficients only for the intra-firm variables. On the other hand, Battisti et al. (2007) found both for Switzerland and the UK positive effects of the intra-firm variable, but no effects for Switzerland and a negative effect for the UK for the inter-firm variable; the findings for Switzerland are in accordance with the results of this study. Finally, Battisti and Stoneman (2005) could not find any significant effects of external effects on intra-firm adoption. On the whole, the empirical findings for intra-firm adoption are more heterogeneous than those for inter-firm adoption. A first possible explanation for this difference could be that intra-firm dissemination of technology is much more idiosyncratic than inter-firm diffusion, thus depending much stronger than the latter on characteristics such as management abilities, organisation forms, etc.. A further explanation could be that the potential for the more intensive use of such divergent technologies is rather limited as compared, for example, with the utilization potential of ICT technologies.

2.5.5 Motives of Intra-Firm Diffusion

In order to be able to use also the four variables for adoption inducements that were measured only for firms that have adopted at least one technology application in any of the four categories considered in this study, we estimated also a multinomial logit model for a sub- sample that contained only the firms with at least one technology application (table 2.9). For such a procedure of course the issue of potential selection bias of the estimate that are based on the sub-sample arises. A comparison of the results in table 2.8 (all firms) and table 2.9 (only adopting firms), particularly those for the level 2 (columns 2, 4, 6 and 8 in both tables) shows that the estimates remain quite stable

[19] See our remarks to comparable literature in section 5.1.1.

when the observations of non-adopting firms are removed from sample in the estimates in table 2.9. This is a clear hint that sample selection does not make a difference in this case. We also examined the selectivity bias issue in the framework of a bivariate probit model with sample selection (Heckman approach) for the variable MACHINE.[20] The selection as well as the intensity equation contained the same right-hand variables as in table 2.5 and table 2.8; the selection equation included as additional (identifying) variable the employment share of apprentices. The results (not presented here) showed no selection bias. As a consequence, the intensity equation could be estimated as a simple probit model. The results were qualitatively the same as those obtained for the multinomial model in table 2.9. This is additional evidence that the estimates in table 2.9 are quite robust.

Inserting the four variables for adoption motives that reflect inducement effects in the intra- firm adoption equations did not yield substantial new insights. Neither increasing energy prices and/or taxes nor public regulation and/or public incentives (with the exception of public regulation in the case of building technology applications; column 6 in table 2.9) seem to influence significantly the intra-firm adoption rate. However, for two categories of technology application, electromechanical and electronic applications (category (a)) and building applications (category (c)), we obtained a positive effect for the variable OTHER reflecting the following single motives: (1) current or expected demand for environment-friendly products (factor loading 0.66; see table 2.15 in the appendix); (2) protection of environment ("intrinsic" motive; factor loading 0.47); and (3) uncertainty as to future energy bottlenecks (0.21). The single motives (1) and (2) with the higher factor loadings are primarily responsible for the positive effect of the variable OTHER in the estimates for MACHINE and BUILDING. These two single motives reflect two important inducements channels: an "intrinsic" one (positive valuing of environment protection) and a second one that is market intermediated (expected demand for environment-friendly products). These findings demonstrate, in addition to the effects of the variables ENV_AWARE and LN_ENEXP in table 2.8 and table 2.5 (for inter-firm adoption), that there are significant inducement effects, particularly effects related to intrinsic motives for the use of energy-saving technologies.

2.6 Summary and Conclusions

Inter-firm diffusion. We find to a large extent the same pattern with respect to the variables reflecting firm-specific rank effects for all four groups of energy-saving technology applications we define in this study. Obviously the likelihood that at least one of these technology applications is adopted is driven by the same firm characteristics independent from the specific type of technology applications.

Not all firm characteristics included in our variable vector are equally important

[20] We applied the heckprob procedure of STATA.

for technology adoption. With respect to factor endowment the variable for gross investment per employee and the dummy variable for R&D show the expected positive signs. Contrary to our expectations, adopting firms do not use more human capital than non-adopting firms. Firm size shows the expected (non-linear) positive effect. There are some differences among the various technology types with respect to foreign-owned firms. Foreign firms seem to be less inclined than domestic firms to adopt energy-saving technologies in buildings and energy- generating processes. Finally, export activities do not appear to be a specific trait of adopting firms. On the whole, competitive pressures seem to have some influence on the propensity to adopt energy-saving technologies, particularly for firms with substantial energy costs that use machinery intensively and/or generate their own power (electricity or heat).

Inter-firm epidemic (learning and, eventually, network effects) seem to outweigh negative stock and order effects leading to positive net effects that enhance the inter-firm adoption rate of energy-saving technologies. This is not the case for intra-firm epidemic and network effects; for this variable – with the exception of the ENERGY estimates – no significant effect could be found. Thus, relevant for the introduction of energy-saving technologies is the experience of first use of such technologies in other firms and in most cases not the intensity of usage (for example, the number and width of used technology applications). Lack of compatibility with current product programme or current production technology seems to be the main barrier for firms that hinder them from adopting any kind of energy- saving technologies. Contrary to our expectations, we obtained significant but positive coefficients for the variables for financing obstacles and for information and knowledge barriers also in all four estimates. We conclude that information on impediments in surveys should not be interpreted as impenetrable barriers. Rather, they often reflect a problem awareness that increases with experience in technology use

Intra-firm diffusion. There are significant differences from the pattern of relevant explanatory factors for inter-firm adoption. Some of the firm-specific factors (rank effects) that are important for the inter-firm adoption rate lose their importance for explaining the extent of usage of energy-saving technologies. Factor endowment in the form of gross investment per employee and R&D show practically no effect on the rate of intra-firm adoption. Firm size shows a positive effect in three out of four equations for intra-firm adoption. Foreign firms are less inclined than domestic firms to more intensive use of energy-saving technologies (with the exception of transport-related technologies). Competitive pressures are still relevant but non-price competition appears to be more effective than price competition in the case of intra- firm adoption. The results with respect to the variables for the inter-firm and intra-firm external effects are symmetrical to those for inter-firm diffusion. The intra-diffusion effects (direct effects) are significantly positive in three out of four types of technology applications, positive but statistically insignificant in the case of the fourth category (d) of power- generating technology applications. All four cross-effects (inter-diffusion) are insignificant. As to adoption costs, information and knowledge obstacles show positive coefficients for machinery-related and building-related technology applications. Financial and organizational barriers are of no relevance. Finally, compatibility barriers that appear to be "proper" impediments of adoption in case of inter-firm diffusion changed the sign to positive in the equation for transport-related equation.

Finally, positive inducement effects, particularly effects related to intrinsic motivation for using energy-saving technologies could be found for both inter-firm and intra-firm technology adoption.

Some implications for economic policy. If economic policy is to promote the spreading of energy-saving technologies there is much more to do to encourage the intra-firm than the inter-firm adoption of such technologies. The importance of rank effect indicates that the patterns of firm diffusion reflect the different strengths of firms with different characteristics. Thus, it is difficult to conceive a policy that fits to all firms. The heterogeneity of firms (for example, with respect to firm size or the existence of R&D activities) has to be taken into consideration when a promotion policy is formulated. On the other hand, we find almost the same pattern of diffusion for all four categories of technology applications. Thus, policy has to be specific to firm categories but not to technology types to be effective. Intrinsic motivation based on positive valuing of environmental protection is an important determinant of adoption that can be enhanced by policy measures. Finally, although our results are based only on a single cross-section of firms and are not definite, they yield some evidence that there exist positive technological (and eventually network externalities) in the diffusion of energy-saving technologies that would enhance the propensity as well as the extent of usage of such technologies.[21] For power-generating technology applications (category (d)) we could not find such externalities with respect to intra-firm adoption. In this case public promotion of information platforms, etc. that provide firms with information about the technical possibilities of energy-saving strategies in the framework of firm-specific integrated energy- saving programmes can be useful.

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[21]In the presence of such externalities firms with a "first adopter" profile may be discouraged to invest in the technology or invest sub-optimally if they are not able to appropriate all revenues from their investment. We cannot exclude this case but in our estimates (with just one exception) potential negative stock and order effects are outweighed by positive learning effects.

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Table 2.1: Definition of the *Dependent* Variables

Variable	Description (reference year: 2008)
Inter-firm Diffusion	
MACHINE	Binary variable: 1: adoption of at least one out of five technology applications listed under (a) in table 2.2; 0: otherwise
TRANSPORT	Binary variable: 1: adoption of at least one out of three technology applications listed under (b) in table 2.2; 0: otherwise
BUILDING	Binary variable: 1: adoption of at least one out of five technology applications listed under (c) in table 2.2; 0: otherwise
ENERGY	Binary variable: 1: adoption of at least one out of four technology applications listed under (d) in table 2.2; 0: otherwise
MACHINE_T	Ordinal variable: 2: adoption of at least one out of five technology applications listed under (a) in table 2.2 before 2004; 1: adoption 2004 and later; 0: otherwise
TRANSPORT_T	Ordinal variable: 2: adoption of at least one out of three technology applications listed under (b) in table 2.2 before 2004; 1: adoption 2004 and later; 0: otherwise
BUILDING_T	Ordinal variable: 2: adoption of at least one out of five technology applications listed under (c) in table 2.2 before 2004; 1: adoption 2004 and later; 0: otherwise
ENERGY_T	Ordinal variable: 2: adoption of at least one out of four technology applications listed under (c) in table 2.2 before 2004; 1: adoption 2004 and later; 0: otherwise
Intra-firm Diffusion	
MACHINE_N_0	3-level ordinate variable: level 2: adoption of 3, 4 or 5 of the technology applications listed under (a) in table 2.2; level 1: adoption of 1 or 2 of the technology applications listed under (a); level 0: otherwise
TRANSPORT_N_0	3-level ordinate variable (level 2: adoption of 2 or 3 of the technology applications listed under (b) in table 2.2; level 1: adoption of 1 of the technology applications listed under (b); level 0: otherwise
BUILDING_N_0	3-level ordinate variable (level 2: adoption of 3, 4 or 5 of the technology applications listed under (c) in table 2.2; level 1: adoption of 1 or 2 of the technology applications listed under (a); level 0: otherwise
ENERGY_N_0	3-level ordinate variable (level 2: adoption of 2, 3 or 4 of the technology applications listed under (d) in table 2.2; level 1: adoption of 1 of the technology applications listed under (d); level 0: otherwise
MACHINE_N_5	5-level ordinate variable: 1, 2, 3, 4, 5 of the technology applications listed under (a) in table 2.2; reference level: 0
TRANSPORT_N_3	3-level ordinate variable: 1, 2, 3 of the technology applications listed under (b) in table 2.2; reference level: 0
BUILDING_N_5	5-level ordinate variable: 1, 2, 3, 4, 5 of the technology applications listed under (c) in table 2.2; reference level: 0
ENERGY_N_4	4-level ordinate variable: 1, 2, 3, 4 of the technology applications listed under (d) in table 2.2; reference level: 0

Table 2.2: Definition of the *Independent* Variables

Variable	Description
Independent variables	
Firm-specific rank effects	
LN_EMPL	Natural logarithm of the number of employees (in full-time equivalents) by the end of the year 2008
LN_INVEST/L	Natural logarithm of gross investment expenditure per employee (value null for firms with null gross investment) in the year 2008
INVEST/L_0	Dummy variable for firms with null gross investment in the year 2008
HQUAL	Employment share of employees with tertiary-level education by the end of the year 2008
R&D	R&D activities yes/no (dummy variable) in the period 2006-2008
EXPORT	Export activities yes/no in the year 2008
FOREIGN	Foreign-owned firm yes/no (dummy variable)
Rank effects as to a firm's market environment	
DEMAND_EXPECT	Expected change of demand for a firm' s main product for the period 2009-2011 (5-level ordinate variable based on a five-point intensity scale: values 1 to 5)
IPC	Intensity of price competition (5-level ordinate variable based on a five-point intensity scale: values 1 to 5)
INPC	Intensity of non-price competition (5-level ordinate variable based on a five-point intensity scale: values 1 to 5)
IND1-IND7	Subsectors: IND1: NACE 22, 335, 36, 37; IND2: NACE 21, 23, 24, 25, 26, 27, 28, 40, 41; IND3: NACE 29, 31, 30, 31, 32, 331-334, 34, 35 ; IND4: NACE 45; IND5: 50, 51, 52; IND6: 55, 60-63, 70, 71; IND7: 64, 65-67, 72, 73, 74, 93; reference: NACE 15-20
Epidemic effects	
Inter-firm	
INTER_MACHINE	Share of firms adopting at least one out of 5 technology applications listed under (a) in table 2.3 by 2-digit industry
INTER_TRASPORT	Share of firms adopting at least one out of 3 technology applications listed under (b) in table 2.3 by 2-digit industry
INTER_BUILDING	Share of firms adopting at least one out of 5 technology applications listed under (c) in table 2.3 by 2-digit industry
INTER_ENERGY	Share of firms adopting at least one out of 4 technology applications listed under (d) in table 2.3 by 2-digit industry
Intra-firm	
INTRA_MACHINE	Mean of adopted technology applications listed under (a) in table 2.3 (only adopting firms) by 2-digit industry
INTRA_TRANSPORT	Mean of adopted technology applications listed under (b) in table 2.3 (only adopting firms) by 2-digit industry
INTRA_BUILDING	Mean of adopted technology applications listed under (c) in table 2.3 (only adopting firms) by 2-digit industry
INTRA_ENERGY	Mean of adopted technology applications listed under (d) in table 2.3 (only adopting firms) by 2-digit industry

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Variable	Description
Adoption costs	
Barriers of adoption: Factor values; see table 2.14 in the appendix	
INFO	Information and knowledge barriers: uncertainty with respect to technology performance, uncertainty about the future price development
COMPAT	Adjustment barriers: lack of compatibility with current product programme or current production technology
FIN	Financing barriers: high investment expenditures, liquidity constraints
ORGAN	Organizational and managerial barriers: lack of know-how, of specialized personnel, of management attention
Inducement effects	
LN_ENEXP	Natural logarithm of the sales share of energy costs (value null for firms with null sales share) in the year 2008
ENEXP_0	Dummy variable for firms with null sales share
ENV_AWARE	Environmental criteria are taken into consideration for purchases of intermediate inputs (5-level ordinate variable based on a five-point intensity scale: values 1 to 5)
Motives of adoption: Factor values; see table 2.15 in the appendix	
PRICE_TAX	Current and/or expected increases of energy prices and/or energy taxes
PUBLIC_INCENT	Public incentives for energy efficiency and/or CO_2 reduction
PUBLIC_REGUL	Public regulations and/or agreements between firms and government agencies concerning energy efficiency
OTHER	Demand for environment-friendly products; expected energy bottlenecks

Table 2.3: Inter-Firm Diffusion of Energy-Saving Technologies

Type of energy-saving technology application	Number and share of adopters; total N	%	Number and share of adopters; before 2004 N	%	Number and share of adopters; 2004 and later N	%
(a) Energy-saving technologies in electromechanical and electronic applications, namely:	914	39.6	335	14.5	817	35.4
- in electrical machines and drive systems	567	24.6	172	7.5	465	20.2
- in information and communication technologies	554	24.0	106	4.6	484	21.0
- in consumer electronics	213	9.2	76	3.3	146	6.3
- in components of process engineering (e.g., compressors; pumps; heat exchangers	577	25.0	193	8.4	448	19.4
- in process engineering	358	15.5	115	5.0	285	12.4
(b) Energy-saving technologies in motor vehicles and in traffic engineering, namely:	421	18.3	121	5.2	365	15.8
- in engines of motor vehicle	369	16.0	83	3.6	314	13.6
- in motor vehicle bodies (e.g., through the decrease of weight; the improvement of aerodynamics	164	7.1	63	2.7	109	4.7
- in traffic management systes	138	6.0	44	1.9	99	4.3
(c) Energy-saving technologies in buildings, namely:	1038	45.0	424	18.4	896	38.9
- in temperature isolation	631	27.4	211	9.2	468	20.3
- in lighting (incl. respective control systems	732	31.7	171	7.4	601	26.1
- in heating (incl. respective control systems	717	31.1	246	10.7	508	22.0
- in cooling systems	468	20.3	145	6.3	350	15.2
- in air ventilation and air conditioning	562	24.4	176	7.6	419	18.2
(d) Energy-saving technologies in power-generating processes, namely:	501	21.7	241	10.5	347	15.0
- Combined heat and power generation based on biomass	25	1.1	10	0.4	18	0.8
- Combined heat and power generation based on oil/gas/carbon	83	3.6	53	2.3	45	2.0
- Heat pumps	223	9.7	98	4.2	147	6.4
- Heat recuperation systems	406	17.6	186	8.1	267	11.6
Share of adopters with respect to all technology applications	1231	53.4	629	27.3	1137	49.3

Notes: shares of firms with at least 1 technology application in the respective type of technology applications; reference: all firms. The shares for the single applications are percentages of technology adopting firms.

Table 2.4: Intra-Firm Diffusion of Energy-Saving Technologies

Type of energy-saving technology application	Number and share of adopters; N	%	Number and share of adopters; N	%
	With 1 or 2 technology applications		With 3, 4 or 5 technology applications	
(a) Energy-saving technologies in electromechanical and electronic applications	507	22.0	407	17.6
	With 1 technology application		With 2 or 3 technology applications	
(b) Energy-saving technologies in motor vehicles and in traffic engineering	245	10.6	176	7.6
	With 1 or 2 technology applications		With 3, 4 or 5 technology applications	
(c) Energy-saving technologies in buildings	440	19.1	598	25.9
	With 1 technology applications		With 2, 3 or 4 technology applications	
(d) Energy-saving technologies in energy-generating Processes	318	13.8	183	7.9

Notes: Shares of firms; reference: all firms.

Table 2.5: Determinants of Inter-Firm Adoption of Several Types of Energy-Saving Technologies; Probit Estimates

Explanatory variables	MACHINE		TRANSPORT		BUILDING		ENERGY	
LN_EMPL	0.180***	(0.022)	0.162***	(0.024)	0.254***	(0.023)	0.220***	(0.025)
LN_INVEST/L	0.092***	(0.025)	0.053*	(0.029)	0.100***	(0.025)	0.210***	(0.030)
INVEST/L_0	0.429	(0.311)	-0.172	(0.419)	0.460	(0.311)	1.500***	(0.404)
HQUAL	-0.000	(0.002)	-0.003	(0.002)	-0.002	(0.002)	-0.004*	(0.002)
LN_ENEXP	0.031	(0.029)	-0.014	(0.033)	-0.027	(0.030)	0.070**	(0.034)
ENEXP_0	-0.476***	(0.177)	-0.419*	(0.214)	-0.300*	(0.165)	-0.291	(0.213)
R&D	0.436***	(0.076)	0.191**	(0.088)	0.283***	(0.077)	0.305***	(0.083)
FOREIGN	0.014	(0.087)	-0.168	(0.103)	-0.213**	(0.088)	-0.230**	(0.100)
EXPORT	-0.014	(0.075)	-0.119	(0.085)	0.010	(0.075)	0.023	(0.087)
ENV_AWARE	0.226***	(0.030)	0.156***	(0.034)	0.184***	(0.030)	0.163***	(0.034)
DEMAND_EXPECT	0.051	(0.037)	0.008	(0.043)	0.106***	(0.037)	0.062	(0.043)
INFO	0.152***	(0.030)	0.143***	(0.035)	0.232***	(0.031)	0.091***	(0.035)
COMPAT	-0.242***	(0.030)	-0.129***	(0.035)	-0.255***	(0.030)	-0.214***	(0.035)
FIN	0.213***	(0.031)	0.135***	(0.036)	0.290***	(0.031)	0.139***	(0.036)
ORGAN	0.040	(0.030)	0.013	(0.034)	0.012	(0.030)	-0.025	(0.034)
IPC	0.082***	(0.031)	0.054	(0.035)	0.041	(0.031)	0.069*	(0.035)
INPC	0.027	(0.033)	-0.019	(0.038)	0.042	(0.034)	-0.009	(0.038)
IND1	-0.060	(0.202)	0.149	(0.212)	-0.046	(0.187)	0.110	(0.210)
IND2	-0.048	(0.139)	0.101	(0.175)	0.051	(0.130)	0.134	(0.143)
IND3	-0.081	(0.158)	0.202	(0.191)	0.007	(0.146)	0.141	(0.165)
IND4	0.111	(0.224)	0.255	(0.186)	0.200	(0.180)	0.596**	(0.284)
IND5	0.044	(0.220)	0.281*	(0.164)	0.204	(0.172)	0.447**	(0.226)
IND6	-0.005	(0.189)	0.024	(0.174)	0.135	(0.149)	0.288	(0.221)
IND7	0.100	(0.225)	0.304*	(0.175)	0.272	(0.178)	0.571**	(0.242)
INTER_MACHINE	1.711**	(0.685)						
INTRA_MACHINE	-0.095	(0.213)						
INTER_TRANSPORT			3.405***	(0.429)				
INTRA_TRANSPORT			0.144	(0.228)				
INTER_BUIDING					1.778***	(0.642)		
INTRA_BUIDING					-0.021	(0.146)		
INTER_ENERGIE							3.300***	(0.629)
INTRA_ENERGIE							-0.921**	(0.374)
Const.	-3.774***	(0.668)	-3.761***	(0.580)	-4.189***	(0.539)	-4.448***	(0.527)
No. of obs.	2285		2285		2285		2285	
Pseudo-R2	0.183		0.149		0.209		0.215	
LR chi2	560.2		323.3		656.7		515.0	
p-Value	0.000		0.000		0.000		0.000	

Notes: See table 2.1 and 2.2 for the definition of the variables. ***, **, * denote statistical significance at the 1%, 5% and 10% test level.

Table 2.6: Determinants of Inter-Firm Adoption of Several Types of Energy-Saving technologies; tetravariate probit estimates

Explanatory variables	MACHINE		TRANSPORT		BUILDING		ENERGY	
LN_EMPL	0.180***	(0.022)	0.163***	(0.024)	0.247***	(0.023)	0.214***	(0.024)
LN_INVEST/L	0.089***	(0.025)	0.053*	(0.029)	0.101***	(0.024)	0.209***	(0.029)
INVEST/L_0	0.426	(0.304)	-0.066	(0.397)	0.531*	(0.294)	1.632***	(0.381)
HQUAL	0.000	(0.002)	-0.003	(0.002)	-0.002	(0.002)	-0.002	(0.002)
LN_ENEXP	0.030	(0.029)	-0.020	(0.032)	-0.029	(0.028)	0.062*	(0.033)
ENEXP_0	-0.428**	(0.167)	-0.439**	(0.207)	-0.310**	(0.157)	-0.294	(0.212)
R&D	0.398***	(0.076)	0.195**	(0.085)	0.261***	(0.076)	0.304***	(0.082)
FOREIGN	0.004	(0.086)	-0.131	(0.100)	-0.188**	(0.085)	-0.187*	(0.095)
EXPORT	0.006	(0.075)	-0.120	(0.083)	0.028	(0.073)	0.027	(0.085)
ENV_AWARE	0.230***	(0.030)	0.147***	(0.033)	0.181***	(0.029)	0.156***	(0.033)
DEMAND_EXPECT	0.056	(0.037)	-0.002	(0.042)	0.104***	(0.036)	0.056	(0.041)
INFO	0.151***	(0.031)	0.147***	(0.035)	0.220***	(0.030)	0.103***	(0.034)
COMPAT	-0.246***	(0.030)	-0.139***	(0.034)	-0.237***	(0.030)	-0.213***	(0.034)
FIN	0.215***	(0.031)	0.152***	(0.036)	0.277***	(0.031)	0.143***	(0.035)
ORGAN	0.039	(0.030)	0.013	(0.033)	0.007	(0.029)	-0.023	(0.033)
IPC	0.081***	(0.031)	0.057*	(0.034)	0.040	(0.030)	0.063*	(0.034)
INPC	0.032	(0.033)	-0.027	(0.037)	0.048	(0.032)	-0.010	(0.037)
IND1	0.097	(0.196)	0.089	(0.204)	0.068	(0.180)	0.077	(0.202)
IND2	0.024	(0.136)	0.049	(0.165)	0.101	(0.127)	0.085	(0.138)
IND3	0.014	(0.153)	0.169	(0.180)	0.055	(0.140)	0.132	(0.158)
IND4	0.241	(0.211)	0.191	(0.180)	0.318*	(0.174)	0.579**	(0.266)
IND5	0.230	(0.209)	0.265*	(0.158)	0.348**	(0.163)	0.464**	(0.214)
IND6	0.114	(0.182)	-0.033	(0.168)	0.168	(0.144)	0.282	(0.208)
IND7	0.223	(0.213)	0.259	(0.168)	0.327*	(0.168)	0.543**	(0.226)
INTER_MACHINE	2.103***	(0.610)						
INTRA_MACHINE	-0.070	(0.181)						
INTER_TRANSPORT			3.624***	(0.404)				
INTRA_TRANSPORT			0.119	(0.210)				
INTER_BUIDING					1.998***	(0.571)		
INTRA_BUIDING					0.073	(0.122)		
INTER_ENERGIE							3.336***	(0.580)
INTRA_ENERGIE							-0.789**	(0.335)
Const.	-4.139***	(0.613)	-3.652***	(0.547)	-4.635***	(0.493)	-4.550***	(0.492)
No. of obs.	2285							
LR chi2	1096.7							
p-Value	0.000							
Estimated Residual Correlation Coefficients:								
Rho21	0.578***	(0.031)						
Rho31	0.725***	(0.020)						
Rho41	0.533***	(0.031)						
Rho32	0.545***	(0.031)						
Rho42	0.291***	(0.038)						
Rho43	0.632***	(0.029)						

Notes: See table 2.1 and 2.2 for the definition of the variables. ***, **, * denote statistical significance at the 1%, 5% and 10% test level.

Table 2.7: Determinants of inter-firm adoption of several types of energy-saving Technologies (Adoption Point in Time); Ordered Probit Estimates

Explanatory variables	MACHINE_T		TRANSPORT_T		BUILDING_T		ENERGY_T	
LN_EMPL	0.172***	(0.020)	0.144***	(0.023)	0.203***	(0.020)	0.211***	(0.023)
LN_INVEST/L	0.082***	(0.023)	0.064**	(0.028)	0.063***	(0.022)	0.188***	(0.029)
INVEST/L_0	0.318	(0.291)	-0.020	(0.402)	0.151	(0.284)	1.307***	(0.385)
HQUAL	-0.000	(0.002)	-0.003	(0.002)	-0.002	(0.002)	-0.002	(0.002)
LN_ENEXP	0.031	(0.027)	-0.021	(0.032)	-0.021	(0.026)	0.079**	(0.032)
ENEXP_0	-0.461***	(0.167)	-0.427**	(0.209)	-0.257*	(0.151)	-0.330	(0.205)
R&D	0.380***	(0.068)	0.240***	(0.084)	0.239***	(0.068)	0.309***	(0.079)
FOREIGN	-0.033	(0.078)	-0.163	(0.100)	-0.198**	(0.077)	-0.260***	(0.095)
EXPORT	-0.005	(0.068)	-0.150*	(0.082)	-0.003	(0.066)	0.023	(0.083)
ENV_AWARE	0.200***	(0.027)	0.143***	(0.032)	0.155***	(0.026)	0.155***	(0.033)
DEMAND_EXPECT	0.034	(0.034)	0.001	(0.041)	0.095***	(0.033)	0.045	(0.041)
INFO	0.137***	(0.028)	0.130***	(0.034)	0.214***	(0.027)	0.080**	(0.033)
COMPAT	-0.213***	(0.028)	-0.111***	(0.033)	-0.197***	(0.027)	-0.201***	(0.033)
FIN	0.191***	(0.028)	0.127***	(0.035)	0.243***	(0.028)	0.151***	(0.035)
ORGAN	0.029	(0.027)	0.004	(0.033)	0.019	(0.026)	-0.013	(0.032)
IPC	0.060**	(0.028)	0.052	(0.034)	0.048*	(0.027)	0.055	(0.034)
INPC	0.020	(0.030)	-0.007	(0.037)	0.032	(0.030)	-0.016	(0.036)
IND1	0.002	(0.182)	0.120	(0.203)	-0.091	(0.165)	0.181	(0.199)
IND2	0.028	(0.121)	0.054	(0.168)	0.003	(0.112)	0.142	(0.133)
IND3	-0.031	(0.141)	0.138	(0.183)	-0.081	(0.127)	0.143	(0.156)
IND4	0.101	(0.203)	0.212	(0.177)	0.107	(0.161)	0.640**	(0.272)
IND5	0.053	(0.199)	0.218	(0.157)	0.009	(0.152)	0.503**	(0.216)
IND6	0.057	(0.171)	-0.020	(0.165)	0.067	(0.131)	0.339	(0.211)
IND7	0.110	(0.203)	0.214	(0.167)	0.084	(0.157)	0.615***	(0.231)
INTER_MACHINE	1.410**	(0.612)						
INTRA_MACHINE	0.015	(0.191)						
INTER_TRANSPORT			3.095***	(0.408)				
INTRA_TRANSPORT			0.235	(0.218)				
INTER_BUIDING					1.000*	(0.567)		
INTRA_BUIDING					0.047	(0.129)		
INTER_ENERGIE							3.212***	(0.596)
INTRA_ENERGIE							-0.963***	(0.351)
cut1	3.554***	(0.601)	3.779***	(0.555)	3.279***	(0.469)	4.016***	(0.489)
cut2	4.504***	(0.603)	4.606***	(0.558)	4.197***	(0.471)	4.615***	(0.491)
No. of obs.	2285 2285	2285	2285					
Pseudo-R2	0.131 0.117	0.126	0.166					
LR chi2	556.1 312.1	571.3	510.6					
p-Value	0.000 0.000	0.000	0.000					

Notes: See table 2.1 and 2.2 for the definition of the variables. ***, **, * denote statistical significance at the 1%, 5% and 10% test level.

Table 2.8: Determinants of Intra-Firm Adoption of Several Types of Energy-Saving Technologies; Multinomial Logit Estimates

	MACHINE_N_0		TRANSPORT_N_0		BUILDING_N_0		ENERGY_N_0	
	0	2	0	2	0	2	0	2
LN_EMPL	-0.201*** (0.043)	0.252*** (0.052)	-0.244*** (0.053)	0.119* (0.071)	-0.287*** (0.048)	0.249*** (0.051)	-0.312*** (0.051)	0.227*** (0.070)
LN_INVEST/L	-0.159*** (0.045)	0.002 (0.059)	-0.134** (0.060)	-0.038 (0.086)	-0.127*** (0.047)	0.097* (0.055)	-0.322*** (0.059)	0.098 (0.091)
HQUAL	-0.001 (0.003)	-0.004 (0.004)	0.010** (0.005)	0.008 (0.007)	0.004 (0.004)	-0.002 (0.004)	0.009** (0.004)	0.009 (0.006)
LN_ENEXP	-0.076 (0.055)	0.065 (0.068)	0.026 (0.066)	0.133 (0.096)	0.023 (0.058)	0.036 (0.065)	-0.085 (0.066)	0.208** (0.095)
R&D	-0.638*** (0.146)	0.192 (0.174)	-0.182 (0.191)	0.446 (0.279)	-0.341** (0.157)	0.287* (0.169)	-0.490*** (0.166)	0.137 (0.243)
FOREIGN	-0.154 (0.161)	-0.368* (0.201)	0.263 (0.224)	-0.215 (0.346)	0.172 (0.176)	-0.343* (0.194)	0.175 (0.192)	-0.776** (0.317)
EXPORT	0.106 (0.143)	0.183 (0.182)	0.080 (0.187)	-0.300 (0.271)	-0.021 (0.153)	-0.040 (0.172)	0.002 (0.175)	0.089 (0.262)
ENV_AWARE	-0.310*** (0.058)	0.205*** (0.076)	-0.198*** (0.074)	0.223** (0.111)	-0.182*** (0.060)	0.254*** (0.070)	-0.223*** (0.070)	0.231** (0.109)
DEMAND_EXPECT	-0.098 (0.071)	-0.006 (0.089)	-0.016 (0.092)	0.030 (0.135)	-0.175** (0.076)	0.032 (0.085)	-0.113 (0.086)	0.001 (0.128)
INFO	-0.198*** (0.059)	0.166** (0.076)	-0.204*** (0.076)	0.130 (0.112)	-0.337*** (0.064)	0.112 (0.072)	-0.190*** (0.071)	-0.081 (0.104)
COMPAT	0.427*** (0.059)	0.039 (0.075)	0.323*** (0.075)	0.214* (0.109)	0.371*** (0.063)	-0.115 (0.070)	0.398*** (0.071)	0.031 (0.107)
FIN	-0.370*** (0.060)	-0.016 (0.079)	-0.265*** (0.079)	-0.081 (0.117)	-0.550*** (0.066)	-0.119 (0.075)	-0.295*** (0.073)	-0.136 (0.111)
ORGAN	-0.076 (0.057)	-0.025 (0.072)	-0.016 (0.073)	0.042 (0.107)	-0.087 (0.061)	-0.122* (0.068)	0.041 (0.068)	-0.011 (0.101)
IPC	-0.131** (0.060)	0.004 (0.074)	-0.138* (0.077)	-0.106 (0.108)	-0.019 (0.063)	0.088 (0.070)	-0.052 (0.070)	0.205* (0.107)
INPC	-0.061 (0.065)	-0.037 (0.080)	0.099 (0.082)	0.171 (0.119)	-0.007 (0.068)	0.131* (0.076)	0.064 (0.076)	0.193* (0.112)
IND1	0.164 (0.387)	-0.007 (0.465)	-0.273 (0.484)	0.269 (0.704)	0.010 (0.377)	-0.133 (0.423)	-0.130 (0.409)	0.018 (0.645)
IND2	0.199 (0.268)	0.215 (0.290)	-0.150 (0.427)	-0.139 (0.548)	-0.093 (0.264)	-0.008 (0.276)	-0.216 (0.269)	-0.042 (0.388)
IND3	0.245 (0.308)	0.195 (0.351)	-0.282 (0.457)	0.352 (0.615)	-0.126 (0.292)	-0.172 (0.316)	-0.178 (0.319)	-0.022 (0.486)
IND4	-0.114 (0.440)	0.117 (0.527)	-0.411 (0.423)	0.509 (0.568)	-0.224 (0.364)	0.176 (0.415)	-0.727 (0.579)	0.536 (0.889)
IND5	0.049 (0.424)	0.080 (0.518)	-0.378 (0.387)	0.629 (0.505)	-0.195 (0.351)	0.243 (0.392)	-0.512 (0.453)	0.408 (0.709)
IND6	0.103 (0.364)	-0.006 (0.440)	0.201 (0.417)	0.483 (0.552)	-0.276 (0.299)	-0.135 (0.326)	-0.316 (0.438)	0.154 (0.687)
IND7	0.093 (0.440)	0.205 (0.530)	-0.579 (0.412)	0.180 (0.555)	-0.502 (0.360)	-0.150 (0.402)	-0.858* (0.483)	0.197 (0.742)
INTER_MACHINE	-2.974** (1.318)	-0.495 (1.549)						
INTRA_MACHINE	0.925** (0.447)	1.509*** (0.502)						
INTER_TRANSPORT			-5.708*** (0.958)	0.338 (1.387)				
INTRA_TRANSPORT			0.750 (0.542)	2.962*** (0.712)				
INTER_BUILDING					-3.165** (1.294)	-0.713 (1.446)		
INTRA_BUILDING					0.677** (0.304)	1.195*** (0.334)		
INTER_ENERGY							-5.174*** (1.239)	0.531 (1.881)
INTRA_ENERGY							1.815** (0.744)	0.755 (1.061)
Const.	4.388*** (1.344)	-5.770*** (1.558)	5.271*** (1.316)	-6.961*** (1.831)	4.257*** (1.120)	-6.747*** (1.225)	6.186*** (1.049)	-6.584*** (1.511)
No. of obs. (total)	2285		2285		2285		2285	
Pseudo-R2	0.152		0.141		0.169		0.188	
LR chi2	653.1		386.0		767.1		571.0	
p-Value	0.000		0.000		0.000		0.000	

Notes: See table 2.1 and 2.2 for the definition of the variables; base group: firms with 1 or 2 technology applications for MACHINE_N_0; firms with only 1 technology application for TRASPORT_N_0; BUILDING_N_0; and ENERG_N_0. Due to technical reasons the dummy variables ENEXP_0 and INVEST_0 were dropped. ***, **, * denote statistical significance at the 1%, 5% and 10% test level.

Table 2.9: Determinants of Intra-Firm Adoption of Several Types of Energy-Saving Technologies; Multinomial Logit Estimates including Adoption Motives (only Adopting Firms)

	MACHINE_N_0				TRANSPORT_N_0				BUILDING_N_0				ENERGY_N_0			
	0		2		0		2		0		2		0		2	
LN_EMPL	0.046	(0.057)	0.237***	(0.053)	-0.089	(0.057)	0.111	(0.073)	-0.135*	(0.071)	0.252***	(0.052)	-0.173***	(0.055)	0.232***	(0.071)
LN_INVEST/L	-0.031	(0.059)	0.008	(0.060)	-0.021	(0.066)	-0.012	(0.088)	0.016	(0.070)	0.106*	(0.056)	-0.264***	(0.065)	0.119	(0.094)
HQUAL	-0.003	(0.005)	-0.003	(0.004)	0.011**	(0.005)	0.009	(0.007)	0.010*	(0.005)	-0.002	(0.004)	0.008*	(0.005)	0.008	(0.006)
LN_ENEXP	-0.146*	(0.075)	0.051	(0.070)	0.037	(0.073)	0.128	(0.100)	0.120	(0.089)	0.033	(0.067)	-0.097	(0.073)	0.204**	(0.096)
R&D	-0.682***	(0.205)	0.159	(0.177)	0.004	(0.200)	0.429	(0.283)	-0.015	(0.231)	0.282	(0.173)	-0.233	(0.180)	0.200	(0.245)
FOREIGN	-0.539**	(0.234)	-0.353*	(0.206)	0.054	(0.235)	-0.138	(0.350)	0.263	(0.254)	-0.266	(0.198)	0.113	(0.208)	-0.709**	(0.319)
EXPORT	0.104	(0.196)	0.211	(0.187)	0.033	(0.202)	-0.286	(0.276)	-0.283	(0.234)	-0.069	(0.177)	-0.025	(0.193)	0.071	(0.268)
ENV_AWARE	-0.288***	(0.082)	0.169**	(0.081)	-0.017	(0.084)	0.244**	(0.117)	0.022	(0.095)	0.186**	(0.074)	-0.032	(0.080)	0.187	(0.115)
DEMAND_EXPECT	0.001	(0.099)	-0.032	(0.093)	0.101	(0.101)	0.007	(0.140)	-0.247**	(0.116)	0.011	(0.088)	-0.055	(0.095)	-0.014	(0.130)
INFO	0.147*	(0.087)	0.163**	(0.083)	-0.012	(0.089)	0.091	(0.122)	-0.202**	(0.102)	0.080	(0.079)	0.020	(0.085)	-0.081	(0.113)
COMPAT	0.035	(0.082)	-0.008	(0.079)	0.043	(0.085)	0.198*	(0.115)	-0.065	(0.097)	-0.122	(0.074)	0.155*	(0.080)	0.039	(0.111)
FIN	0.083	(0.087)	-0.006	(0.084)	0.011	(0.090)	-0.096	(0.125)	-0.252**	(0.101)	-0.146*	(0.080)	-0.011	(0.086)	-0.131	(0.117)
ORGAN	-0.054	(0.079)	-0.015	(0.075)	0.005	(0.081)	0.039	(0.111)	-0.070	(0.093)	-0.113	(0.072)	0.078	(0.076)	-0.003	(0.105)
ENERGY_PRICE	-0.037	(0.079)	0.104	(0.076)	-0.051	(0.080)	0.142	(0.110)	0.107	(0.095)	0.036	(0.071)	0.017	(0.077)	0.015	(0.103)
PUBLIC_REGUL	-0.015	(0.078)	0.113	(0.072)	0.019	(0.079)	0.113	(0.105)	0.126	(0.094)	0.129*	(0.069)	0.007	(0.073)	-0.003	(0.097)
PUBLIC_INCENT	0.022	(0.077)	-0.098	(0.072)	0.073	(0.078)	-0.048	(0.105)	0.012	(0.093)	-0.048	(0.068)	0.127*	(0.073)	0.031	(0.099)
OTHER	0.079	(0.080)	0.159**	(0.077)	-0.187**	(0.084)	-0.073	(0.116)	-0.080	(0.093)	0.233***	(0.073)	-0.262***	(0.079)	0.138	(0.111)
IPC	-0.076	(0.080)	-0.000	(0.076)	-0.084	(0.083)	-0.114	(0.109)	0.126	(0.096)	0.092	(0.072)	0.010	(0.076)	0.203*	(0.108)
INPC	-0.073	(0.087)	-0.046	(0.082)	0.116	(0.089)	0.194	(0.123)	-0.124	(0.104)	0.128*	(0.078)	0.097	(0.083)	0.192*	(0.113)
IND1	0.365	(0.576)	0.039	(0.469)	-0.528	(0.509)	0.243	(0.712)	-0.317	(0.556)	-0.146	(0.430)	-0.219	(0.444)	0.076	(0.644)
IND2	0.499	(0.394)	0.258	(0.295)	-0.118	(0.437)	-0.160	(0.549)	-0.494	(0.398)	0.007	(0.281)	-0.280	(0.299)	0.036	(0.390)
IND3	0.939**	(0.446)	0.243	(0.357)	-0.179	(0.468)	0.377	(0.615)	0.158	(0.420)	-0.171	(0.321)	-0.037	(0.347)	0.088	(0.489)
IND4	0.380	(0.630)	0.231	(0.541)	-0.535	(0.458)	0.587	(0.581)	-0.605	(0.554)	0.144	(0.427)	-0.727	(0.621)	0.745	(0.895)
IND5	0.939	(0.616)	0.110	(0.528)	-0.455	(0.408)	0.661	(0.511)	-0.283	(0.515)	0.210	(0.401)	-0.482	(0.486)	0.573	(0.714)
IND6	1.037**	(0.525)	0.056	(0.450)	0.140	(0.443)	0.454	(0.560)	-0.117	(0.437)	-0.122	(0.336)	-0.168	(0.473)	0.325	(0.693)
IND7	0.856	(0.628)	0.221	(0.540)	-0.715*	(0.430)	0.255	(0.561)	-0.871	(0.535)	-0.179	(0.412)	-0.884*	(0.519)	0.341	(0.746)
INTER_MACHINE	-1.936	(1.878)	-0.345	(1.587)												
INTRA_MACHINE	1.696***	(0.553)	1.516***	(0.510)												
INTER_TRANSPORT					-6.937***	(1.060)	0.506	(1.431)								
INTRA_TRANSPORT					1.032*	(0.567)	2.870***	(0.717)								
INTER_BUILDING									-2.494	(1.891)	-0.804	(1.478)				
INTRA_BUILDING									0.330	(0.457)	1.118***	(0.340)				
INTER_ENERGY													-5.581***	(1.342)	0.768	(1.888)
INTRA_ENERGY													2.215***	(0.812)	0.630	(1.076)
Const.	-2.668	(1.799)	-5.654***	(1.612)	1.158	(1.409)	-7.133***	(1.879)	0.597	(1.726)	-6.232***	(1.274)	2.432**	(1.177)	-6.609***	(1.569)
No. of obs. (total)	1219				1219				1219				1219			
Pseudo-R2	0.084				0.120				0.087				0.126			
LR chi2	220.1				255.5				213.9				289.4			
p-Value	0.000				0.000				0.000				0.000			

Notes: See table 2.1 and 2.2 for the definition of the variables; (*): these dependent variables are similarly constructed as the variables in table 2.8 but without the non-adopting firms; base group: firms with 1 or 2 technology applications for MACHINE_N_0; firms with only 1 technology application for TRASPORT_N_0; BUILDING_N_0; and ENERG_N_0. Due to technical reasons the dummy variables ENEXP_0 and INVEST_0 were dropped. ***, **, * denote statistical significance at the 1%, 5% and 10% test level.

2.8 Appendix

Table 2.10: Composition of Data Set by Industry and Size Class

	Number of firms	Percentage of firms (%)	Percentage of firms with energy-saving technologies by industry; size class (*)
Industry (NACE classification):			
Food, beverage, tobacco (15, 16)	98	4.2	72.4
Textiles (17)	24	1.0	66.7
Clothing, leather (18, 19)	10	0.4	40.0
Wood processing (20)	37	1.6	51.4
Paper (21)	25	1.1	68.0
Printing (22)	68	2.9	52.9
Chemicals (23, 24)	85	3.7	61.2
Plastics, rubber (25)	52	2.3	63.5
Glass, stone, clay (26)	41	1.8	68.3
Metal (27)	31	1.3	54.8
Metal working (28)	167	7.2	47.9
Machinery (29)	194	8.4	60.3
Electrical machinery (31)	58	2.5	56.9
Electronics, instruments (30, 32, 331-334)	126	5.5	50.0
Vehicles (34, 35)	40	1.7	35.0
Watches (335)	22	1.0	63.6
Other manufacturing (36, 37)	37	1.6	51.4
Energy, water (40, 41)	49	2.1	75.5
Construction (45)	203	8.8	47.3
Wholesale trade (50. 51)	172	7.5	47.1
Retail trade (52)	149	6.5	7.0
Hotels, catering (55)	105	4.6	57.1
Transport, telecommunication (60-63)	142	6.2	61.3
Telecommunication (64)	11	5.6	63.6
Banks, insurance (65-67)	129	0.8	45.7
Real estate, leasing (70, 71)	18	2.2	55.6
Computer services (72, 73)	50	6.5	44.0
Business services (74)	149	0.6	38.9
Personal services (93)	14	0.5	78.6
Firm size:			
Small (less than 50 employees)	1114	48.3	40.2
Medium-sized (50-249 employees)	838	36.3	60.6
Large (250 employees and more)	354	15.4	77.7
Total	2324	100	53.5

Notes: (*) At least 1 technology application.

Table 2.11: Descriptive Statistics

Variable	N	Mean	Std. Dev.
LN_EMPL	2324	4.027	1.475
LN_INVEST/L	2324	8.877	1.927
INVEST/L_0	2324	0.027	0.161
HQUAL	2324	21.721	20.528
LN_ENEXP	2324	0.632	1.099
ENEXP_0	2324	0.037	0.190
R&D	2314	0.309	0.462
FOREIGN	2312	0.143	0.350
EXPORT	2316	0.475	0.500
ENV_AWARE	2324	3.219	1.042
DEMAND_EXPECT	2324	3.575	0.829
INFO	2324	0.000	1.000
COMPAT	2324	0.000	1.000
FIN	2324	0.000	1.000
ORGAN	2324	0.000	1.000
IPC	2324	3.871	0.976
INPC	2324	3.220	0.909
ENERGY_PRICE	1294	0.000	1.000
PUBLIC_REGUL	1294	0.000	1.000
PUBLIC_INCENT	1294	0.000	1.000
OTHER	1294	0.000	1.000
INTER_MACHINE	2324	0.389	0.087
INTRA_MACHINE	2324	2.452	0.263
INTER_TRANSPORT	2324	0.180	0.097
INTRA_TRANSPORT	2324	1.565	0.207
INTER_BUIDING	2324	0.446	0.078
INTRA_BUIDING	2324	2.984	0.258
INTER_ENERGIE	2324	0.210	0.100
INTRA_ENERGIE	2324	1.452	0.151

Table 2.12: Correlation Matrix; Basic Model

	LN_EMPL	LN_INVEST/L	INVEST/L_0	HQUAL	LN_ENEXP	ENEXP_0	R&D	FOREIGN	EXPORT	ENV_AWARE	DEMAND_EXPECT	INFO	COMPAT	FIN	ORGAN	IPC	INPC	INTER_MACHINE	INTRA_MACHINE	INTER_TRANSPORT	INTRA_TRANSPORT	INTER_BUILDING	INTRA_BUILDING	INTER_ENERGY	INTRA_ENERGY
LN_EMPL	1.000																								
LN_INVEST/L	0.205	1.000																							
INVEST/L_0	-0.118	-0.761	1.000																						
HQUAL	0.041	-0.031	0.033	1.000																					
LN_ENEXP	-0.108	0.066	0.027	-0.149	1.000																				
ENEXP_0	0.052	-0.054	0.039	0.123	-0.114	1.000																			
R&D	0.253	0.113	-0.061	0.165	-0.050	-0.032	1.000																		
FOREIGN	0.169	-0.006	-0.005	0.158	-0.102	0.068	0.121	1.000																	
EXPORT	0.218	0.087	-0.040	0.143	-0.091	0.032	0.469	0.195	1.000																
ENV_AWARE	0.076	0.071	-0.015	-0.039	0.148	-0.075	0.037	-0.013	-0.039	1.000															
DEMAND_EXPECT	0.168	0.178	-0.121	0.039	-0.103	-0.004	0.130	0.061	0.150	0.033	1.000														
INFO	0.145	0.103	-0.060	-0.052	0.066	-0.050	0.028	-0.050	-0.018	0.142	0.073	1.000													
COMPAT	-0.109	-0.064	0.019	0.009	-0.031	0.010	-0.029	-0.042	0.009	-0.074	0.005	-0.004	1.000												
FIN	0.025	0.006	0.004	-0.134	0.094	-0.084	0.068	0.020	0.033	0.043	-0.043	0.006	0.003	1.000											
ORGAN	-0.049	0.008	-0.022	-0.035	0.025	-0.047	-0.008	-0.027	-0.006	-0.017	-0.025	-0.001	-0.003	0.001	1.000										
IPC	0.091	-0.007	-0.047	-0.033	-0.074	0.002	-0.006	0.037	-0.004	-0.020	0.018	0.016	0.071	0.099	-0.023	1.000									
INPC	0.072	0.045	-0.043	0.119	-0.122	-0.007	0.103	0.045	0.103	-0.006	0.026	0.012	0.007	-0.006	-0.011	0.055	1.000								
INTER_MACHINE	0.088	0.132	-0.028	-0.056	0.148	-0.089	0.333	0.032	0.304	0.079	0.021	0.022	-0.037	0.120	0.004	-0.063	-0.009	1.000							
INTRA_MACHINE	0.016	0.073	-0.008	-0.327	0.244	-0.125	0.038	-0.066	-0.035	0.077	-0.027	0.055	-0.009	0.135	0.022	0.027	-0.136	0.455	1.000						
INTER_TRANSPORT	0.020	0.131	-0.013	-0.101	0.215	0.009	-0.186	-0.101	-0.219	0.043	-0.045	0.074	-0.038	-0.043	-0.027	-0.094	-0.113	-0.121	0.207	1.000					
INTRA_TRANSPORT	-0.028	-0.004	-0.006	-0.119	0.087	0.015	-0.190	-0.090	-0.210	0.019	-0.128	0.037	-0.040	0.021	0.013	0.019	-0.001	-0.037	0.286	0.309	1.000				
INTER_BUILDING	0.081	0.143	-0.015	-0.186	0.211	-0.084	0.176	0.002	0.148	0.086	0.007	0.046	-0.065	0.120	0.003	-0.070	-0.020	0.810	0.631	-0.001	0.211	1.000			
INTRA_BUILDING	0.046	0.061	0.034	-0.004	0.016	0.027	-0.049	0.003	-0.073	0.057	-0.042	0.020	-0.072	-0.053	-0.014	-0.102	0.094	0.116	0.019	-0.112	-0.068	0.317	1.000		
INTER_ENERGY	0.094	0.155	-0.014	-0.087	0.195	-0.058	0.174	-0.023	0.135	0.092	-0.002	0.047	-0.066	0.071	-0.010	-0.084	-0.025	0.851	0.504	0.006	-0.011	0.895	0.433	1.000	
INTRA_ENERGY	0.029	0.091	-0.008	0.044	0.176	0.063	-0.233	-0.106	-0.334	0.024	-0.092	0.069	-0.084	-0.113	-0.073	-0.058	-0.088	-0.090	0.168	0.591	0.319	0.161	0.165	0.231	1.000

Note: The correlation coefficients are larger than 0.04 are statistically significant at the 10% test-level.

Table 2.13: Correlation Matrix; Model with Motive Variables

	LN_EMPL	LN_INVEST/L	INVEST/L_0	HQUAL	LN_ENEXP	ENEXP_0	R&D	FOREIGN	EXPORT	ENV_AWARE	DEMAND_EXPECT	INFO	COMPAT	FIN	ORGAN	IPC	INPC	INTER_MACHINE	INTRA_MACHINE	INTER_TRANSPORT	INTRA_TRANSPORT	INTER_BUILDING	INTRA_BUILDING	INTER_ENERGY	INTRA_ENERGY	ENERGY_PRICE	PUBLIC_REGUL	PUBLIC_INCENT	OTHER
LN_EMPL	1.000																												
LN_INVEST/L	0.171	1.000																											
INVEST/L_0	-0.076	-0.631	1.000																										
HQUAL	0.077	-0.033	0.078	1.000																									
LN_ENEXP	-0.097	0.153	-0.041	-0.170	1.000																								
ENEXP_0	0.061	-0.029	0.029	0.039	-0.098	1.000																							
R&D	0.226	0.108	-0.070	0.185	-0.060	-0.043	1.000																						
FOREIGN	0.139	-0.025	0.016	0.152	-0.097	0.046	0.109	1.000																					
EXPORT	0.209	0.089	-0.053	0.157	-0.115	0.008	0.495	0.206	1.000																				
ENV_AWARE	0.051	0.034	0.027	-0.013	0.136	-0.015	0.001	-0.006	-0.024	1.000																			
DEMAND_EXPECT	0.125	0.162	-0.092	0.036	-0.104	-0.015	0.094	0.062	0.140	0.064	1.000																		
INFO	0.084	0.069	-0.056	-0.010	0.045	0.001	0.001	-0.045	-0.050	0.071	0.046	1.000																	
COMPAT	-0.065	-0.077	0.041	-0.020	-0.014	-0.004	-0.011	-0.047	0.031	-0.010	-0.001	0.120	1.000																
FIN	-0.045	-0.063	0.014	-0.100	0.056	-0.070	0.053	0.067	0.032	-0.022	-0.053	-0.174	0.102	1.000															
ORGAN	-0.080	-0.003	-0.027	-0.045	-0.013	-0.054	-0.001	-0.023	-0.007	-0.084	-0.035	-0.038	0.064	-0.097	1.000														
IPC	0.051	-0.072	0.010	-0.005	-0.068	0.024	-0.015	0.026	0.024	-0.026	-0.027	0.003	0.075	0.086	-0.042	1.000													
INPC	0.023	0.005	0.017	0.120	-0.135	-0.029	0.072	0.024	0.092	0.025	0.017	0.009	0.010	-0.030	-0.020	0.081	1.000												
INTER_MACHINE	0.081	0.179	-0.062	-0.039	0.187	-0.090	0.351	0.074	0.305	0.055	-0.014	-0.017	-0.003	0.087	0.003	-0.070	-0.006	1.000											
INTRA_MACHINE	0.029	0.098	-0.055	-0.291	0.264	-0.083	0.063	-0.038	-0.025	0.060	-0.033	0.007	0.064	0.076	-0.008	0.003	-0.139	0.493	1.000										
INTER_TRANSPORT	0.004	0.208	-0.036	-0.111	0.275	0.007	-0.221	-0.150	-0.285	0.083	-0.050	0.077	-0.038	-0.103	-0.042	-0.142	-0.125	-0.081	0.207	1.000									
INTRA_TRANSPORT	-0.037	-0.018	-0.014	-0.158	0.104	-0.012	-0.165	-0.111	-0.222	0.023	-0.147	0.037	-0.005	0.010	-0.001	0.044	0.008	-0.018	0.322	0.265	1.000								
INTER_BUILDING	0.092	0.196	-0.056	-0.165	0.247	-0.072	0.186	0.027	0.142	0.071	-0.026	0.008	-0.020	0.067	-0.013	-0.083	-0.017	0.834	0.648	0.038	0.198	1.000							
INTRA_BUILDING	0.095	0.089	0.066	0.005	0.041	0.043	-0.034	-0.025	-0.077	0.073	-0.034	0.072	-0.089	-0.051	-0.023	-0.120	0.120	0.191	0.050	-0.032	-0.100	0.365	1.000						
INTER_ENERGY	0.101	0.219	-0.048	-0.072	0.241	-0.050	0.177	-0.004	0.124	0.093	-0.032	0.028	-0.037	0.026	-0.023	-0.096	-0.019	0.862	0.534	0.080	-0.017	0.905	0.488	1.000					
INTRA_ENERGY	0.033	0.166	-0.020	0.026	0.253	0.035	-0.246	-0.135	-0.360	0.059	-0.096	0.088	-0.102	-0.161	-0.085	-0.078	-0.090	-0.008	0.218	0.644	0.264	0.234	0.218	0.321	1.000				
ENERGY_PRICE	0.015	-0.016	-0.018	-0.056	-0.014	-0.055	0.033	-0.018	0.030	-0.011	0.093	0.215	0.115	0.113	0.115	0.048	0.023	0.046	0.049	-0.039	0.058	0.053	-0.051	0.018	-0.079	1.000			
PUBLIC_REGUL	0.147	0.052	-0.018	0.032	0.044	-0.003	0.004	-0.012	-0.008	0.053	0.002	0.139	0.058	0.027	0.046	-0.004	-0.003	-0.013	-0.009	0.037	-0.002	0.001	0.077	0.013	0.032	-0.003	1.000		
PUBLIC_INCENT	0.003	-0.005	-0.006	-0.002	0.071	-0.008	-0.037	-0.016	-0.032	0.050	-0.051	0.146	0.012	0.019	0.104	-0.057	-0.056	0.029	0.036	0.060	0.052	0.030	0.016	0.039	0.051	-0.004	0.004	1.000	
OTHER	0.022	0.026	0.016	0.012	0.025	-0.015	0.008	-0.057	-0.040	0.304	0.064	0.128	-0.009	-0.010	-0.051	0.036	0.044	-0.007	-0.006	0.024	-0.009	0.011	0.068	0.037	0.060	0.005	0.016	-0.004	1.000

Note: The correlation coefficients larger than 0.04 are statistically significant at the 10% test-level.

Table 2.14: Principal Components Factor Analysis of Barriers of Technology Adoption (Rotated Factor Pattern; Factor Loadings)

Obstacles	Factor 1	Factor 2	Factor 3	Factor 4
Anticipated falling price trend makes adoption currently unattractive	0.27	-0.00	-0.06	0.00
Technology not mature enough	0.41	-0.14	-0.08	-0.04
Information problems / costs	0.29	-0.13	-0.05	-0.01
Performance of technology still uncertain	0.37	-0.13	0.05	0.01
Technology too expensive	0.14	0.47	-0.14	-0.07
Too large investment volume	-0.13	0.39	-0.10	0.00
Too long payback period	-0.06	0.37	-0.11	0.01
Lack of liquidity	-0.22	0.22	-0.05	0.02
Inadequate know-how	-0.08	-0.10	0.41	-0.02
Lack of specialized personnel	-0.07	-0.10	0.40	-0.02
Management thoroughly absorbed by other tasks	-0.08	-0.05	0.36	-0.02
Uncertainty with respect to public regulation	0.05	0.03	0.12	0.02
Lack of compatibility with current product programme	-0.04	-0.01	-0.03	0.53
Lack of compatibility with current production technology	-0.04	0.01	-0.05	0.53
Statistics				
Number of observations	2324			
Kaiser's measure of sampling adequacy (MSA)	0.860			
Root mean square off-diagonal residuals (RMSE)	0.052			
Variance explained by each factor	2.811	2.576	2.722	1.834
Final communality estimate	9.943			
Characterization of the four factors based on the factor pattern:				
Factor 1: INFO				
Factor 2: FIN				
Factor 3: ORGAN				
Factor 4: COMPAT				

Note: The original 14 variables were measured on a five-point Likert-scale. The four-factor solution was chosen according to statistical criteria that are implemented in the software we used (SAS). In addition, we took a look whether these results made a sense in economic terms.

Table 2.15: Principal Components Factor Analysis of Motives of Technology Adoption (Rotated Factor Pattern; Factor Loadings)

Obstacles	Factor 1	Factor 2	Factor 3	Factor 4
Too high / increasing energy prices	0.43	-0.03	-0.14	-0.04
Current energy taxes	0.42	-0.12	-0.03	-0.03
Expected energy taxes	0.41	-0.05	-0.04	-0.04
Uncertainty as to future energy bottle-necks	0.16	0.21	0.06	-0.13
Current or expected demand for environment-friendly products	-0.08	0.66	-0.22	-0.01
Protection of environment	-0.08	0.47	0.10	-0.14
Public incentives for CO_2 reduction	-0.07	-0.09	0.61	-0.15
Public promotion of energy efficiency	-0.13	-0.08	0.61	-0.14
Compliance to current public regulation	-0.05	-0.13	-0.16	0.57
Compliance to expected new public regulation	-0.05	-0.08	-0.12	0.53
Compliance to agreements with government agencies	-0.12	0.22	-0.09	0.30
Statistics				
Number of observations	1294			
Kaiser's measure of sampling adequacy (MSA)	0.830			
Root mean square off-diagonal residuals (RMSE)	0.072			
Variance explained by each factor	2.258	2.073	1.878	1.633
Final communality estimate	7.840			
Characterization of the four factors based on the factor pattern:				
Factor 1: Energy prices, taxes(ENERGY_PRICE)				
Factor 2: (OTHER)				
Factor 3: Public incentives (PUBLIC_INCENT)				
Factor 4: Compliance to public regulation (PUBLIC_REGUL)				

Note: The original 11 variables were measured on a five-point Likert-scale. The four-factor solution was chosen according to statistical criteria that are implemented in the software we used (SAS). In addition, we took a look whether these results made a sense in economic terms.

Table 2.16: Probit Estimates of the Adoption of Several Types of Energy-Saving Technologies; Marginal Effects

	MACHINE		TRANSPORT		BUILDING		ENERGY	
LN_EMPL	0.056***	(0.007)	0.036***	(0.005)	0.078***	(0.007)	0.051***	(0.006)
LN_INVEST/L	0.029***	(0.008)	0.012*	(0.007)	0.031***	(0.008)	0.048***	(0.007)
INVEST/L_0	0.134	(0.097)	-0.039	(0.094)	0.142	(0.096)	0.345***	(0.092)
HQUAL	-0.000	(0.001)	-0.001	(0.000)	-0.001	(0.001)	-0.001*	(0.000)
LN_ENEXP	0.010	(0.009)	-0.003	(0.007)	-0.008	(0.009)	0.016**	(0.008)
ENEXP_0	-0.148***	(0.055)	-0.094*	(0.048)	-0.092*	(0.051)	-0.067	(0.049)
R&D	0.136***	(0.023)	0.043**	(0.020)	0.087***	(0.024)	0.070***	(0.019)
FOREIGN	0.004	(0.027)	-0.038	(0.023)	-0.066**	(0.027)	-0.053**	(0.023)
EXPORT	-0.004	(0.023)	-0.027	(0.019)	0.003	(0.023)	0.005	(0.020)
ENV_AWARE	0.070***	(0.009)	0.035***	(0.008)	0.057***	(0.009)	0.037***	(0.008)
DEMAND_EXPECT	0.016	(0.012)	0.002	(0.010)	0.033***	(0.011)	0.014	(0.010)
INFO	0.047***	(0.009)	0.032***	(0.008)	0.072***	(0.009)	0.021***	(0.008)
COMPAT	-0.075***	(0.009)	-0.029***	(0.008)	-0.079***	(0.009)	-0.049***	(0.008)
FIN	0.066***	(0.009)	0.031***	(0.008)	0.089***	(0.009)	0.032***	(0.008)
ORGAN	0.012	(0.009)	0.003	(0.008)	0.004	(0.009)	-0.006	(0.008)
IPC	0.026***	(0.010)	0.012	(0.008)	0.013	(0.010)	0.016*	(0.008)
INPC	0.009	(0.010)	-0.004	(0.009)	0.013	(0.010)	-0.002	(0.009)
IND1	-0.019	(0.063)	0.034	(0.048)	-0.014	(0.058)	0.025	(0.048)
IND2	-0.015	(0.043)	0.023	(0.040)	0.016	(0.040)	0.031	(0.033)
IND3	-0.025	(0.049)	0.046	(0.043)	0.002	(0.045)	0.032	(0.038)
IND4	0.035	(0.070)	0.058	(0.042)	0.062	(0.056)	0.137**	(0.065)
IND5	0.014	(0.069)	0.063*	(0.037)	0.063	(0.053)	0.103**	(0.052)
IND6	-0.002	(0.059)	0.005	(0.039)	0.042	(0.046)	0.066	(0.051)
IND7	0.031	(0.070)	0.068*	(0.039)	0.084	(0.055)	0.131**	(0.056)
INTER_MACHINE	0.533**	(0.213)						
INTRA_MACHINE	-0.030	(0.066)						
INTER_TRANSPORT			0.768***	(0.094)				
INTRA_TRANSPORT			0.032	(0.051)				
INTER_BUIDING					0.548***	(0.197)		
INTRA_BUIDING					-0.006	(0.045)		
INTER_ENERGIE							0.759***	(0.142)
INTRA_ENERGIE							-0.212**	(0.086)
No. of obs.	2285		2285		2285		2285	
Pseudo-R2	0.183		0.149		0.209		0.215	
LR chi2	560.2		323.3		656.7		515.0	
p-Value	0.000		0.000		0.000		0.000	

Notes: See table 2.1 and 2.2 for the definition of the variables. ***, **, * denote statistical significance at the 1%, 5% and 10% test level.

Table 2.17: Intra-Firm Adoption of Several Types of Energy-Saving Technologies; Ordered Probit Estimates (3 Levels)

	MACHINE_N		TRANSPORT_N		BUILDING_N		ENERGY_N	
LN_EMPL	0.187***	(0.020)	0.159***	(0.023)	0.256***	(0.021)	0.220***	(0.023)
LN_INVEST/L	0.075***	(0.023)	0.050*	(0.028)	0.114***	(0.023)	0.202***	(0.029)
INVEST/L_0	0.200	(0.295)	-0.174	(0.407)	0.757***	(0.289)	1.368***	(0.395)
HQUAL	-0.000	(0.002)	-0.002	(0.002)	-0.002	(0.002)	-0.003	(0.002)
LN_ENEXP	0.039	(0.027)	-0.014	(0.032)	-0.020	(0.027)	0.079**	(0.032)
ENEXP_0	-0.433***	(0.168)	-0.508**	(0.213)	-0.234	(0.155)	-0.350*	(0.206)
R&D	0.391***	(0.069)	0.216**	(0.085)	0.273***	(0.070)	0.279***	(0.079)
FOREIGN	-0.044	(0.078)	-0.163	(0.100)	-0.237***	(0.080)	-0.284***	(0.095)
EXPORT	0.011	(0.068)	-0.125	(0.082)	0.005	(0.068)	0.032	(0.083)
ENV_AWARE	0.220***	(0.027)	0.161***	(0.033)	0.197***	(0.027)	0.169***	(0.033)
DEMAND_EXPECT	0.042	(0.034)	0.009	(0.041)	0.094***	(0.034)	0.051	(0.041)
INFO	0.157***	(0.028)	0.146***	(0.034)	0.228***	(0.028)	0.073**	(0.033)
COMPAT	-0.206***	(0.028)	-0.103***	(0.034)	-0.240***	(0.028)	-0.191***	(0.033)
FIN	0.181***	(0.028)	0.128***	(0.035)	0.235***	(0.029)	0.116***	(0.034)
ORGAN	0.040	(0.027)	0.018	(0.033)	-0.000	(0.027)	-0.018	(0.032)
IPC	0.067**	(0.028)	0.047	(0.034)	0.053*	(0.028)	0.080**	(0.034)
INPC	0.020	(0.031)	-0.007	(0.037)	0.056*	(0.031)	0.010	(0.036)
IND1	-0.032	(0.183)	0.170	(0.205)	-0.080	(0.170)	0.099	(0.199)
IND2	0.009	(0.122)	0.105	(0.169)	0.032	(0.116)	0.129	(0.132)
IND3	-0.014	(0.142)	0.230	(0.184)	-0.019	(0.131)	0.155	(0.156)
IND4	0.102	(0.204)	0.297*	(0.178)	0.202	(0.165)	0.570**	(0.270)
IND5	0.057	(0.200)	0.322**	(0.158)	0.203	(0.156)	0.444**	(0.215)
IND6	0.016	(0.171)	0.088	(0.165)	0.086	(0.134)	0.283	(0.210)
IND7	0.128	(0.204)	0.309*	(0.168)	0.194	(0.161)	0.538**	(0.230)
INTER_MACHINE	1.316**	(0.618)						
INTRA_MACHINE	0.160	(0.194)						
INTER_TRANSPORT			3.173***	(0.406)				
INTRA_TRANSPORT			0.378*	(0.219)				
INTER_BUIDING					1.394**	(0.583)		
INTRA_BUIDING					0.149	(0.133)		
INTER_ENERGIE							2.944***	(0.594)
INTRA_ENERGIE							-0.727**	(0.349)
cut1	4.002***	(0.608)	4.114***	(0.560)	4.718***	(0.488)	4.662***	(0.492)
cut2	4.812***	(0.610)	4.736***	(0.562)	5.375***	(0.490)	5.465***	(0.496)
No. of obs.	2285		2285		2285		2285	
Pseudo-R2	0.139		0.123		0.160		0.174	
LR chi2	597.4		337.2		724.8		528.3	
p-Value	0.000		0.000		0.000		0.000	

Notes: See table 2.1 and 2.2 for the definition of the variables. ***, **, * denote statistical significance at the 1%, 5% and 10% test level.

Table 2.18: Intra-Firm Adoption of Several Types of Energy-Saving Technologies; Ordered Probit Estimates (6 Levels)

	MACHINE_N_5		TRANSPORT_N_3		BUILDING_N_5		ENERGY_N_4	
LN_EMPL	0.183***	(0.019)	0.155***	(0.023)	0.257***	(0.020)	0.222***	(0.023)
LN_INVEST/L	0.077***	(0.022)	0.051*	(0.028)	0.129***	(0.022)	0.200***	(0.028)
INVEST/L_0	0.216	(0.288)	-0.128	(0.399)	0.866***	(0.279)	1.339***	(0.392)
HQUAL	-0.000	(0.002)	-0.003	(0.002)	-0.002	(0.002)	-0.003	(0.002)
LN_ENEXP	0.049*	(0.026)	-0.008	(0.031)	-0.008	(0.025)	0.081***	(0.031)
ENEXP_0	-0.419**	(0.164)	-0.492**	(0.212)	-0.256*	(0.149)	-0.363*	(0.205)
R&D	0.350***	(0.066)	0.214**	(0.083)	0.231***	(0.066)	0.250***	(0.077)
FOREIGN	-0.097	(0.075)	-0.173*	(0.099)	-0.245***	(0.076)	-0.259***	(0.094)
EXPORT	0.021	(0.066)	-0.118	(0.081)	0.018	(0.065)	0.023	(0.082)
ENV_AWARE	0.228***	(0.026)	0.159***	(0.032)	0.196***	(0.026)	0.167***	(0.032)
DEMAND_EXPECT	0.041	(0.033)	-0.004	(0.041)	0.082**	(0.032)	0.053	(0.040)
INFO	0.162***	(0.027)	0.139***	(0.034)	0.227***	(0.027)	0.079**	(0.033)
COMPAT	-0.188***	(0.027)	-0.098***	(0.033)	-0.222***	(0.027)	-0.178***	(0.032)
FIN	0.175***	(0.028)	0.119***	(0.034)	0.215***	(0.027)	0.120***	(0.034)
ORGAN	0.036	(0.026)	0.015	(0.032)	0.010	(0.026)	-0.027	(0.032)
IPC	0.059**	(0.027)	0.042	(0.033)	0.052*	(0.027)	0.080**	(0.033)
INPC	0.034	(0.030)	0.002	(0.036)	0.055*	(0.029)	0.003	(0.035)
IND1	-0.077	(0.175)	0.161	(0.203)	-0.068	(0.161)	0.091	(0.197)
IND2	-0.054	(0.116)	0.107	(0.166)	0.025	(0.109)	0.140	(0.130)
IND3	-0.051	(0.135)	0.210	(0.182)	0.038	(0.124)	0.158	(0.154)
IND4	0.075	(0.196)	0.275	(0.176)	0.195	(0.157)	0.519*	(0.267)
IND5	0.026	(0.192)	0.277*	(0.155)	0.213	(0.149)	0.405*	(0.213)
IND6	-0.019	(0.165)	0.023	(0.163)	0.123	(0.127)	0.254	(0.208)
IND7	0.046	(0.196)	0.299*	(0.166)	0.207	(0.153)	0.488**	(0.227)
INTER_MACHINE	1.079*	(0.591)						
INTRA_MACHINE	0.167	(0.185)						
INTER_TRANSPORT			3.053***	(0.403)				
INTRA_TRANSPORT			0.406*	(0.216)				
INTER_BUIDING					1.220**	(0.557)		
INTRA_BUIDING					0.161	(0.126)		
INTER_ENERGIE							2.758***	(0.586)
INTRA_ENERGIE							-0.541	(0.342)
cut1	3.911***	(0.580)	4.062***	(0.552)	4.791***	(0.460)	4.823***	(0.480)
cut2	4.284***	(0.581)	4.684***	(0.554)	5.066***	(0.461)	5.625***	(0.484)
cut3	4.724***	(0.583)	5.158***	(0.557)	5.448***	(0.462)	6.509***	(0.494)
cut4	5.208***	(0.584)	5.839***	(0.464)	7.050***	(0.507)		
cut5	5.749***	(0.586)	6.219***	(0.466)				
No. of obs.	2285		2285		2285		2285	
Pseudo-R2	0.103		0.109		0.119		0.164	
LR chi2	602.1		324.2		763.4		536.6	
p-Value	0.000		0.000		0.000		0.000	

Notes: See table 2.1 and 2.2 for the definition of the variables. ***, **, * denote statistical significance at the 1%, 5% and 10% test level.

Chapter 3

Insights into the Determinants of Innovation in Energy Efficiency

3.1 Introduction

This study empirically analyses the factors explaining firms' innovative activities related to energy efficient technologies (EET), focussing both on demand-pull and on technology push (such as human capital and competition) effects. To this aim, a novel dataset of innovative activity in a broad setting of energy-efficient technological applications has been conducted recently (spring 2009) among Swiss firms belonging to both the manufacturing and service sectors. More than 2300 participants returned valid questionnaires (resulting in a response rate of nearly 40%), enabling a number of general insights to issues relevant to corporate management as well as for the academic and political debate.

Technical change and innovative behaviour have been playing a central role in modern growth theory. However, two inherent characteristics of innovations — that the investments required to generate them and their potential benefit are uncertain ex ante, and that not all of the benefits of successfully having generated innovations may be appropriable by the firm — make it likely that profit-maximising firms will invest substantially less efforts into generating technological advances than would be socially optimal. If, moreover, progress in a field such as environmental technology has the potential to reduce negative externalities like pollution and greenhouse gas emissions, the problem of a rate of technological progress below a socially desirable level is aggravated even more, giving rise to a "Two Market Failures" problem (Jaffe et al. 2005). Not surprisingly, ecological innovation and its policy implications have become a prominent and complex field of economic investigation.

The question of optimal level of aggregate environmental research activity ultimately is a macroeconomic one, as is the problem of finding an appropriate mix of policy measures to achieve this in the long term (for a formal solution, see Acemoglu et al. 2009). A better understanding at the microeconomic level — about the determinants of environmental innovation activity at the firm or even at the project level, how it relates to overall (i.e. not environment relevant) innovation activity and what its implications in term of efficiency or profitability are — is however necessary for a thorough understanding of how to achieve this macroeconomic goal. This study is a contribution to this type of research, focusing however on specific question of energy related technologies, namely those that enable enterprises and households to reduce their energy inputs for given production or consumption requirements, thus improving energy efficiency.

Concerns about the sustainability of the current patterns of energy use have gained such prominence in recent years (raising awareness about the scarcity of energy sources, price volatility and, last but not least, climate change being the main concerns) that it seems justified to pay particular attention to questions related to energy and energy efficiency from an economist's viewpoint (Popp et al. 2009). Ambitious emission reduction goals for greenhouse gases have been formulated by environmental lobbyists, natural scientists and (increasingly) by governments. There is an overwhelming consensus (at least among economists) that in order to meet such goals, technological progress in the area of energy generation and consumption needs to be fastened dramatically.

Enabling and (if deemed useful) actively supporting innovation of energy efficient technologies thus becomes a policy priority. A better understanding of the economic environment in which such EET innovations are best brought to success is indispensable if such policy is to be formulated. Of major importance in this context is the idea of *price-induced innovation*, dating back to Hicks (1932, as quoted e.g. by Jaffe et al. 2000) and stating that innovation activity in technologies that allow for substitution in input factors responds to the evolution of relative prices of these factors. Under this hypothesis, implementing policies that persistently increase the price of energy inputs may be feasible to trigger the expected technological improvements in energy efficiency in a long run perspective. Robust empirical analysis of the price-induced innovation hypothesis ideally relies on time-series data and thus is out of reach of this paper (but has been the topic of several other fruitful studies). However, one transmission mechanism by which price-induced innovation would function is by increased demand for energy efficient capital goods by firms and households using energy as an input, which in turn should prompt more pronounced efforts in the development of such technology by firms providing these goods — an effect which the present study can offer some insights on.

My analysis thus attempts to take into account demand-pull determinants (related to the characteristics and size of markets that current and potential providers of such technology operate in) as well as technology-push factors (firms' and industries' intrinsic capabilities to research innovate), and in particular to reveal how these effects differ from determinants of overall innovative activity.

Whereas this study does not cover the topic of determinants of the (broader) concept of eco-innovations, the 2009 survey allowed for firms to inform about their overall innovative behaviour, besides items related to innovations in a vast list of different technologies related to energy efficiency and alternative (renewable) energy generation. Data for average per-employee energy efficiency related R&D investment at the firm level has also been obtained, with some reservations made due to the small number of enterprises actually researching in this field.

The remainder of this paper is organised as follows. Section 2 resumes findings of related (mostly empirical) literature, section 3 presents the data sources alongside with some remarks concerning the construction of variables, section 4 describes the econometric framework and the results, and section 5 concludes.

3.2 Related Literature

To the best of my knowledge, no empirical study so far has looked at the microeconomic determinants for innovation related to energy efficient technology. This may be attributed not so much to a lack of interest, but rather to the restricted availability of data (stemming partly from the fact that the topic itself and, in consequence, funding for data collection exercises have received substantial attention only since recently). Related empirical studies may be grouped according to the dimension in which they deviate from the present paper: *macro- or mesoeconomic* studies having industries or countries as their unit of analysis; studies related to *ecological innovation* which is a related but potentially broader technological category than EET; and studies attempting to explain *diffusion* of EET, thus looking at the stage subsequent to actual innovation in the process of technological change. In addition, analyses of the effects of *energy policy* on innovation and of the *profitability or productivity* effects of innovation are worth mentioning here, as they look at EET innovation from a different perspective (or from a different point in the causality chain).

Turning to the *macro- or meso-economic* level, studies explicitly focusing on innovation of energy efficient technologies are Popp (2002) and Verdolini and Galeotti (2009). Both rely on panel data constructed of patent counts and address the issue of induced innovation. The former uses energy efficiency related patent categories as the cross sectional dimension, whereas the latter features cross country data in order to study the geographical and technological channels through which energy-efficient innovation and knowledge disseminate, thus explicitly modelling international technology spillovers. Both studies confirm the importance of demand-pull effects proxied by energy prices as determinants for EET related innovation and suggest furthermore that knowledge stocks (modelled by past research efforts) should be taken into account in the kind of dynamic framework they use.

Testing the induced innovation hypothesis has been the motivation for a number of energy technology related empirical works. Energy efficiency innovation is a phenomenon that ideally lends itself to empirically test for this, since energy prices are universally observed across time and affect economic agents homogeneously, due to the uniform price evolution of energy inputs.[1] Besides this, energy spendings can make up for a large share of production costs of firms in many industries and for expenditure in households. A comprehensive effort is undertaken by Linn (2008), comparing US plant-level energy efficiency data between new entrants and industry incumbents. He finds a significant positive effect (albeit weak in magnitude) for energy prices on the relative efficiency of new plants, supporting the induced innovation hypothesis. Popp et al. (2009, page 29), reviewing other empirical studies addressing the same hypothesis, support this finding of positive and statistically significant induced innovation effects, which are however small in magnitude.

The broader concept of *environmental innovation* has been analysed by economists more prominently than energy innovation, perhaps since many environmental issues have gained public attention (and in consequence environmental standards have been introduced) much earlier than has been the case with energy. Johnstone and Labonne (2006) provide both a recent survey and an empirical investigation, with a specific focus on the effects of public policy frameworks on environmental R&D. In their influential article, Brunnermeier and Cohen (2003) find a positive impact of pollution abatement pressures (as proxied by the corresponding expenditure) on successful patent applications related to ecological technologies. Some recent econometric studies at the firm-level have analysed the effects of Environmental Management Systems (EMS) on the propensity to innovate. Both Wagner (2007) and Horbach (2008) do this for German manufacturing firms. The former uses both patent data and self-reported questionnaire data, while the latter relies on two panel datasets from different sources.

Finally, the main findings of the literature on determinants of overall innovative activity are also of importance here. The broad availability of innovation indicators at the micro level, as exemplified by the CIS (Community Innovation Survey) in European countries, has generated a vast body of empirical studies covering virtually all aspects of innovation. Crépon et al. (1998) provide probably the most systematic operationalisation of an integrated empirical model of innovation that covers the outcomes of R&D, patenting and productivity, and which has been influential to all subsequent research. To resume just some of the most prominent of the important findings of the mentioned study and those who have followed, the firm size effect on innovation is found to be positive (as far as innovation *propensity* is concerned, i.e. when analysing binary indicators of whether a firm is innovative or not), but turns out to be quite ambiguous as for the *intensity* of innovation (when looking at indicators such as R&D expenditure per employees or the share of innovative products in total sales). Stating whether demand-pull factors (emphasised by Schmookler 1966) or technology-push determinants are more important is difficult, as different studies use different sets of variables to accommodate these, reaching mixed conclusions.

[1] At least, prices within the two categories making up for the vast majority of energy inputs in the economy (fossil fuels and electricity) can be expected to exhibit little variation across geography and users at a given point in time.

3.3 Data and Construction of Variables

The dataset has been constructed on the basis of the Swiss Enterprise Panel maintained by KOF Swiss Economic Institute at ETH Zürich, using survey response data both from the Energy Technology Survey conducted in 2009, and from the 2008 Innovation Survey. The sample used for both surveys was identical (except for any attrition due to firms dropping out, following an explicit refusal from their part to participate or due to bankruptcy), and can be considered as representative of the private sector of the Swiss economy. Questionnaires were provided in German, French and Italian versions for both surveys mentioned.

3.3.1 The 2009 Energy Technology Survey

KOF Swiss Economic Institute decided to undertake a survey among Swiss enterprises covering specifically the topic of innovation and diffusion of technologies related to energy efficiency and alternative energy sources in 2009. Over 2000 participants returned valid questionnaires. For the present analysis, which limits itself to technological *innovation* (as opposed to *diffusion*, i.e. application of such technologies by firms which purchase them from other providers), some industries belonging to the service sector have been excluded since they are, due to the nature of their main business activity, highly unlikely to be innovative in the area of energy efficient technology, resulting in a reduced data set of 1577 enterprises. For an overview of the industries retained for this analysis and their respective counts in the dataset, see the first column of table 3.1. Due to missing data in some of the variables, the number of observations retained for the econometric analysis presented in the next chapter further drops to 1309.

In the questionnaire, the section covering EET innovation asked respondents to specify if they had generated such innovations in the past five years, and if yes, to which technological field(s) those innovations belong, out of a list of 35 specific fields. In addition, questions about the magnitude of their EET related R&D investments (relative to total R&D investments) and sales of energy technology related innovative products or services (relative to total sales) were featured. These latter two allow constructing measures of intensity of both R&D (as an input measure in the innovation chain) and of innovation success (an output measure) related to EET, which are then used to complement the econometric analysis of binary indicators for R&D and innovation in this paper.

Table 3.1 shows the composition of the data set by industry and size classes as well as the number and percentage of EET innovators for each class. Not surprisingly, fairly large proportions of EET innovators (more than 20%) can be found among manufacturers of electrical and non-electrical machinery, vehicle manufacturers and the energy facilities. A finding also in line with other studies of general or specific innovativeness is that the fraction of innovators is significantly larger among large firms than among small ones (see lower half of table 3.1). In total, 162 firms are — by their own judgement — innovators in energy efficiency related technologies.

Table 3.2 provides a brief overview of how often the four different dimensions of innovative activity of interest in this paper — EET innovation, as discussed in the preceding paragraph, being one of them — appear in our data. Nearly two out of three firms (64.7%) turn out to have generated innovations of any kind (including, but not only EET) within the tree years up to the date of the survey. Formal R&D activities are conducted by a share of 41.2%. The relative frequencies of innovators in EET and of R&D performers in EET, in comparison, are much smaller (10.3% and 6.3%, respectively), but still sufficient to obtain valuable econometric insights. Consequently, the four dimensions of innovative activity just described make up the (binary) dependent variables in the econometric models presented in subsection 3.4.1: INNO_ALL (the firm has generated innovations of any kind), RND_ALL (the firm does research related to any field), INNO_EET (the firm has generated EET related innovations), and RND_EET (the firm does research related to EET).

For purely descriptive purposes, I also list the technological fields featured in the questionnaire and the number of occurrences of each of them in table 3.3. Electrical engineering clearly is the most prominent of the broader fields here, while building technology and heat generation (two fields with a fairly broad range of applications) exhibit a moderate degree of importance. Transport/vehicles and electricity generation/transmission seem of lesser significance. The latter findings might be due to the fact that (final assembly of) vehicles is of little importance in Switzerland, and that electricity generation and transmission systems (where some large Swiss firms are competitive in the world market) tend to be large-scale applications requiring substantial investment volumes and highly integrated solutions, allowing only a handful of very large corporations to successfully compete.

3.3.2 Variables

I know turn to the explanatory variables used in the econometric analysis that follows (Table 3.4 provides a summary of the information given the present subsection).

Basic Firm Characteristics

In line with the widely confirmed empirical finding that larger firms are more likely to undertake research and to generate innovations, the variable LN_EMPL captures firm size, measured as the natural logarithm of the number of full-time equivalent employees. Since innovative activity is also likely to depend on capital intensity, it would be desirable to include this measure in my analysis. However, only a flow measure (i.e. investment) is available in our dataset, as opposed to a true capital stock variable. As including an investment measure might give rise to endogeneity issues, I do not include it in the analysis that follows.[2]

Further firm characteristics include binary variables indicating whether a firm is held by foreign owners in majority (FOREIGN), and whether it declares itself to be an exporter (EXPORT). Both can in principle be expected to have a positive impact on innovative behaviour, since international involvement of any kind — whether it is by exporting goods to foreign markets or by being in foreign ownership — tends to facilitate access to knowledge, markets and funding, all of which are essential in fostering successful innovation. Human capital intensity within the firm is measured by the proportion of employees having completed higher education (HI_EDU); again, this variable captures a factor that is essential in the development of new products and processes and thus should positively affect any innovative activity. A preference of the firms' management to use environmentally friendly material inputs in its production process is captured by the variable ECO_FRIENDLY, serving as a proxy to a broader commitment by the management to position itself as an environmentally responsible actor. A positive effect, at best, may be expected for innovations related to energy efficiency, but less probably so for overall innovative activity.

The remaining explanatory variables can broadly be categorised into either market or technology related, thus loosely following the distinction made by many previous empirical studies between demand-pull and technology-push factors (see Cohen 1995).

Market Related

This category comprises firms' assessment of the evolution of demand for its products, both retrospectively in the three years up to 2008 (DEMAND_R) and as expectations for the current/upcoming three years from 2009 (DEMAND_F). Variables expressing how firms perceive the intensity of competition on its product markets, both in their price (PCOMP) and non-price (NPCOMP) dimensions also enter in this category. Answers to all of these four variables are available on a five-point Likert scale, as specified on the questionnaire.

Technology Related

Technology (or, technological capacity) related variables can be constructed on the basis of firms' indications as to the relevance of innovation protectability/appropriability measures, knowledge sources, innovation obstacles and -goals.

TECH_PROT simply expresses the perceived effectiveness of protection measures against technological imitation by other firms — no matter whether they are of formal (patents, copyrights) or informal (such as secrecy or inherent complexity) nature.

[2] As a robustness check, all of the estimations that follow have also been calculated in a version that includes the log of total investments divided by employees. Whereas this investment variable was significant in one case (binary indicator for overall R&D), results for the other variables were not affected significantly by including it.

Appropriability, thus defined, is generally regarded as providing positive incentives on R&D efforts, as firms are capable of reaping the benefits of their research efforts rather than losing them partly or entirely due to outgoing spillovers. For achieving a socially desirable combination of R&D effort and knowledge dissemination levels across firms, however, appropriability may pose an obstacle rather than a solution by artificially generating monopolistic situations and wasteful duplication of research; an important point made by Spence (1984). A positive effect of this variable on innovation and R&D performance — as I expect to find in the econometric analysis — therefore should not be regarded as unconditionally positive from a perspective of social optimality, even though it might be so from the individual firm's viewpoint.

The importance of two different sources of knowledge is captured by the two variables KS_CUST, referring to firms' customers, and KS_PAT, referring to patent disclosures. OBST_MARKET, OBST_FUNDS and OBST_HR reflect whether the firm encountered obstacles in its innovation process that were attributable respectively to marketability risks, (insufficient) external funding and (lack of) dedicated R&D personnel. Finally, GOAL_ENV expresses that generating new environmentally friendly products was an important goal in the firm's innovation strategy.

Again, these technology related variables are measured on a five-point scale. However, since they were not part of the 2009 survey our dataset stems from and are only available through the 2008 wave of the Swiss Innovation Survey[3], I had to rely on using three-digit and four-digit industry average values obtained from the 2008 survey and assigning the corresponding value to each observation in the dataset. This obviously raises some questions about their representativeness, but also brings about certain advantages, to be discussed in the next subsection.

Various Control Variables

Further controls for the regression equations include dummy variables for six industry groups and dummies for the language of the questionnaire submitted to and returned by the respective enterprise (LANG_FR and LANG_IT). The choice of the latter is due to the fact that there might be slight (but empirically noticeable) differences in the interpretations of the notions "Innovation" and "Research and Development" (or any of the notions of concern for the explanatory variables obtained from the survey) across different languages, let alone differing innovative behaviours across the linguistic regions in Switzerland.[4]

[3]Conducted by KOF Swiss Economic Institute, ETH Zürich

[4]I found that using controls for seven geographical regions instead of the dummies for three languages (which overlap with the regions to a large degree anyway) in the estimation did not result in any effective improvement of coefficient significance or model fit.

3.3.3 A Note on the Construction of Some Explanatory Variables

The technology related explanatory variables are derived from a previously conducted survey, as mentioned above (the Energy Survey 2009 questionnaire did not contain any such questions). One-to-one matching from responses obtained by the previous survey (Innovation 2008) to observations in the Energy Survey has been rejected, and instead three-digit and four-digit within-industry means for these variables have been calculated and attributed to each observation according to its industry classification. To be more precise, in the main dataset built on the basis of the 2009 survey, each observation has been assigned the mean value of the respective variable calculated over all firms in the 2008 survey belonging to either the same three-digit industry or the same four-digit industry.[5] Since different economic activities as captured by the NACE classification appear with different frequencies in a given population, and since the number of appearances of each activity category in a random sample are random themselves, the size of cells used for calculation of these means varies largely in our data. As both cells that are too small or too large may contribute to measurement error — by inflating random variation induced by individual observations that are not smoothed out by a sufficient number of economically similar observations, and by introducing more economic heterogeneity into a cell — an algorithm was chosen in order to achieve some degree of balance between "too small" and "too large" cells (see footnote 5). Table 3.10 summarises the frequencies by which certain cell sizes appear as a result of the procedure. While most cells contain between two and twenty observations, roughly a quarter are either smaller (of one single observation) or larger (more than twenty), while the average cell size is 8.8.

As mentioned, relying on such within-industry means is foremost, motivated by data limitations (the overlap between the respondent set of the two surveys is far from perfect). Less evident — but perhaps more important — is the concern that obstacles to innovation (and, to a lesser extent, knowledge sources) are *learned* through innovation: they are perceived more pronouncedly by firms that actively pursue innovation projects, since non-innovators evidently do not get any first-hand experience about them (at least not for obstacles that typically do not come up in the early stages of innovation projects). This phenomenon has been empirically addressed in depth and convincingly confirmed by Baldwin and Lin (2002).[6] As a consequence, micro-econometric regression exercises using obstacles perceived by individual firms as explanatory variables to predict their innovation outcomes may fail to produce unbiased estimates for the innovation hampering effect of such obstacles, as they suffer from serious endogeneity issues (which

[5]The decision criterion for whether to use three-digit or four-digit means was the respective size in terms of number of observations of the corresponding cell: if the number of 2008 survey participants in a three-digit industry exceeded 25, four-digit means were used, otherwise three-digit means.

[6]And apparently cannot be neglected in our own data, since for the majority of obstacle categories, innovators consistently report higher scores in the survey than non-innovators, as outlined on pages 66–67 in Arvanitis et al. (2010).

may in the worst case produce estimates of a different sign than expected, i.e. positive rather than negative).

Constructing explanatory variables on the basis of within-industry means potentially alleviates this bias by providing average measures stemming from firms similar (in terms of economic activity) to the one in question. Evidently, this procedure gives rise to other problems. If heterogeneity of firms *within* a four-digit industry with respect to these variables is too high, the information content relevant to the individual firm captured by such means might be too little to produce significant estimates. Moreover, it cannot be ruled out that *between-industry* heterogeneity (which I actually need to rely on in order to identify the effects of these variables in the approach chosen) is related to innovative behaviour through other channels than direct causality. In the worst case, this means that the issue of endogeneity is not eliminated but rather shifted to a different level — from the individual firm towards the industry. In particular, industries exhibiting systematically higher innovation propensities (in terms of the proportion of firms innovating) may be expected to consistently yield higher means for some of the explanatory variables in question. Despite all these drawbacks, the use of within-industry means remains my preferred specification, and a number of robustness checks, outlined further in the next section, have actually been carried out to address — at least partly — these concerns. Consequently, only those findings that have been found to be robust to all of these checks (which is the case for the majority of those findings) enter the interpretations of the results that follow.

3.4 Econometric Framework and Results

As mentioned, the aim of this study is twofold: to identify the factors determining energy efficiency technology (EET) related innovation, and to find out in what respect they differ from the determinants of overall innovative activity as indicated by our data and by previous empirical exercises. Since we capture innovative activity at two different stages of the innovation process — R&D and actual innovations generated — and, at each stage, in two measures (as a binary indicator whether the firm is active at the respective stage, and as an intensity measure for those firms who are active), the following procedure has been chosen. Subsection 3.4.1 uses binary dependent variable (Probit) models to predict the four outcomes *overall R&D* and *overall innovation* as well as *EET related innovation* and *EET related R&D*:

$$Pr(OUTCOME_i^k = 1) = f^k(\beta_k X_i + \gamma_k F_{j(i)} + \epsilon_{ik}) \tag{3.1}$$

where i identifies the firm, $k = 1..4$ indexes one of the four outcomes mentioned such that $OUTCOME_i^k$ is one out of RND_ALL_i, RND_EET_i, $INNO\_ALL_i$ and $INNO\_EET_i$; and where X_i and $F_{j(i)}$, respectively, are the firm-specific and industry specific (for industry j to which firm i belongs) explanatory variables. Admitting the

f^k's to be normal cumulative density functions and the error terms ϵ_{ik} to be distributed normally, the model parameters β_k and γ_k may be consistently estimated by the standard Probit model. Furthermore, assuming cross correlation between the ϵ_{ik}'s (such that $E(\epsilon_{ij}\epsilon_{ik}) \neq 0$ for $j \neq k$), efficient estimates can be obtained by applying a Multivariate Probit model.

Subsection 3.4.2 extends this analysis to measures of innovation and R&D intensity (for the case of EET innovativeness only) using a Generalised Tobit (Type 2) selection model to accommodate for potential selectivity, thus following the framework for empirical analysis used by Crépon et al. (1998) with regards to R&D intensity and by Mohnen et al. (2006) with regards to innovation intensity, in order to control for potential selectivity bias:

$$rnd_i^{EET} = \alpha_1 X_i + \eta_i^1 \tag{3.2}$$

$$innosales_i^{EET} = \alpha_2 X_i + \eta_i^2 \tag{3.3}$$

where $rndexp_i^{EET}$ and $innosales_i^{EET}$ are the intensity measures used for EET R&D (the logarithm of R&D investments per employee) and innovations (the sales share of EET related innovative products, logistically transformed), which are defined only for those firms conducting such research and having generated such innovations, respectively. Selectivity means that the residuals η_i^{rnd} and $\eta_i^{innosales}$ may be correlated with the respective residuals of the binary outcome equation (3.1), requiring the Generalised Tobit approach mentioned above for consistent estimation of the parameters α_1 and α_2.[7]

3.4.1 Binary Innovation and Research Indicators

Table 3.5 compares the parameter estimates for determinants of overall R&D to those of EET related R&D, and table 3.6 does likewise for overall innovations and EET innovations, obtained each from standard Probit estimations. Since the reference period for the indicators considered here overlap (even if not perfectly so), we should not expect a firm to take the respective decisions to engage in any of these four activities independently from each other. A simultaneous estimation procedure, as provided by the Multivariate Probit model, would then provide efficient and thus preferable estimates, and at the same time reveal if cross-correlation among the four equations is present. I report such estimates in table 3.7.[8] Since the six estimated correlation coefficients between the four equations are significantly different from zero, cross-correlation is present and therefore the estimates in table 3.7 are the preferred ones I will refer to in what follows (the qualitative differences to the equation-by-equation estimates being only marginally different,

[7]For concerns of econometric identification and model stability, industry specific explanatory variables are assumed to have no effect upon research and innovation intensity — section 3.4.2 explains this in more detail.

[8]Based on the `mvprobit` implementation for Stata by Lorenzo Cappellari and Stephen P. Jenkins

however).

It appears that for a number of variables, primarily those related to basic firm characteristics and demand, the qualitative effect does not change when passing from measures of overall to EET innovativeness, and is in accordance with previous findings in the empirical literature. Firm size, the proportion of employees having completed higher education, evolution of demand (either previous or as expected for the future) and being an exporter all positively affect the probability of both engaging in R&D activities and being innovative. Deviations from this pattern of similarity between overall and EET related innovativeness are EXPORT (which positively affects overall innovations but has no significant effect upon EET innovations), as well as the influence of demand with regards to R&D: overall R&D seems to be affected by (forward looking) demand expectations, whereas only a small and insignificant effect can be found for EET R&D.

As a somewhat puzzling finding, firms that have been contacted by means of a French questionnaire report less innovations, regardless of whether overall or EET related innovations are the concern. This result cannot be attributed to differences in economic structure between the linguistic regions, as economic activity has been controlled for using industry dummies.[9] Without any further investigation, and since there are no comparable studies using language dummies based on Swiss data, currently the only tenable explanation is that speakers of the French language have a narrower understanding of the term “innovation”, which results in them being more reluctant to classify their firms’ new or improved products and processes as innovative. The finding that no statistically significant linguistic difference emerges in our data in the context of R&D — being a notion that brings about less ambiguities in its potential interpretations than “innovations” — supports this explanation. Of more importance for the present study is the finding that this peculiarity in our results for firms belonging to the French speaking language region equally arises for both overall and EET innovations, i.e. no language specific innovation patterns appear when looking at the special case of energy efficient technologies.

Substantial differences between the determinants for overall and for EET related innovativeness appear among the remaining variables. A first insight concerns some explanatory factors related to market environment in a broad sense: non-price competition favours overall but not EET related innovativeness — the effect is negative but not significant for the latter.[10] This positive effect on overall innovativeness is in accordance with existing literature. Risks associated to marketability, on the contrary, have a significantly negative effect on EET innovations only, whereas a slight (significant at the 10% level) positive coefficient results for overall innovations.[11] These findings — along-

[9]Replacing the seven broad industry dummies by dummies for each NACE 2-digit industry (i.e. controlling for economic activity at a more detailed aggregation level) did not change this result.

[10]While customers as knowledge source (KS_CUST) exhibits a similar effect, this is not robust to controlling for firm-specific effects and only partly robust to controlling for lagged within-industry average innovation — see subsection 3.4.3.

[11]This positive effect disappears when controlling for lagged within-industry average innovation, unlike

side the result that being an exporter does not increase the probability of innovating in energy efficient technologies — raises concerns that EET innovation, as captured by our survey, does not follow a pattern of *market-orientedness* to the degree that innovative activity and research of other kinds do. This concern will be further addressed in the concluding section.

The informative content provided by two variables related to *innovation protection* — TECH_PROT and KS_CUST — is inconclusive. Patents are deemed an important source of knowledge as far as both overall and EET research and development activities are concerned, as opposed to innovation outcomes (overall or EET), where they do not seem to matter. Somewhat counterintuitive is the significantly negative coefficient of TECH_PROT with regards to both EET R&D and innovation, and the fact that this variable does not turn out significant for overall R&D and innovation, as could have been expected from earlier studies using this same variable (see, for instance, Arvanitis 2006). A potential explanation is that such protection measures effectively prevent the *imitation* of EET related innovations, resulting in a smaller number of innovating firms (our definition of innovation here includes products and processes that represent imitations of other firms' pioneering works) than would be the case without such measures in place, but not necessarily resulting in a smaller number of first "pioneering" innovators. As already outlined in section 3.3, having effective barriers to imitation of innovations cannot be considered a priori good or bad — it means that research and innovation efforts are better appropriable to the first mover, providing a natural incentive to undertake such efforts in the first place. Additionally, since the importance of such measures, as observed in our data, may very well be due to natural (informal) circumstances, which unlike institutional measures (patents, copyrights) cannot be influenced by public policy, I refrain from drawing any policy conclusions in this matter.

A glance at the two variables representing obstacles related to the fundamental resources essential in the innovation process — skilled personnel and funding — reveals only limited evidence that scarcity of any of these would be a serious issue among the EET innovators in our survey. In contrast to overall R&D and innovation, where significantly negative coefficients for OBST_FUNDS appear, lack of external funding is of no significance for EET researchers and innovators. Positive and significant coefficients for OBST_HR appear for overall R&D and for EET innovation; however, there is no clear interpretation for these positive effects[12], and it cannot be ruled out that (in the case of EET innovation) the effect is spurious, as the robustness checks addressing both multicollinearity and within-industry aggregation effects did not confirm it. A prudent policy implication of these findings is that, in order to further strengthen the transformation

the negative effect on EET innovations.

[12]Learning effects in these variables, as already mentioned earlier, might theoretically be strong enough to carry over to the within-industry means used in this analysis, resulting in a spurious (endogenous) effect. Due to data limitations, robustness checks, as outlined in subsection 3.4.3, only provide inconclusive evidence if this is the case here.

of our energy system towards more efficiency, measures intended to extend access to external funding to R&D performers and innovators (including direct subsidies) should currently not be the highest priority; or at least they should be complemented by other policy measures, directed for instance at higher rates of diffusion or expanding end-user demand of such technologies.

3.4.2 Intensity Measures for Innovation and Research

Before taking a look at the results of this subsection, some introductory remarks are necessary. First, due to the small number of innovators and R&D performers that actually report how much of their sales are due to EET innovative products (87), or how much R&D investments they devote to EET (80) respectively, the intensity equation estimates should not be expected to be too informative. I present them here mainly in order to examine whether the qualitative findings of the preceding subsection can be corroborated or, on the contrary, if the qualitative results found here hint to a different interpretations of things.

Second, it should be noted that the selection (first stage) part of the estimates here in some way relates to the preceding subsection. Given the nature of our dataset, EET *innovation* intensity is observed for some (but not for all) firms that declared themselves as EET innovators. By contrast, some positive number of EET *R&D* intensity is observed for all EET researchers and developers present in our dataset (since having EET R&D activities has been defined by a positive value in the corresponding item of the questionnaire). Consequently, the selection equation for innovativeness presented here captures the probability of revealing some nonzero share of innovative sales (which differs from what table 3.6 reports), whereas the selection equation for R&D measures the same as the corresponding binary outcome equation of the subsection above and therefore perfectly coincides with table 3.5 (since I use a two-step procedure and the set of explanatory variables is the same).

The intensity measures for EET R&D and innovation constituting the dependent variables in this subsection are: R&D investments attributable to energy efficient technology research, on a per employee basis; and the share of new or enhanced products related to energy technology among the firm's sales. As the former variable is strictly positive for firms undertaking EET R&D, and the latter bounded between zero and 100%, I use logarithmic and logistic transformations, respectively, in order to adjust their domain to the complete set of real numbers.

Table 3.8 reports estimates for intensity models for both innovativeness and research in energy efficient technologies (in two columns, respectively). The upper panel displays the Generalised Tobit estimates, and is again subdivided in an upper (intensity equation, i.e. second stage) and lower (selection equation, i.e. first stage) part. The lower panel contains ordinary least squares estimates for the intensity stage (and thus ignoring selectivity, which potentially biases these results). As mentioned above, for better comparability with the results from the preceding subsection, estimates reported here are from a two-stage procedure.[13] The list of explanatory variables for the intensity equation of these estimations is a subset of those used for the selection equation (which are in turn identical to those used in the previous subsection), thus providing for the excluding restrictions that are essential for model identification. The variables excluded from the intensity equation are those derived from the 2008 Innovation Survey plus the language and industry dummies. The choice of these excluded variables is based on purely empirical considerations: block-wise inclusion of any of these variable groups in the intensity stage did not result in any (neither jointly nor individually) statistically significant coefficients there. Interpretations related to the effects of innovation protection, knowledge sources and innovation obstacles upon the intensity of EET R&D or innovation are therefore not possible, as no empirical findings can be extracted from our data.

The main findings can be summarised briefly as follows: there seems to be selectivity in the case of EET R&D but not for EET innovation. However, the qualitative results from both intensity equations essentially remain the same if selection is not controlled for. As far as the qualitative results are concerned, none of the coefficients that are statistically significant with regards to intensity are in direct opposition to the findings related to the binary indicators discussed in the preceding subsection, neither for innovativeness nor for R&D.

However, EXPORT now has a significantly positive impact on the share of EET related innovative sales, while I did not find this variable to be of any effect on the fundamental outcome of being an innovator or not. This provides some relief for the lack of market-orientation concern expressed earlier. It could be argued that firms wanting to successfully compete on foreign markets need to have a more specialised product portfolio, which means that many of them will abstain completely from introducing new energy efficient products (thus no effect of EXPORT in the binary estimation is observed), but those exporters who actually do so will be highly specialised in such products and therefore exhibit a large proportion of sales belonging to this product category.

Somewhat surprising are the effects of the perceived degree of competition and demand evolution on R&D and innovation intensity. Non-price competition, despite being of no effect on the binary EET R&D variable, positively affects the magnitude of EET R&D investments among those firms undertaking such research and development. As for EET innovations, the variable for price competition exhibits a positive effect, rather than non-price competition, while so far in this paper (and elsewhere in the empirical literature), out of the two competition variables, the latter has been the one revealing stronger and more significant effects on any innovation indicators.[14] Finally, future

[13] When estimating the Generalised Tobit model using a maximum likelihood procedure, none of the qualitative findings for either equation change.

[14] It can be plausibly expected, however, that fierce price competition induces firms to cut their own

demand expectations — rather than previous demand evolution, as in the binary dependent variable model for EET innovations — seem to positively affect the sales success of EET innovators. Reverse causality might be at the root of this last finding, as firms whose new products experience a successful launch on the market will hardly expect their demand to drop in the near future. However, rather than delving too deeply into any speculation about these findings, I deem it more useful to emphasise that they do not fundamentally put into question what has been found in the previous subsection.

3.4.3 Robustness Checks

In the preceding sections, a number of potential pitfalls related to the estimation strategy chosen here have already been mentioned briefly. Consequently, this subsection outlines the various robustness checks I have conducted in order to corroborate the results presented earlier. For the sake of brevity, detailed result tables are not included in this paper but can be obtained from the author on request.

As table 3.9 indicates, a number of explanatory variables heavily suffer from multicollinearity. The problem seems most serious for the variables constructed on the basis of within-industry means from the 2008 Innovation Survey, and a short glance at the table indicates that correlation coefficients above the value of 0.3 solely appear in conjunction with the four variables TECH_PROT, KS_PAT, OBST_MARKET and OBST_HR. I therefore repeated the binary outcome estimations reported in tables 3.5 and 3.6 with each one of these variables omitted once (on a one-by-one basis). In only few instances did this lead to a noteworthy loss of statistical significance in these or in any other variables, and no coefficient which was significant at the 10% or at a more restrictive level in the baseline estimations reversed its sign.[15]

The advantages of constructing variables stemming from the 2008 Innovation Survey on the basis of within-industry means have been outlined in the preceding section. Nevertheless, estimations for tables 3.5 and 3.6 have been carried out using variables constructed by one-to-one matching of observations between the two surveys. As the sample would dramatically shrink if unmatched respondents for the main survey were just thrown away, dummy variables for nonresponse in the 2008 survey were included as well and the values for the 2008 variables of these observations (where no responses are available) were assigned a standard value of zero in these alternative regressions. The results can be resumed as follows: with two minor exceptions, coefficients for the obstacle variables OBST_MARKET, OBST_FUNDS and OBST_HR tended to be more

energy expenses by promoting innovations for in-house use intended to improve the energy efficiency of their own production. By dropping those EET innovators who declared that they were generating such innovations for in-house use from the sample, the significant effect of PCOMP actually disappeared.

[15] Among the findings worth mentioning are: DEMAND_F ceased to be significant for overall and EET innovations in some instances; OBST_FUNDS lost some significance (in the order of one "star" at most) for overall R&D and innovations; TECH_PROT and KS_PAT mutually depend on each other appearing in the estimation for EET R&D in order to remain significant at the 10% level; and both TECH_PROT and OBST_HR lost some significance (in the order of one "star" at most) for EET innovations.

positive when estimated on individually matched data, which is compatible with the learning hypothesis outlined in the preceding section.[16] The pattern looks similar for the variable TECH_PROT, implying that learning effects may also be present for this variable. As for the two knowledge source variables KS_CUST and KS_PAT, coefficients lost statistical significance in several cases, and in particular came out negative (although not statistically significant) instead of the previously positive outcome of KS_CUST on both overall R&D and Innovation. This loss of significance is not surprising, given that among the respondents of the 2008 Innovation Survey, a considerable number refused to fill in these questions, resulting in an even smaller pool of observations providing actual information for this exercise and inflating the associated estimated standard errors. This effect is even more pronounced for GOAL_ENV, being based on a question only the innovating firms in the 2008 Innovation Survey were asked to answer.

The preceding section also briefly addressed concerns that potential endogeneity due to learning effects in the variables for innovation protection, knowledge sources and obstacles might be shifted from the (firm specific) individual level to the industry level by the approach I have chosen, rather than alleviating it: industries with a priori higher propensities to research and/or to innovate may have mean values (for these explanatory variables) which systematically differ due to the larger proportion of responses plagued by learning effects. One possibility to obtain some insights about the magnitude of this effect is to include the proportion of 2008 innovators — which is equivalent to the mean value of the binary variable for whether firms were innovators or not at the time of that survey — as controls in my regressions. I conducted this kind of check for the estimations in tables 3.5 and 3.6, including both the proportions of product and of process innovators of the 2008 survey in the list of explanatory variables.[17] The effect on the estimates of introducing these controls is stronger with respect to overall R&D and overall innovation (in both models, the significance category of four explanatory variables was affected) than it is for EET R&D (where KS_PAT turns out slightly more significant) and EET innovation (with no changes in significance categories). I thus conclude that the loss of significance of some explanatory variables, following the introduction of these controls, is more likely due to high correlation of the controls with the dependent variables (that is, of within-industry average lagged innovation with current innovation and current R&D) rather than due to spuriousness of these explanatory variables.[18] Again, in any case, the interpretations here are based on individual observed coefficients only whose significance is not affected by this check.

[16]The two exceptions are OBST_MARKET for overall innovation and OBST_HR for EET innovation, which both lose their statistically significant (at the 10% level) effect, while remaining positive in sign.

[17]The distinction between product and process innovators is sensible here, since some of the explanatory variables in question, in particular KS_CUST and OBST_MARKET, are likely to be affected by learning effects if the firm is a product innovator, but not so if it is a (pure) process innovator.

[18]This assumption is further supported by the fact that the controls turn out statistically significant only in the estimations with current overall innovations and R&D as the dependent variables.

3.5 Implications and Conclusion

Empirical comparison of the determinants for research and development (R&D) and innovation related to energy efficient technology (EET), on the one hand, to those related to overall technological progress on the other hand, has provided several insights about the innovative behaviour of Swiss firms. While a number of fundamental firm characteristics, such as firm size, human capital intensity or foreign ownership, do not seem to differ much in their impact on the two sets of innovative activity, some notable differences among other variables have been found. They can be summarised by the three broadly defined concepts of *market-orientedness*, *innovation protection* and productive *inputs* in the innovation process.

Perhaps the most pronounced finding of this paper is related to *market-orientedness*, or a lack thereof when it comes to R&D and innovation in EET, exemplified by the absence of statistically significant effects of exports and competition and the presence of marketability related risks in my estimations concerned with this specific subgroup of innovations. There are a number of potential explanations why this finding might be related to the very nature of innovation in energy efficient technologies:

- The entrepreneurial success of EET innovation — which is, after all, what firms are furthermost concerned with — is largely dependent on the cyclical evolution of fundamentals in the world economy: the crude oil price drop coming into effect shortly before the date of our survey, ending a several year-long period of oil price hikes, might have temporarily lessened the chances of generating profits from EET innovations. However, this claim conflicts with the finding that many EET improvements in our dataset are related to efficiency in the use of electricity rather than fossil fuels, and electricity prices in most world regions — in contrast to those for most fossil fuels — have been less volatile in the recent past and are widely expected to increase in the near future.

- New products characterised by improved energy efficiency, by their very nature, require less customer interaction than innovations of most other types, as there is little room for customisation. Consequently, it should not come as a surprise to see fewer indications of market-orientedness for this specific group of innovations than for others in our data.

- There may be motives other than immediate market success for firms to innovate in EET: reputational gains; accessing funds from public or private institutions supporting such innovations; innovating for internal use. However, as far as the last one of these motives is concerned, excluding all EET innovators declaring to innovate for in-house use from the sample should partly remove those effects, which is not the case in our data.

While all of these explanations would imply that there is not too much to worry about this finding, none of them seems completely satisfactory. A further complication to deeper analysis of the reasons is that we do not dispose about project-level data for energy efficient innovations — all of our indicators are aggregated at the firm or industry levels. Given the current state of information, it is certainly prudent for policymakers to carefully observe if any of the concerns related to missing market-orientedness manifests itself in other data sources or in individual cases. Potentially meaningful indications may be obtained by comparing the failure rate of such research projects, once initiated, related to EET; the commercial success of such projects; or the specific difficulties in exporting energy efficient technology.

The implications provided by variables related to *innovation protection* are, as already mentioned, less clear-cut — technology protection measures, where they are perceived as being effective, have a somewhat dampening effect on the innovation propensity in EET. However, the broad definition of this variable (it measures all kinds of informal protection measures, in addition to formal legal protection by patents) and the fact that it is not overly robust does not allow us to derive too much interpretation from this finding.

Somehow more optimistic, as far as policy is concerned, are the findings that two essential productive *inputs* in the innovation process — funding and human resources — do not seem to be limiting factors in the innovation process with regards to energy efficient technology. Moreover, demand for energy technology — exemplified both by past demand evolution and future demand expectations — at various instances have statistically significant positive effects upon R&D as well as innovation related to EET. This is substantial (if not sufficient) microeconomic evidence that demand-induced innovation may constitute an important transmission channel through which both market prices and energy policy can positively affect the pace of technological change. Price signals induced by current or expected scarcity of energy sources, or by CO_2 pricing as an outcome of implicit or explicit public policy measures, can thus be expected to be effective in helping to transform the economy into a less energy intensive one in the long run. It is thus reasonable to stress the finding — also put forward by recent theoretical literature, see Acemoglu et al. (2009), for instance — that the optimal design of energy policy should combine direct support for R&D by public and private bodies with measures putting an explicit price on non-renewable energy consumption, or more concretely, the CO_2 emissions associated with it.

3.6 References

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3.7 Appendix

Table 3.1: Composition of Data Set by Industry and Size Class

Industry (NACE)	Number of firms	Percentage of firms (%)	Number of EET innovating firms	Percentage of EET innovating firms (% within industry)
Food, beverage, tobacco (15, 16)	98	6.2	1	1.0
Textiles (17)	24	1.5	2	8.3
Clothing, leather (18, 19)	10	0.6	0	0.0
Wood processing (20)	37	2.3	2	5.4
Paper (21)	25	1.6	2	8.0
Printing (22)	68	4.3	0	0.0
Chemicals (23, 24)	85	5.4	5	5.9
Plastics, rubber (25)	52	3.3	4	7.7
Glass, stone, clay (26)	41	2.6	0	0.0
Metal (27)	31	2.0	4	12.9
Metal working (28)	167	10.6	14	8.4
Machinery (29)	194	12.3	43	22.2
Electrical machinery (31)	58	3.7	19	32.8
Electronics, instruments (30, 32, 331-334)	126	8.0	23	18.3
Watches (335)	40	2.5	1	2.5
Vehicles (34, 35)	22	1.4	6	27.3
Other manufacturing (36, 37)	37	2.3	1	2.7
Energy, water (40, 41)	49	3.1	14	28.6
Construction (45)	203	12.9	4	2.0
Computer services (72, 73)	50	3.2	8	16.0
Business services (74)	149	9.4	8	5.4
Telecommunication (64)	11	0.7	1	9.1
Total	1577	100.0	162	10.3
Size class (number of employees)				
Small (< 50)	720	45.7	40	5.6
Medium ($50 - 250$)	617	39.1	72	11.7
Large (≥ 250)	240	15.2	50	20.8
Total	1577	100.0	162	10.3

Table 3.2: Number of Innovators and R&D Performers in Sample

	Variable	Frequency	Relative Frequency (%)
Overall innovators	INNO_ALL	1021	64.7
Overall R&D performers	RND_ALL	650	41.2
EET innovators	INNO_EET	162	10.3
EET R&D performers	RND_EET	100	6.3
Total		1577	100.0

Table 3.3: Occurrences of EET Related Technology Fields in Dataset

Technology Field	Occurrences (firms researching in this field)	Relative occurrence (to total number of firms researching in EET, %)
Electrical engineering	118	72.8
Electric motors	60	37.0
IT related	34	21.0
Consumer electronics	14	8.6
Process technology components	60	37.0
Process technology systems	53	32.7
Fuel cells	13	8.0
Turbines	13	8.0
Transport and vehicles	51	31.5
Engines/traction systems	27	16.7
Vehicle bodies	10	6.2
Hydrogen based engine	7	4.3
Electricity based engine	28	17.3
Traffic management systems	6	3.7
Building technology	86	53.1
Insulation	35	21.6
Lightning	42	25.9
Heating	52	32.1
Cooling/shadowing	38	23.5
Air conditioning	37	22.8
Electricity generation/transmission	53	32.7
Photovoltaics	32	19.8
Electricity from biomass	16	9.9
Wind power	16	9.9
CC using biomass	11	6.8
CC using fossil fuels	12	7.4
Decentralised CC	6	3.7
Hydroelectric	17	10.5
Fossil fuel power	7	4.3
Nuclear power	9	5.6
HVDC transmission	4	2.5
Superconductors	1	0.6
Heat generation and transmission	71	43.8
Solar heat	29	17.9
Heat from biomass	14	8.6
Geothermal	8	4.9
Heat pumps	26	16.0
Waste heat recovery	37	22.8
District heating	12	7.4
Carbon Capturing and Storage	4	2.5
Total	162	100.0

Table 3.4: Definition of Explanatory Variables

Variable	Description	Type	Source
LN_EMPL	Firm size (natural logarithm of the number of full-time equivalent employees)	continuous	Energy 2009
FOREIGN	Firm is held by foreign owners in majority	binary	
EXPORT	Firm is an exporter	binary	
HI_EDU	Human capital intensity (proportion of employees having completed higher education)	continuous (0–100%)	
ECO_FRIENDLY	Preference of the firms' management to use environmentally friendly material inputs in its production process	5-point Likert	
DEMAND_R	Assessment of the evolution of demand for products (retrospectively in the three years up to 2008)	5-point Likert	Energy 2009
DEMAND_F	Assessment of the evolution of demand for products (upcoming in the three years from 2009 onwards)	5-point Likert	
PCOMP	Perceived intensity of competition (in prices)	5-point Likert	
NPCOMP	Perceived intensity of competition (non-price dimensions)	5-point Likert	
TECH_PROT	Perceived effectiveness of protection measures against technological imitation by other firms, both formal (patents, copyrights) or informal (secrecy or inherent complexity etc.)	5-point Likert	Inno. 2008
GOAL_ENV	Importance of generating new environmentally friendly products in the firm's innovation strategy	5-point Likert	
KS_CUST	Importance of firm's customers as knowledge source	5-point Likert	
KS_PAT	Importance of patent disclosures as knowledge source	5-point Likert	
OBST_MARKET	Importance of marketability risks as an obstacle to innovation	5-point Likert	
OBST_FUND	Importance of (insufficient) external funding as an obstacle to innovation	5-point Likert	
OBST_HR	Importance of (lack of) dedicated R&D personnel as an obstacle to innovation	5-point Likert	
(*Reference group; omitted*)	Questionnaire language: German	dummies	Energy 2009
LANG_FR	Questionnaire language: French		
LANG_IT	Questionnaire language: Italian		
Industry dummies	Industry (six categories)	dummies	Energy 2009

Table 3.5: Results of Binary Outcome Estimations — Firms' Decisions to Conduct R&D

	RND_ALL		RND_EET	
(Intercept)	-4.1407***	(-6.90)	-4.5367***	(-5.01)
LN_EMPL	0.2443***	(7.53)	0.1518***	(3.09)
FOREIGN	-0.1435	(-1.21)	0.0015	(0.01)
HI_EDU	0.0135***	(5.58)	0.0142***	(4.03)
EXPORT	0.7566***	(7.54)	0.4769**	(2.26)
ECO_FRIENDLY	0.0020	(0.05)	0.0102	(0.15)
DEMAND_R	-0.0008	(-0.02)	0.1287	(1.57)
DEMAND_F	0.1593***	(3.25)	0.0926	(1.24)
PCOMP	0.0049	(0.11)	0.0261	(0.36)
NPCOMP	0.1006**	(2.21)	-0.0967	(-1.29)
LANG_FR	0.0951	(0.81)	-0.3799	(-1.57)
LANG_IT	-0.0490	(-0.23)	-0.1822	(-0.50)
GOAL_ENV	0.1097	(1.49)	0.3287***	(2.87)
TECH_PROT	0.0682	(0.66)	-0.3390*	(-1.96)
KS_CUST	0.1789*	(1.75)	-0.0888	(-0.55)
KS_PAT	0.2167*	(1.72)	0.3844*	(1.94)
OBST_MARKET	0.1138	(1.12)	-0.1761	(-0.97)
OBST_FUNDS	-0.2647***	(-2.65)	0.1757	(1.08)
OBST_HR	0.1961**	(2.14)	-0.0445	(-0.29)
Industry Dummies	Yes		Yes	
N	1309		1309	
Maximised log-L	-644.7		-223.8	
Null log-L	-890.6		-298.4	

z-Values in brackets. Stars denote statistical significance at the 10% (*), 5% (**) and 1% (***) levels respectively.

Dependent Variables: R&D Activities related to any Technology (RND_ALL) or related to Energy Efficient Technologies (RND_EET)

Table 3.6: Results of Binary Outcome Estimations — Firms' Innovation Outcomes

	INNO_ALL		INNO_EET	
(Intercept)	-3.0545***	(-5.45)	-3.8448***	(-4.97)
LN_EMPL	0.1955***	(6.12)	0.1536***	(3.87)
FOREIGN	-0.1672	(-1.35)	-0.0105	(-0.07)
HI_EDU	0.0068***	(2.88)	0.0118***	(4.08)
EXPORT	0.3995***	(4.19)	0.0781	(0.54)
ECO_FRIENDLY	0.1081***	(2.80)	0.0996*	(1.87)
DEMAND_R	0.1421***	(2.96)	0.2093***	(3.09)
DEMAND_F	0.0805*	(1.67)	0.1023*	(1.66)
PCOMP	0.0322	(0.77)	-0.0160	(-0.28)
NPCOMP	0.1401***	(3.22)	-0.0875	(-1.46)
LANG_FR	-0.5821***	(-5.34)	-0.5694***	(-2.92)
LANG_IT	-0.1741	(-0.89)	-0.3337	(-1.06)
GOAL_ENV	-0.0061	(-0.09)	0.3225***	(3.52)
TECH_PROT	0.0023	(0.02)	-0.2797**	(-2.01)
KS_CUST	0.2786***	(2.80)	0.0793	(0.61)
KS_PAT	-0.0622	(-0.51)	0.1454	(0.89)
OBST_MARKET	0.1777*	(1.73)	-0.3802**	(-2.56)
OBST_FUNDS	-0.1974**	(-2.04)	0.0292	(0.22)
OBST_HR	0.0215	(0.24)	0.2170*	(1.68)
Industry Dummies	Yes		Yes	
N	1309		1309	
Maximised log-L	-696.5		-357.2	
Null log-L	-839.1		-451.5	

z-Values in brackets. Stars denote statistical significance at the 10% (*), 5% (**) and 1% (***) levels respectively.

Dependent Variables: Innovation outcomes related to any Technology (INNO_ALL) or related to Energy Efficient Technologies (INNO_EET)

Table 3.7: Results of Tetravariate Probit Estimations

Same models as in tables 3.5 and 3.6, estimated simultaneously

	RND_ALL	RND_EET	INNO_ALL	INNO_EET
(Intercept)	-4.0588*** (-6.79)	-4.3922*** (-4.81)	-2.9808*** (-5.39)	-3.9641*** (-5.27)
LN_EMPL	0.2407*** (7.42)	0.1658*** (3.39)	0.1879*** (6.01)	0.1684*** (4.38)
FOREIGN	-0.1299 (-1.09)	-0.0093 (-0.06)	-0.1538 (-1.25)	-0.0263 (-0.19)
HI_EDU	0.0136*** (5.65)	0.0114*** (3.24)	0.0070*** (3.00)	0.0112*** (4.10)
EXPORT	0.7439*** (7.44)	0.3984* (1.87)	0.4068*** (4.34)	0.0010 (0.01)
ECO_FRIENDLY	-0.0104 (-0.26)	0.0317 (0.50)	0.1003*** (2.65)	0.1010** (2.06)
DEMAND_R	0.0126 (0.26)	0.1663** (2.01)	0.1448*** (3.05)	0.2036*** (3.13)
DEMAND_F	0.1524*** (3.12)	0.1098 (1.49)	0.0750 (1.58)	0.1093* (1.86)
PCOMP	0.0042 (0.10)	0.0028 (0.04)	0.0345 (0.83)	-0.0202 (-0.37)
NPCOMP	0.1060** (2.32)	-0.0952 (-1.34)	0.1463*** (3.38)	-0.0894 (-1.60)
LANG_FR	0.0725 (0.61)	-0.4002 (-1.64)	-0.5705*** (-5.18)	-0.5604*** (-3.10)
LANG_IT	-0.0659 (-0.32)	-0.1987 (-0.57)	-0.1745 (-0.93)	-0.3569 (-1.12)
GOAL_ENV	0.1250* (1.68)	0.2331** (2.01)	0.0053 (0.08)	0.2772*** (3.14)
TECH_PROT	0.0566 (0.54)	-0.2924* (-1.69)	-0.0089 (-0.09)	-0.3108** (-2.28)
KS_CUST	0.1685* (1.65)	-0.0561 (-0.34)	0.2834*** (2.88)	0.0880 (0.72)
KS_PAT	0.2232* (1.73)	0.3838** (1.98)	-0.0661 (-0.55)	0.1603 (1.03)
OBST_MARKET	0.1139 (1.13)	-0.1834 (-0.98)	0.1717* (1.71)	-0.3283** (-2.33)
OBST_FUNDS	-0.2541** (-2.55)	0.0351 (0.22)	-0.2021** (-2.11)	-0.0222 (-0.18)
OBST_HR	0.1548* (1.70)	0.0456 (0.29)	0.0099 (0.11)	0.3042** (2.48)
Industry Dummies	Yes	Yes	Yes	Yes
No. of obs. (total)	1309			
LR chi2	662.6			
p-Value	0.0000			
Estimated cross-equation correlation coefficients:				
ρ_{21}	0.5125*** (7.24)			
ρ_{31}	0.5080*** (12.03)			
ρ_{41}	0.3855*** (6.83)			
ρ_{32}	0.2672*** (3.83)			
ρ_{42}	0.7673*** (21.46)			
ρ_{43}	0.2360*** (3.58)			

z-Values in brackets. Stars denote statistical significance at the 10% (*), 5% (**) and 1% (***) levels respectively.

Table 3.8: Results of Generalised Tobit Estimations

	rnd^{EET}		$innosales^{EET}$	
	Intensity Equation			
(Intercept)	13.4596***	(4.84)	-4.2584*	(-1.96)
LN_EMPL	-0.2459	(-1.51)	-0.1819	(-1.32)
FOREIGN	0.6162	(1.29)	-0.0163	(-0.04)
HI_EDU	-0.0083	(-0.77)	-0.0037	(-0.39)
EXPORT	0.6159	(0.76)	1.3406***	(2.66)
ECO_FRIENDLY	0.1609	(0.73)	0.0851	(0.45)
DEMAND_R	-0.0014	(0.00)	-0.1508	(-0.54)
DEMAND_F	-0.2070	(-0.86)	0.4492**	(2.15)
PCOMP	-0.1690	(-0.73)	0.4371**	(2.24)
NPCOMP	0.6673***	(3.28)	-0.1088	(-0.62)
invMillsRatio	-1.2400**	(-2.18)	0.0699	(0.17)
	Selection Equation			
(Intercept)	-4.5367***	(-4.90)	-5.5545***	(-5.95)
LN_EMPL	0.1518***	(3.10)	0.1304***	(2.71)
FOREIGN	0.0015	(0.01)	-0.0062	(-0.04)
HI_EDU	0.0142***	(4.02)	0.0099***	(2.80)
EXPORT	0.4769**	(2.25)	0.0430	(0.24)
ECO_FRIENDLY	0.0102	(0.15)	-0.0159	(-0.25)
DEMAND_R	0.1287	(1.55)	0.1994**	(2.39)
DEMAND_F	0.0926	(1.24)	0.1927***	(2.59)
PCOMP	0.0261	(0.36)	0.0372	(0.53)
NPCOMP	-0.0967	(-1.32)	0.0722	(1.02)
LANG_FR	-0.3799	(-1.58)	-0.5115**	(-2.05)
LANG_IT	-0.1822	(-0.50)	-0.3907	(-0.94)
GOAL_ENV	0.3287***	(2.83)	0.4299***	(3.80)
TECH_PROT	-0.3390*	(-1.94)	-0.3494**	(-2.07)
KS_CUST	-0.0888	(-0.55)	0.1060	(0.69)
KS_PAT	0.3844*	(1.92)	0.0565	(0.27)
OBST_MARKET	-0.1761	(-0.95)	-0.3647*	(-1.88)
OBST_FUNDS	0.1757	(1.07)	0.0844	(0.51)
OBST_HR	-0.0445	(-0.28)	0.2774*	(1.70)
Industry Dummies	Yes		Yes	
sigma	2.0286		1.5695	
rho	-0.6113		0.0446	
N(total)	1309		1309	
N(uncensored)	79		86	
Adj. R2	0.1708		0.0767	

Comparison Model:
Intensity Equation Estimated without Controlling for Selection

(Intercept)	8.8116***	(4.62)	-3.9971**	(-2.45)
LN_EMPL	-0.0973	(-0.63)	-0.1918	(-1.45)
FOREIGN	0.6127	(1.23)	-0.0094	(-0.02)
HI_EDU	0.0017	(0.16)	-0.0043	(-0.46)
EXPORT	1.3484*	(1.70)	1.3351**	(2.49)
ECO_FRIENDLY	0.1298	(0.56)	0.0904	(0.46)
DEMAND_R	0.1175	(0.39)	-0.1661	(-0.59)
DEMAND_F	-0.0274	(-0.12)	0.4384**	(2.07)
PCOMP	-0.1263	(-0.52)	0.4377**	(2.11)
NPCOMP	0.6806***	(3.23)	-0.1142	(-0.62)
N	79		86	
Adj. R2	0.1286		0.0886	
P(F).value	0.0266		0.0618	

z-Values in brackets. Stars denote statistical significance at the 10% (*), 5% (**) and 1% (***) levels respectively.

Dependent variables: logarithm of firm's EET related R&D investments per employee (left); logistic transformation of the firm's sales share of new or enhanced products related to EET (right).

Table 3.9: Correlation Coefficients — Explanatory Variables

	LN_EMPL	FOREIGN	HI_EDU	EXPORT	ECO_FRIENDLY	DEMAND_R	DEMAND_F	PCOMP	NPCOMP	GOAL_ENV	TECH_PROT	KS_CUST	KS_PAT	OBST_MARKET	OBST_FUNDS	OBST_HR
LN_EMPL	1.000															
FOREIGN	0.164	1.000														
HI_EDU	0.007	0.123	1.000													
EXPORT	0.199	0.204	0.167	1.000												
ECO_FRIENDLY	0.071	-0.004	-0.022	-0.027	1.000											
DEMAND_R	0.166	0.065	0.042	0.170	0.033	1.000										
DEMAND_F	-0.024	-0.061	0.092	-0.120	0.119	0.074	1.000									
PCOMP	0.101	0.016	-0.059	-0.015	-0.029	0.017	-0.146	1.000								
NPCOMP	0.058	0.040	0.129	0.102	-0.009	0.032	0.033	0.036	1.000							
GOAL_ENV	0.065	-0.035	-0.218	-0.078	0.099	-0.011	-0.019	0.037	-0.089	1.000						
TECH_PROT	0.133	0.193	0.081	0.391	-0.026	0.094	-0.159	0.010	0.081	-0.007	1.000					
KS_CUST	0.068	0.122	0.039	0.297	-0.055	0.064	-0.126	0.067	0.055	0.040	0.361	1.000				
KS_PAT	0.150	0.206	0.073	0.448	-0.027	0.146	-0.082	-0.029	0.058	0.065	0.647	0.394	1.000			
OBST_MARKET	0.080	0.086	0.015	0.307	-0.012	0.095	-0.060	0.027	0.057	0.008	0.306	0.365	0.415	1.000		
OBST_FUNDS	-0.050	-0.084	-0.175	-0.080	0.003	0.003	-0.020	0.015	-0.040	0.207	-0.172	0.083	-0.103	0.167	1.000	
OBST_HR	0.078	0.094	0.123	0.326	-0.022	0.158	-0.091	0.006	-0.021	0.039	0.391	0.318	0.546	0.482	0.108	1.000

Table 3.10: Size Distribution of (Number of Valid Observations in each) Modified 4-Digit Industry Cells Used for Calculation of Innovation Survey 2008 Variables

Number of Valid Observations in each Cell	Number of Cells
1	53
2–3	74
4–5	51
6–10	71
11–20	91
21–100	51
Total	391
Mean cell size	8.8

Chapter 4

Public Support for Energy Efficient Technology in Switzerland — An Impact Analysis Based on a Matching Approach

4.1 Introduction

A number of measures have been put into place in Switzerland during the last two decades to support innovation and diffusion of energy saving technologies. This study uses firm level data, collected by means of a recent survey (spring 2009) among Swiss firms belonging to both the manufacturing and service sectors, to determine the effectiveness of some of those measures directed at the diffusion stage.

Public awareness that energy systems need to become more efficient and less reliant on non-renewable sources — furthermost, fossil ones — has gradually increased over the last decades, much due to concerns that current use and technology of energy are not sustainable. From a purely economic perspective, justifications for government intervention destined at supporting the adoption of energy saving technologies, can be grouped in two broad fields: those referring to *externalities*, which can be of the negative type (implicit costs inflicted upon society through the consumption of energy from certain sources), or of the positive type (implicit benefits received not only by the implementing firm but also by other enterprises and/or individuals); and justifications on the grounds of other *market failures*.

Negative *externalities* may arise either from external costs of use of energy that are not imposed on the user in the absence of well-designed policy instruments (such as levies or tradable permits). The most prominently and vigorously debated topic here of course is global climate change attributable to the burning of fossil fuels, causing the release of massive amounts of carbon dioxide (CO_2) into the atmosphere. In the context of technological change, positive externalities of adoption of new technology are sometimes put forward — the fact that a firm's decision to apply new technology may ultimately benefit its competitors or other enterprises (such as suppliers of the relevant technology or other potential end-users), resulting in a net benefit to the economy that actually exceeds what the initial adopter may reap in terms of enhanced productivity or market share. The positive externality argument, however, is more commonly used in the context of private research and innovation activities rather than in the diffusion context this paper is concerned with.

Alleged *market failures* of other types than externalities are a rather complex topic, as various types have been proposed by different authors to be relevant in the case of diffusion of energy saving technology (see pages 31ff in Popp et al. 2009, for a review of these). They are by no means only limited to the spreading of technological advances in energy efficiency, but have received growing attention and are believed to be of more pronounced magnitude in this context by many authors (Battisti 2008). To sum up, the motives for public policy to intervene in the diffusion of energy efficient technologies in market-based economies are vast and complex (and beyond the scope of this paper to analyse in more depth), but successful implementation of such policies requires ongoing analysis of the effectiveness of the measures put into place to this end — a task this paper intends to contribute to.

The remainder of this paper is organised as follows. Section 2 describes the current institutional setting of support measures for EET diffusion in Switzerland alongside with the availability of data for the present paper, section 3 resumes findings of the relevant literature, section 4 outlines the methodological approach and its implementation chosen, section 5 presents the results and section 6 concludes.

4.2 Institutional Background and Data Considerations

Efforts by the Swiss confederation, cantons and municipalities to support households and firms in reducing their energy requirements reach back at least two decades. There is considerable heterogeneity both in the design and magnitude of these measures across these entities. As a general pattern, however, the local public entities (cantons and municipalities) primarily support energy-saving measures related to construction, both in renovation of existing buildings and in construction of new ones, whereas energy efficiency in traffic and within industry and household applications is primarily addressed by federal law and institutions[1].

The enactment of the Federal CO_2 Emission Reduction Law[2] in 1999 has prompted

[1] As is the case with support for energy efficiency related R&D, which is however not in the scope of this paper.

[2] *Bundesgesetz vom 8. Oktober 1999 über die Reduktion der CO_2-Emissionen* (CO_2-Gesetz)

the creation of two new schemes promoting dedicated projects to reduce CO_2 emissions by firms: the *Climate Cent Foundation*; and the possibility for firms of being exempt from the CO_2 levy conditional on implementing emission reduction measures, often with assistance from the private sector based *Energy Agency of the Swiss Economy.* Based on an mandate negotiated with the federal government, both of these private sector based institutions can provide support; either in the form of investment subsidies to firms implementing technology that effectively reduces CO_2 emissions (in the case of the former) or by providing expertise to firms wishing to be exempt from the CO_2 levy (in the case of the latter).

The existence of two complementary schemes is mainly due to the fact that, based on political considerations, the federal government has decided to impose a CO_2 levy on fossil fuels for heating purposes only, whereas no such levy has yet been introduced on fuels used to power engines for transportation or other purposes.[3] This decision has been reached following a joint effort by private sector organisations to form the *Climate Cent Foundation* in order to impose a moderate *voluntary* levy on engine fuel imports[4] and to allocate the proceeds towards selected projects directed at reducing CO_2 emissions both domestically and abroad, thus avoiding the (ultimately much higher) federal CO_2 levy to cover fossil engine fuels as well. Every firm or public institution is in principle eligible to apply for subsidies granted by the Climate Cent Foundation, no matter whether the proposed reduction of CO_2 emission is achieved by cutting the use of engine or heating fuel.

In contrast, the *Energy Agency of the Swiss Economy's* mission is to assist firms to mitigate the potentially severe effects (particularly, loss of international competitiveness) of the federal CO_2 levy by providing them expertise related to technical, reporting and legal issues required for a successful application towards the federal government for exemption from the CO_2 levy. Such an exemption is granted if the firm undertakes efforts to reduce its CO_2 emissions as appropriate in the individual case, a possibility explicitly provided for in the CO_2 Emission Reduction Law. Thus, only users of fossil fuels for heating purposes are potential beneficiaries of this scheme.

Our survey has featured questions about participation in both of these schemes, besides having received support from local public entities (cantons or municipalities). Despite disposing of this breadth of information, only the answers related to support from public entities and the Climate Cent Foundation are used, thus neglecting the beneficiaries of the Energy Agency of the Swiss Economy in this analysis. This is due to the limited potential reach of the latter scheme: only firms with significant expenses for fossil fuels for heating purposes may participate, whereas the outcome variables in

[3]The rate of the levy is currently set (with effect from January 1 2010) at CHF36 — roughly EUR25 at current exchange rates — per ton of CO_2.

[4]Since no fossil fuels of any kind are mined in Switzerland, all domestic consumption is affected by this voluntary import levy. It amounts to CHF 0.015 per litre of petrol and diesel imports, which is a sixth of the effective rate of the federal CO_2 levy currently applied to fossil fuels for heating purposes.

my analysis are related to increasing energy efficiency for all applications and all kinds of energy sources.

Outcome variables that potentially provide measures of success of diffusion support are: number of technological fields in which newly acquired technologies can be classified (count variable); if any reduction of CO_2 emissions has resulted from technology adoption (binary variable); and investments related to energy efficient technologies (nonnegative flow measure). Since our data stems from a non-experimental setting, the probability of receiving any support for a given firm is not random, but must be expected to depend on various firm characteristics known to the supporting agency prior to taking its decision whether to grant any support or not. Supporting agencies usually are charged with the task of scrutinising all applications for such support in a manner to allocate funds or expertise to those potential beneficiaries where the expected benefits, in terms of enhanced energy efficiency or reduced emission of pollutants or greenhouse gases, are highest. Not controlling for this non-random dependence of support on firm characteristics would result in biased estimates of the impact of diffusion support (a problem referred to as *selection bias*, or absence of *random assignment* or *random treatment* by different authors), and therefore parametric or non-parametric methods are required in order to rule out this source of bias.

4.3 Links to Existing Literature and Statistical Foundations

The present study relates to two broad directions of research. First, existing theoretical and empirical literature predicting and analysing the outcomes of various types of public support on technology diffusion (or concerned with the justifications thereof); and second, methodological studies providing the statistical tools for being able to measure the effects of such policies, while avoiding to incur the kind of bias that inevitably arises if the problem of non-random treatment is not taken into account properly.

4.3.1 Policy Instruments

On the theoretical side, a notable body of literature compares the effectiveness of different policy measures in reaching the ultimate goal of promoting energy efficient or green (if pollution reduction is the aim) technology. Most of these exercises reach the conclusion that market-based instruments (such as taxes or emission permits) outperform direct measures (as resumed by Popp et al. 2009, page 24). A number of authors however stress the fact that a combination of several instruments might be the adequate solution, allowing for emission reductions at a significantly lower cost than any single policy (Fischer and Newell 2008).

Existing empirical studies dealing with the microeconomic effects of public support or regulation on innovation or research towards private sector enterprises are far more abundant than those concerned with the diffusion of already existing technology. To the best of my knowledge, none has so far addressed the specific topic of energy efficient technology diffusion.[5]

Arvanitis et al. (2010) applied similar methodology to investigate the impact of a support scheme of the Swiss government on innovation projects. They use several measures of innovation performance as outcome variables and rely on four different statistical matching methods as robustness checks. The impact of this kind of support is found to be positive and significant, and only minor differences in the outcomes are found when comparing various types of matching methods.

4.3.2 Statistical Concerns Related to Analysis of Policy Outcomes

Microeconometric evaluation of the performance of various policy programmes has recently become an active area of research, perhaps most prominently in labour economics, where the political desire to provide ex post insights about the effectiveness of such measures has been strongest, resulting in a vast array of methods and estimators being proposed to this end (Caliendo and Hujer 2005). Of most interest in the literature concerned with analysing policy outcomes is the *average treatment effect on the treated (ATT)*, defined e.g. by Ho et al. (2007) as

$$ATT = \frac{1}{\sum_{i=1}^{n} T_i} \sum_{i=1}^{n} T_i \left[E(y_i|X_i; T_i = 1) - E(y_i|X_i; T_i = 0) \right]$$

where n is the number of firms in the sample, T_i a binary variable taking the values 1 for firms having received treatment and 0 otherwise, y_i the outcome variable (or, potentially, a vector of outcomes) of the ith observation, and $E(y_i|X_i; T_i)$ expresses the expected value of the outcome variable conditional of whether treatment has been administered ($T_i = 1$) or not ($T_i = 0$), i.e. any diffusion support granted or not. X_i is a vector of observable covariates on which the probability of being treated may depend. Since the above equation implies that we sum over those observations having received treatment only (where $T_i = 1$), the outcome following treatment is actually observed as y_i and the above simplifies to

$$ATT = \frac{1}{\sum_{i=1}^{n} T_i} \sum_{i=1}^{n} T_i \left[y_i - E(y_i|X_i; T_i = 0) \right]$$

The fundamental problem of causal inference (Holland, 1986) in this context is exemplified by the fact that there remains an unobserved term for the expected outcome given no treatment $E(y_i|X_i; T_i = 0)$, whose distributional properties are not known. Parametric analysis methods proceed by imposing some specification regarding the joint distribution of (exogenous) covariates X_i, the treatment indicator T_i and the outcome

[5] whereas many specific regulations in the wider context of cleaner technology have received the attention of evaluation exercises, see Popp et al. 2009, pp 26–30 for an overview

y_i, followed by estimation of the parameters of interest. Statistical matching — a non-parametric method — on the other hand attempts to restrict the sample of analysis such that the relationship between X_i and T_i is eliminated or at least reduced to a degree that makes direct comparison of the outcome variables between treated and non-treated observations feasible. More intuitively, matching should result in a subset of *treated* and *matched* observations where the two categories resemble each other in the respective distribution of exogenous covariates X_i the closest possible, a desirable condition referred to as *balance*.

Matching on the propensity score (a comprehensive description of the procedure and its steps is given by Caliendo and Kopeinig 2008) assumes that balance can be achieved by assuring similar distributions of the *propensity score*, i.e. the probability of receiving support conditional on the exogenous covariates (Rosenbaum and Rubin 1983, as quoted by Ho et al. 2007). This is supposed to simplify the matching procedure from a (possibly highly) multidimensional problem to one of matching on a single dimension. Since only in very few cases is the propensity score known a priori, most studies rely on estimating it econometrically before proceeding to matching itself.

Once a consistent estimate of the propensity score has been found, various methods exists as how to assemble the subset of matched observations, conceptually the simplest one being *nearest neighbour matching*: for each treated observation, the untreated observation which is closest in terms of the estimated propensity score is chosen to figure in the subset of matched observations, resulting in a "pairing" of treated and untreated units. More refined methods such as caliper matching, kernel matching, or local linear regression matching exist, with the potential of better efficiency given certain circumstances. Arvanitis et al. (2010), applying each of these methods on the same data and based on the same propensity score estimation in their study, found that discrepancies between the methods were not substantial. I therefore proceed by conducting my analysis using nearest neighbour matching only.

4.4 Methodology and Implementation Issues

4.4.1 Which Observations Should Be Considered for Matching?

Implementing a statistical matching exercise starts by defining a precise set of enterprises which are a priori eligible for entering the comparison group. There are two fundamental concerns when considering which firms to include here:

- A firm figuring in the comparison group must be characterised by the fact that it could reasonably have undertaken some effort to receive support for adopting energy efficient technologies by the institutions we are concerned with here; and could actually have been granted such support, with some probability not too close to zero. More intuitively, we should a priori exclude firms that have no reason to apply for support due to the fact there are no technologies that can be usefully put into place for them. Obviously, this concern is important for firms which do not possess or maintain any buildings, which do not dispose of any fleet of vehicles, which do not rely on energy-consuming industrial processes, or the like.

- The outcome variables, which we use here as indicators to assess the success of policy support measures, must be observed not only for every firm in the treatment group (those who have received support), but also for every firm in the comparison group. Otherwise, missing data problems may arise, rendering the analysis inefficient or, in the worst case, biased.

There is no straightforward criterion that would allow us to fulfil the first of these two requirements: our dataset does not contain any explicit information as to whether participants rely on technologies or infrastructure for which potentially energy efficiency enhancing substitutes exist. To suppose that enterprises below a certain size or belonging to certain branches are less likely to fulfil this criterion would be highly unsatisfactory, since this is clearly not the case in our data (as a short glance at table 4.1 tells).

Turning towards the second criterion, however, it becomes evident that only firms having implemented at least one technological measure enhancing energy efficiency may figure among the candidates for the matched group. The information collected through the survey questionnaire, by its design, excludes the possibility of constructing outcome variables for non-adopters of EET. This is by no means a fault, since no meaningful qualitative indicators related to improvements in energy efficiency exist for non-adopters (and quantitative measures of energy efficiency would have been prohibitively difficult to obtain in the framework of such a survey). Moreover, it is virtually impossible to find instances of firms that have received support without successfully having implemented efficiency enhancing measures, since support is evidently conditional on putting into place some of these very measures.[6] To resume, by excluding non-adopters from the group of potential matches, I assure that outcome variables are non-missing for the comparison group and reduce the danger of biased results in my outcome analysis arising from having matched firms with no potential for energy efficiency enhancements.

4.4.2 Choice of Propensity Score Specification

Given the uncertainty as for the correct specification of the propensity score equation (i.e. which parameters affect the probability of being supported, and through which functional form this influence is best captured), it is crucial to assure that the specification ultimately chosen provides the best possible *balance* of the covariates between

[6]This remark seems very evident in this context; but it should be noted that this is in contrast to the vast body of outcome analyses that are concerned with policies supporting firm-level *R&D activities* rather than *adoption*: the former are characterised by their uncertain outcome of whether some successful technological advances will result in the end or not, unlike adoption of some existing and mature technology.

the treated and matched groups. This is not necessarily the case for the specification providing the most convincing goodness of fit measure of the propensity score equation. In the present analysis, I essentially rely on statistical and visual tools in order to assess balance.

- Table 4.3 provides means for the three covariates YEAR, SIZE and HI_EDU (plus for their underlying, non-transformed values in the case of SIZE and HI_EDU); within each of the group of treated, matched and untreated observations. The fourth and fifth columns contain differences and p-Values for the associated t-Test of nonzero difference between the means of treated and matched. To ensure good balance, this difference should ideally be zero. Since this cannot be usually enforced in empirical applications, the difference should be as small as not to be significantly different from zero. For the five measures considered here, this is clearly fulfilled at conventional levels of statistical significance.

- Since good balance requires similarity in the empirical distributions of the covariates between the groups of treated and matched observations, ensuring equal (or similar) mean values of covariates between these two groups is a necessary but not sufficient criterion for balance. Ideally, the density functions (and hence the cumulative distribution functions) of covariates in both groups should coincide all over their respective support region. There exists no formal test to assess this, but as a visual aid, QQ plots may give some indication as for how closely the empirical distributions of a variable between two samples coincide. Figures 4.1 to 4.3 do this for the three variables YEAR, SIZE and HI_EDU. Coincidence of distributions (which manifests itself by how close the dots come to lie to the 45 degree line) is clearly improved in the course of matching for the variables YEAR and SIZE, whereas the effect is less evident for HI_EDU, but still present in some segments of the distribution range.

The specification and results of the underlying propensity score estimation is given in table 4.2. Industry affiliation for five manufacturing categories, the construction sector and two service categories is controlled for by respective dummy variables; as is questionnaire language. Since linear, quadratic and logarithmic specifications all led to unsatisfactory results in the case of the variables for firm size and firm age, dummy variables are used for these as well, defining four and three classes for the former and the latter, respectively. FOREIGN is another binary variable indicating whether the firm is by majority non-domestically owned. The percentage of employees having completed higher education has been found to perform best after logistically transforming it, which is how the variable HI_EDU is defined.

Both the sample of treated firms and potential control group members needed to be restricted further in order to assure stability of the propensity score estimation and matching results. Very old and very small were excluded from the sample since none of them has been found to have received any support. More precisely, four observations with a year of foundation prior to 1750 and ten observations having less than five full-time equivalent employees have been removed from estimation and matching. Similarly, sixteen firms exceeding the size of 2500 full-time equivalent employees figuring in the original sample have been dropped, as their presence in the sample too evidently interfered with the task of finding a satisfactory model specification and matching quality. This is probably due to the strong propensity to obtain support of such very large firms, violating the common support criterion necessary for consistent matching.

4.5 Results

Table 4.4 presents, for each of the five variants covering the three outcome variables, mean values of the treated, matched and untreated observations. The average treatment effect of the treated (AAT), defined by the difference in means of the treated and matched, is reported on the right-hand side of the table, alongside the p-Value of the associated test for equality.[7] It follows that, for each of the five variants the ATT is positive and significantly different from zero at conventional levels of significance. In other words, all of the three outcome variables are positively and significantly affected by the fact of having received diffusion support. In the case of EET investments, this effect is robust as to whether such investments are measured as a percentage of total investments or in relation to firm size — the statistical significance is however weaker in the second case, only passing the test at a 10% level of significance. The effect on the number of technology fields covered by adoptions is robust to whether this measure is entered linearly or logarithmically transformed.

Provided that no omitted variable bias in the covariates is present, this means that public support measures as provided by cantons, municipalities and the Climate Cent Foundation have indeed been effective.

If the analysis is repeated for the impacts of *public* entities (cantons and municipalities) and *private* sector (Climate Cent Foundation) as supporting institutions separately each, the following tentative findings emerge: no significant positive effect as described above is found any more for private support on EET investment (for neither of the two indicators related to EET investment); and the effect of public support on the number of technologies adopted is weakened (for both respective indicators here), however only weakly. CO_2 emission reduction as an outcome is slightly less significant for both support institutions evaluated separately. However, these differences have little explanatory content as to whether one of the institutions is more effective than the other: to a large extent, the decrease in statistical significance observed here emerges due to the lower number of usable observations.

[7]t-Tests have been conducted for the outcome variables based on EET investments and number of adopted technologies (which are metric measures), and a Fisher test for the yes/no variable for CO_2 reduction (which is a categorical variable).

Having little data of quantitative nature at our disposition, neither with regards to the amount of support received by firms, nor to the magnitude of outcomes in terms of units of energy saved or CO_2 emissions avoided, it is out of reach to quantify the gains of the policy schemes considered here in numerical terms. A valuable insight provided by the present study is, nevertheless, that crowding-out problems do not seem to appear in the context of present public or private sector based support schemes for EET in Switzerland. That is to say, firms have implemented projects that enhance their energy efficiency and invested funds to this end, to an extent that would not have resulted had they not been granted the financial support by the schemes considered here. If this were not the case (due to complete crowding-out), no positive impact would result in our estimates of the Average Effect of Treatment on the Treated (ATT).

It must be stressed, as is usual with such studies, that the results presented here are valid only insofar as no information having any impact on the individual firms' probability of being supported has been omitted in our data, i.e. that the set of explanatory variables in our propensity score estimation presented in table 4.2 is complete, and that the equation has been correctly specified. This is evidently a strong assumption, however one that cannot be circumvented in studies of this kind. In this sense, care has been taken that the present study represents the best possible effort to assess the effectiveness of EET adoption policy in Switzerland, given the data limitations inherent in most outcome analysis based on observational research,

4.6 Conclusion

Survey data covering a representative sample of Swiss firms belonging to the manufacturing, construction and service sectors has been used to assess if any public and private support received by these firms in order to adopt energy efficient technology (EET) has resulted in a favourable outcome in terms of the number of adopted technologies, CO_2 emission reduction and investment related to such technology. A total number of 113 firms have been identified as being beneficiaries of support programmes, either by the private sector based Climate Cent Foundation or by public entities (Cantons or Municipalities). Applying propensity score matching in order to control for non-random treatment issues, all of the outcome variables have been found to positively respond to such support measures.

While the analysis, due to inherent data limitations, does not bring about any conclusions about the magnitude of success (i.e., what has been the gain in terms of reduced energy consumption by monetary unit of means granted, and whether the funds have been allocated in the most cost-effective manner), it provides tangible evidence that no crowding-out effects emerge as a result of these support schemes. This is an important finding that contributes to justifying ongoing efforts to facilitate diffusion of energy efficient technology, given that reducing our energy systems' reliance on non-sustainable and environmentally costly sources of energy is a long-term challenge that cannot be expected to solve itself without decisive and well-coordinated policy intervention.

4.7 References

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4.8 Appendix

Table 4.1: Composition of Data Set by Industry and Size Class

	Number of firms supported by			Total number of	
Industry (NACE)	Climate Cent Fnd.	Cantons, Munici-palities	Any of these	EET adopters	All firms
Food, beverage, tobacco (15, 16)	5	2	7	72	98
Textiles (17)	1	0	1	16	24
Clothing, leather (18, 19)	0	0	0	4	10
Wood processing (20)	0	2	2	21	37
Paper (21)	1	1	2	17	25
Printing (22)	1	0	1	36	68
Chemicals (23, 24)	6	1	7	52	85
Plastics, rubber (25)	3	1	4	34	52
Glass, stone, clay (26)	2	1	3	29	41
Metal (27)	1	1	1	17	31
Metal working (28)	4	4	7	82	167
Machinery (29)	4	4	7	117	194
Electrical machinery (31)	1	1	1	33	58
Electronics, instruments (30, 32, 331-334)	1	2	3	64	126
Watches (335)	0	1	1	15	40
Vehicles (34, 35)	1	1	1	14	22
Other manufacturing (36, 37)	0	1	1	19	37
Energy, water (40, 41)	3	10	11	40	49
Construction (45)	6	8	11	98	203
Wholesale trade (50. 51)	1	3	4	81	172
Retail trade (52)	2	1	3	70	149
Hotels, catering (55)	2	4	6	60	105
Transport, telecommunication (60-63)	3	4	7	87	142
Banks, insurance (65-67)	2	3	5	59	129
Real estate, leasing (70, 71)	3	5	6	10	18
Computer services (72, 73)	0	0	0	22	50
Business services (74)	2	6	7	59	149
Personal services (93)	2	2	3	11	14
Telecommunication (64)	0	1	1	7	11
Total	57	70	113	1246	2306
Size class (number of employees)					
Small (< 50)	4	11	14	458	1114
Medium ($50 - 250$)	28	40	63	512	838
Large (≥ 250)	25	19	36	276	354
Total	57	70	113	1246	2306

Table 4.2: First Stage (Probability of Being Supported) Estimation

(Intercept)	-1.4457***	(-2.73)
IND_MANUF1	-0.4291	(-1.24)
IND_MANUF2	0.1649	(0.76)
IND_MANUF3	-0.3689	(-1.49)
IND_MANUF4	0.0128	(0.05)
IND_CONSTR	-0.3566	(-1.30)
IND_SERV1	0.1794	(0.77)
IND_SERV2	-0.2988	(-1.10)
LANG_FR	-0.3245*	(-1.72)
LANG_IT	-0.4046	(-0.92)
SIZE_1	0.0674	(0.13)
SIZE_2	0.6952	(1.41)
SIZE_3	0.7309	(1.43)
PRE_1970	-0.3521**	(-2.34)
PRE_1925	0.4178***	(2.84)
FOREIGN	-0.3677*	(-1.96)
HI_EDU	0.1204*	(1.80)
N	1076	
Maximised log-L	-283.1	
Null log-L	-314.2	
R2	0.099	

z-Values in brackets. Stars denote statistical significance at the 10% (*), 5% (**) and 1% (***) levels respectively.

Table 4.3: Covariates: Means of Treated and Matched

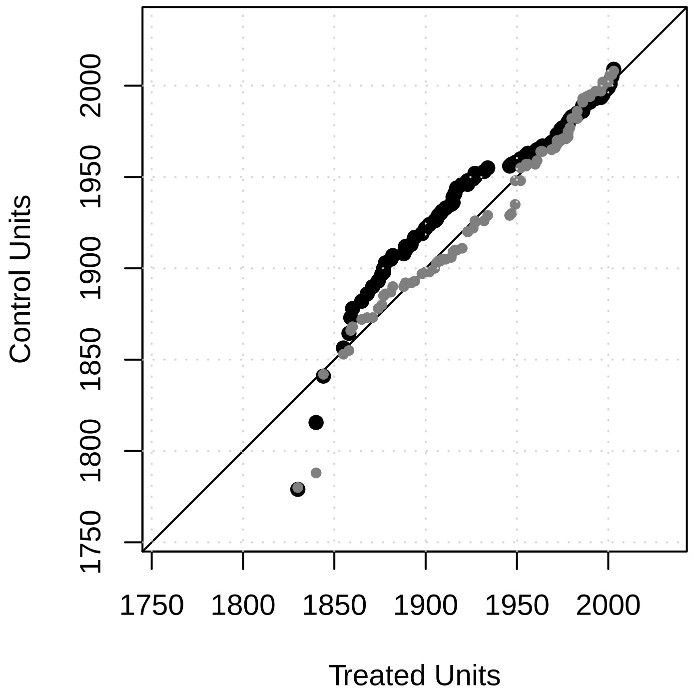
	Means			Difference	
	Treated	Matched	Untreated	Tr – Ma	p-Value
Number of employees	242.217	219.544	170.355	22.673	0.613
SIZE (log Number of employees)	4.896	4.839	4.294	0.058	0.725
YEAR	1935.674	1933.880	1946.124	1.793	0.802
% of employees with higher edu.	20.554	19.412	20.116	1.142	0.671
HI_EDU (logistic transf. of the above)	-1.332	-1.443	-1.424	0.111	0.415

Table 4.4: Outcome Variables: Means of Treated and Matched

	Means			Difference	
	Treated	Matched	Untreated	Tr – Ma (ATT)	p-Value
EET Investments	15.785	8.073	6.062	7.712	0.039**
EET Investments/L	11.961	11.339	11.172	0.621	0.084*
CO2 Reduction yes/no	0.876	0.747	0.691	0.129	0.033**
log N adopted Tech.	1.966	1.522	1.490	0.444	0.000***
N adopted Tech.	8.413	5.576	5.591	2.837	0.000***

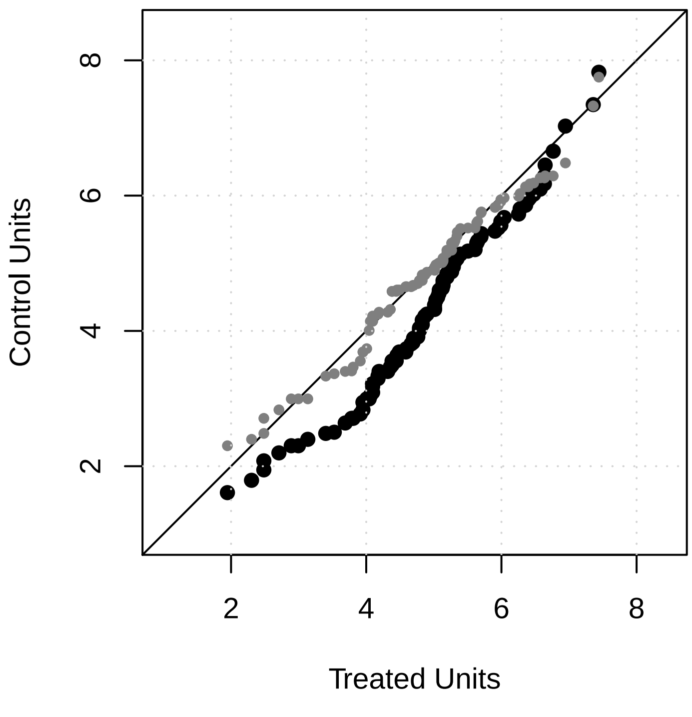
Stars denote statistical significance at the 10% (*), 5% (**) and 1% (***) levels respectively.

Figure 4.1: QQ Plot of Variable YEAR (Treated versus Raw and Matched)



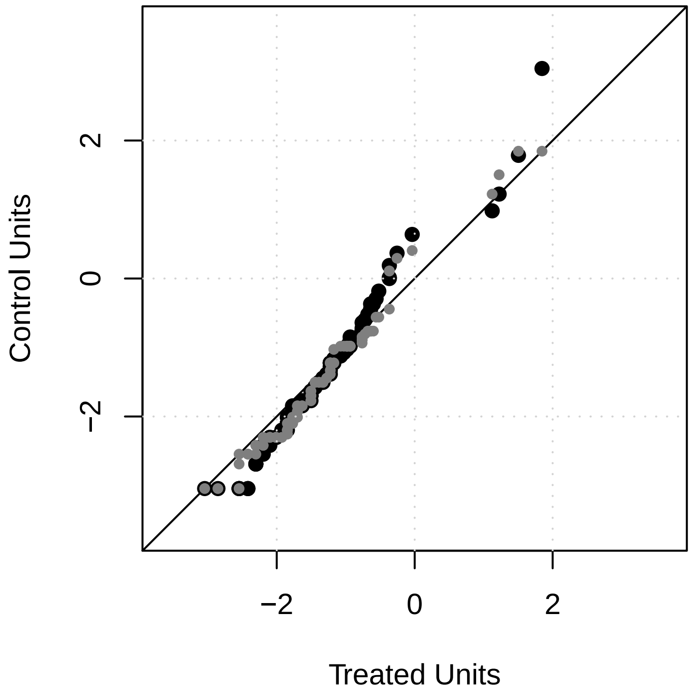
Black: Raw Data; Gray: Matched Data

Figure 4.2: QQ Plot of Variable SIZE (Treated versus Raw and Matched)



Black: Raw Data; Gray: Matched Data

Figure 4.3: QQ Plot of Variable HI_EDU (Treated versus Raw and Matched)



Black: Raw Data; Gray: Matched Data

Appendix — Questionnaire (German Version)

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KOF

Befragung 2009
Entwicklung und Verarbeitung von Energietechnologien

Bitte beachten:

- Alle Angaben werden streng vertraulich behandelt.
- Die Antworten beziehen sich, wenn nicht anders verlangt, auf den Standort Schweiz.
- Bei Unklarheiten bitte die Erläuterungen beachten.
- Der Fragebogen ist für die Rückantwort auf der letzten Seite adressiert.
- Zutreffendes Feld ☒ bitte ankreuzen oder Wert eintragen.

Bitte senden Sie uns den Fragebogen bis spätestens
15. Mai 2009
zurück, auch wenn nicht alle Fragen vollständig beantwortet werden können.

1. Angaben zur Unternehmung und den Marktverhältnissen

1.1 **Gründungsjahr** der Unternehmung (ohne Berücksichtigung rein juristischer Statusveränderungen):

☐☐☐☐ 10

1.2 Ist Ihre Unternehmung mehrheitlich in **ausländischem Besitz?**

Ja ☐ Nein ☐ 11

a) **Falls ja**, bitte Land angeben: ____________________

b) **Falls nein**: Ist Ihre Unternehmung Teil einer Unternehmensgruppe?

Ja ☐ Nein ☐ 33

1.3 Anzahl der **Beschäftigten** in der Schweiz Ende 2008:
(inkl. Lehrlinge; Teilzeitbeschäftigte auf Vollzeitstellen umrechnen)

☐☐☐☐☐ 38

1.4 Der Anteil folgender **Personalkategorien** an der Gesamtbeschäftigung betrug Ende 2008 schätzungsweise:
(Teilzeitbeschäftigte auf Vollzeitstellen umrechnen)

- AkademikerInnen ☐☐☐ %
- Personen mit einem Abschluss höher als Berufslehre ☐☐☐ %
- Gelernte (Berufslehre) ☐☐☐ %
- An- und Ungelernte ☐☐☐ %
- Lehrlinge ☐☐☐ % 53

Total Beschäftigte 1 0 0 %

1.5 **Umsatz** (ohne MwSt) der Unternehmung ab Standort Schweiz 2008:

CHF ☐☐ ☐☐☐ ☐☐☐ ☐☐☐ 64

Banken: Erträge aus Zins-, Handels-und Kommissionsgeschäft sowie Dienstleistungsgeschäft;
Versicherungen: Bruttoprämien + Nettoertrag aus Kapitalanlagen;
Beratungsfirmen u.ä.: Bruttohonorarertrag

1.6 Ihre Unternehmung **exportiert Güter/Dienstleistungen:**

Ja ☐ Nein ☐ 65

Falls **ja**: **Anteil** der **Exporte** am Umsatz 2008: ☐☐☐ % 68

Dienstleistungsexporte beinhalten auch die Dienstleistungen für ausländische Kunden, die in der Schweiz bezogen werden, wie z.B. Hotelaufenthalte ausländischer Touristen.

1.7 Anteil des **Personalaufwandes** am Umsatz 2008: ☐☐☐ %

1.8 Anteil der **Energiekosten** am Umsatz 2008: ☐☐☐ %

1.9 Gesamtwert der **Einkäufe** von Waren und Dienstleistungen (ohne MwSt) als Anteil am Umsatz 2008: ☐☐☐ % 77

Ausgaben für **Waren** (Materialien, Vor-/Zwischenprodukte, usw.) und **Dienstleistungen** von Banken, Versicherungen, Telekom etc., **nicht aber Ausgaben für Investitionsgüter.**
Versicherungen: inkl. Bruttozahlungen für Versicherungsfälle.

1.10 Wie wichtig sind **umweltschonende Vorleistungen** bei Einkäufen Ihrer Unternehmung?

	1	2	3	4	5	
nicht wichtig	☐	☐	☐	☐	☐	sehr wichtig

78

1.11 **Bruttoinvestitionen** (ohne MwSt) 2008:
(notfalls Schätzwert angeben)

CHF ☐☐☐☐☐☐☐☐☐☐☐ 89

Investitionen in eigengenutzten Betriebsbauten (neuerstellten Betriebsbauten, Umbauten, Renovationen etc.), Ausrüstungsinvestitionen (Fahrzeuge, Maschinen, Geräte, Büroausrüstung etc.) und Softwareinvestitionen

1.12 Mittelfristige Entwicklung der **Nachfrage** auf dem **Hauptabsatzmarkt**:

	starker Rückgang 1	2	3	4	starke Zunahme 5	
Periode 2006-2008	☐	☐	☐	☐	☐	
Periode 2009-2011 (Einschätzung)	☐	☐	☐	☐	☐	91

1.13 Anzahl in- und ausländischer **Hauptkonkurrenten** auf dem **Hauptabsatzmarkt**:

bis 5	6 bis 10	11 bis 15	16 bis 50	mehr als 50	
☐	☐	☐	☐	☐	92

1.14 Beurteilung der **Wettbewerbsintensität** auf dem **Hauptabsatzmarkt** hinsichtlich:

	sehr schwach 1	2	3	4	sehr stark 5	
- Preis	☐	☐	☐	☐	☐	
- Nichtpreisliche Wettbewerbsdimensionen	☐	☐	☐	☐	☐	94

Nichtpreisliche Wettbewerbsdimensionen: z. B. Produktdifferenzierung, häufige Einführung neuer Produkte, technischer Vorsprung, Flexibilität bei Kundenwünschen, Serviceleistungen

2. Generelle Innovationsaktivitäten

2.1 Hat Ihre Unternehmung in der Periode 2006-2008 **Innovationen** eingeführt?

	Ja	Nein
	☐	☐ 95
Falls ja: - Produktinnovationen	☐	
- Prozessinnovationen	☐	

Produktinnovationen: Einführung neuer oder stark verbesserter/ modifizierter Produkte bzw. Dienstleistungen

Prozessinnovationen: Einsatz neuer oder stark verbesserter/ modifizierter Fertigungstechniken bzw. Techniken zur Erbringung von Dienstleistungen

2.2 Hat Ihre Unternehmung in der Periode 2006-2008 **Forschung und Entwicklung** (F&E) durchgeführt?

Ja ☐ Nein ☐ 98

Falls ja: kumuliert über die drei Jahre 2006-2008 betrugen unsere F&E-Ausgaben am Standort Schweiz schätzungsweise:

CHF ☐☐☐☐☐☐☐☐☐☐☐ 109

Davon: Anteil für F&E-Aufträge an Dritte ☐☐☐ % 112

2.3 Hat Ihre Unternehmung in der Periode 2006-2008 **Patente** angemeldet?

Ja ☐ Nein ☐

Falls ja: Wieviele? ca. ☐☐☐ 116

Pro Erfindung nur eine Patentanmeldung, also keine Berücksichtigung von Mehrfachanmeldungen (z.B. in verschiedenen Ländern) derselben Erfindung

2.4 Der Umsatz Ihrer Unternehmung verteilte sich 2008 auf folgende **Produktgruppen**:

	Umsatzanteil
- Seit 2006 eingeführte **neue** Produkte	☐☐☐ %
- Seit 2006 eingeführte **erheblich verbesserte** Produkte	☐☐☐ %
- Seit 2006 **nicht** oder **nur unerheblich veränderte** Produkte	☐☐☐ % 125
Total Beschäftigte	1 0 0 %

3. Einsatz von Energietechnologien (ET)

3.1 In unserer Firma verwenden wir mindestens eine der in den **Fragen 3.2 und 3.4** (Seite 3) unten **aufgelisteten Energietechnologien:**

Ja ☐ Nein ☐ 126

Falls nein, bitte weiter zur Frage 3.9

Energiesparende Technologien: Energietechnologien, die zur Erhöhung der Energieeffizienz (Senkung des Energieverbrauchs pro Outputeinheit) beitragen

Technologieelemente: z.B. neue elektronische Komponenten, neue Materialien, neue Software

3.2 In unserer Firma verwenden wir die folgenden **energiesparenden Technologien** bzw. **Technologieelemente**:

Falls Ihre Firma energiesparende Technologien in einem Technologiefeld sowohl in den letzten 5 Jahren als auch früher eingeführt hat, kreuzen Sie bitte beide Felder an.

	ja, wann eingeführt? in den letzten 5 Jahren	früher	**nein**
a) Energiesparende Technologien in elektromechanischen und elektronischen Anwendungen, nämlich:			
- in elektrischen Maschinen und Antrieben	☐	☐	☐
- in Informations- und Kommunikationstechnik	☐	☐	☐
- in Haushalts- und Unterhaltungselektronik	☐	☐	☐
- in verfahrenstechnischen Komponenten (Kompressoren, Pumpen, Wärmetauschern etc.)	☐	☐	☐
- in verfahrenstechnischen Prozessen	☐	☐	☐ 141
b) Energiesparende Technologien in Fahrzeugen und verkehrstechnischen Anwendungen, nämlich:			
- in Antriebssystemen für Fahrzeuge	☐	☐	☐
- in Fahrzeughüllen (z.B. Verbesserungen des Gewichts/der Aerodynamik)	☐	☐	☐
- in Verkehrsleitsystemen	☐	☐	☐ 150
c) Energiesparende Technologien in bautechnischen Anwendungen, nämlich:			
- in Gebäudeisolation	☐	☐	☐
- in Beleuchtung (inkl. Steuerungssysteme)	☐	☐	☐
- in Heizung (inkl. Steuerungssysteme)	☐	☐	☐
- in Kühlung/Beschattung	☐	☐	☐
- in Belüftung und Klimatechnik	☐	☐	☐ 165

d) Energiesparende Technologien in sonstigen Anwendungen, nämlich:

____

____

3.3 Hat der **Einsatz** von **energiesparenden Technologien** auch zu einer Verringerung des **CO_2-Austosses** in Ihrer Firma beigetragen?

Ja ☐ Nein ☐ 166

Die folgende Frage 3.4 betrifft nur Firmen, die ihren Energiebedarf teilweise oder ganz durch eigene Produktion decken, Stromproduzenten sind und/oder eigene Wärmeerzeugungsysteme betreiben.

3.4 In unserer Firma verwenden wir folgenden **Technologien zur Elektrizitätserzeugung und -übertragung bzw. zur Wärmeerzeugung**:

Falls Ihre Firma energiesparende Technologien in einem Technologiefeld sowohl in den letzten 5 Jahren als auch früher eingeführt hat, kreuzen Sie bitte beide Felder an.

	ja, wann eingeführt? in den letzten 5 Jahren	früher	**nein**
a) Technologien zur Elektrizitätserzeugung und -übertragung, nämlich:			
- Photovoltaik	☐	☐	☐
- Elektrizität aus Biomasse	☐	☐	☐
- Windenergie	☐	☐	☐
- Wärme-Kraft-Kopplung			
• auf der Basis von Biomasse	☐	☐	☐
• auf der Basis von Öl/Gas/Kohle	☐	☐	☐
- Wasserkraftwerke	☐	☐	☐
- Kraftwerke auf der Basis von Öl/Gas/Kohle	☐	☐	☐
- Kraftwerke auf der Basis von nuklearen Energieträgern	☐	☐	☐ 190
b) Technologien zur Wärmeerzeugung, nämlich:			
- Solartechnik (Sonnenwärme)	☐	☐	☐
- Wärmeerzeugung aus Biomasse	☐	☐	☐
- Geothermie	☐	☐	☐
- Wärmepumpen (Umweltwärme)	☐	☐	☐
- Wärmerückgewinnungssysteme	☐	☐	☐
- Fernwärmenutzungssysteme	☐	☐	☐ 208

3.5 Anteil der **Investitionen** in **Energietechnologien** (ET) an den Gesamtbruttoinvestitionen im Jahr 2008:

☐☐☐ % 211

3.6 Unsere Firma wurde bei der Einführung von Energietechnologien (ET) **finanziell unterstützt:**

	Ja	Nein
- durch das Bundesamt für Energie (BFE)	☐	☐
- durch die Stiftung Klimarappen	☐	☐
- durch Kantone und Gemeinden	☐	☐ 214

Falls ja, wie stark war der **Impuls** der Förderung auf die Einführung von Energietechnologien (ET)?

sehr schwach 1	2	3	4	sehr stark 5
☐	☐	☐	☐	☐ 215

3.7 Besteht zwischen Ihrer Unternehmung und der Energieagentur der Wirtschaft (EnAW) eine **Verpflichtung zur CO_2-Reduktion** zwecks Befreiung von der CO_2- Abgabe?

Ja ☐ Nein ☐ 216

3.8 Beurteilung der Bedeutung folgender **Motive/auslösender Faktoren** bei der Einführung von Energietechnologien (ET):

	keine 1	2	3	4	sehr grosse 5	
- Zu hohe bzw. steigende Energiepreise	☐	☐	☐	☐	☐	
- Bestehende Energiesteuern und -abgaben	☐	☐	☐	☐	☐	
- Erwartete Energiesteuern und -abgaben	☐	☐	☐	☐	☐	
- Befürchtung von künftigen Engpässen bei der Energieversorgung	☐	☐	☐	☐	☐	
- Schonung der Umwelt	☐	☐	☐	☐	☐	
- Bestehende oder erwartete Nachfrage nach umweltfreundlich produzierten Produkten	☐	☐	☐	☐	☐	
- Staatliche Anreize zur Reduktion des CO_2-Austosses	☐	☐	☐	☐	☐	
- Staatliche Förderung zur Steigerung der Energieeffizienz	☐	☐	☐	☐	☐	
- Erfüllung bestehender staatlicher Auflagen	☐	☐	☐	☐	☐	
- Erfüllung erwarteter neuer staatlicher Auflagen	☐	☐	☐	☐	☐	
- Erfüllung von freiwilligen Vereinbarungen bezüglich Energieeffizienz innerhalb der Branche	☐	☐	☐	☐	☐	227

- Andere, nämlich: ____________________

3.9 Beurteilung der Bedeutung von **Hemmnisfaktoren**, welche zum Verzicht auf ET führten (für Nichtanwender) oder die Einführung von ET erheblich behinderten (für Anwender):

Technologie:	keine 1	2	3	4	sehr grosse 5	
- Technologie zu teuer	☐	☐	☐	☐	☐	
- Fallender Technologie-Preistrend macht sofortigen Einstieg unattraktiv	☐	☐	☐	☐	☐	
- Technologie zu wenig ausgereift	☐	☐	☐	☐	☐	
- Informationsprobleme/-kosten	☐	☐	☐	☐	☐	
- Leistungsfähigkeit zu unsicher	☐	☐	☐	☐	☐	232
Kompatibilität:						
- Nicht sinnvoll/rentabel einsetzbar:						
• bei unserem Produkteprogramm	☐	☐	☐	☐	☐	
• bei unserer Produktionstechnologie	☐	☐	☐	☐	☐	234
Kosten/Finanzierung:						
- Zu grosses Investitionsvolumen	☐	☐	☐	☐	☐	
- Amortisationszeit zu lang	☐	☐	☐	☐	☐	
- Mangelnde Liquidität	☐	☐	☐	☐	☐	
Know-how/Personal/Management:						
- Vorhandenes Wissen zu gering	☐	☐	☐	☐	☐	
- Mangel an qualifiziertem Personal	☐	☐	☐	☐	☐	
- Management anderweitig absorbiert	☐	☐	☐	☐	☐	
Ungewissheit über künftige staatliche Auflagen im Energiebereich	☐	☐	☐	☐	☐	241

Andere Hemmnisse: ____________________

4. Innovationen der Firma in Energietechnologien (ET)

Innovationen im Bereich der Energietechnologien:
Generierung von neuen Energietechnologien bzw. erhebliche Weiterentwicklung von bestehenden Energietechnologien in mindestens einem der in den **Fragen 4.2 und 4.4** aufgelisteten Technologiefeldern.

4.1 Unsere Firma generiert selbst **Innovationen** im Bereich der **Energietechnologien**:

Ja ☐ Nein ☐

Falls ja: für den Eigengebrauch ☐ für den Markt ☐ 244

Falls nein, bitte füllen Sie abschliessend die **Seite 6** aus.

Energiesparende Technologien: Energietechnologien, die zur Erhöhung der Energieeffizienz (Senkung des Energieverbrauchs pro Outputeinheit) beitragen

Technologieelemente: z.B. neue elektronische Komponenten, neue Materialien, neue Software

4.2 Unsere Firma hat in den letzten 5 Jahren Innovationen in den folgenden energiesparenden Technologien bzw. Technologieelementen generiert:

a) Energiesparende Technologien in elektromechanischen und elektronischen Anwendungen, nämlich:

	Ja	Nein	
- in elektrischen Maschinen und Antrieben	☐	☐	
- in Informations- und Kommunikationstechnik	☐	☐	
- in Haushalts- und Unterhaltungselektronik	☐	☐	
- in verfahrenstechnischen Komponenten (Kompressoren, Pumpen, Wärmetauschern etc.)	☐	☐	
- in verfahrenstechnischen Prozessen	☐	☐	
- in Brennstoffzellen	☐	☐	
- in Turbinentechnik	☐	☐	251

b) Energiesparende Technologien in Fahrzeugen und verkehrstechnischen Anwendungen, nämlich:

	Ja	Nein	
- in Antriebssystemen für Fahrzeuge	☐	☐	
- in Fahrzeughüllen (z.B. Verbesserungen in Gewicht/Aerodynamik)	☐	☐	
- basierend auf Wasserstoff als Energieträger	☐	☐	
- basierend auf Elektrizität	☐	☐	
- in Verkehrsleitsystemen	☐	☐	256

c) Energiesparende Technologien in bautechnischen Anwendungen, nämlich:

	Ja	Nein	
- in Gebäudeisolation	☐	☐	
- in Beleuchtung (inkl. Steuerungssysteme)	☐	☐	
- in Heizung (inkl. Steuerungssysteme)	☐	☐	
- in Kühlung/Beschattung	☐	☐	
- in Belüftung und Klimatechnik	☐	☐	261

d) Energiesparende Technologien in sonstigen Anwendungen, nämlich:

____

____

4.3 Trägt der Einsatz der von Ihrer Firma generierten neuen bzw. erheblich weiterentwickelten **energiesparenden Technologien** auch zu einer **Verringerung des CO_2-Austosses** bei?

Ja ☐ Nein ☐ 262

4.4 Unsere Firma hat in den letzten 5 Jahren **Innovationen** in den folgenden Technologiebereichen generiert:

a) Technologien zur Elektrizitätserzeugung und -übertragung, nämlich:

	Ja	Nein	
- Photovoltaik	☐	☐	
- Elektrizität aus Biomasse	☐	☐	
- Windenergie	☐	☐	
- Wärme-Kraft-Kopplung			
• auf der Basis von Biomasse	☐	☐	
• auf der Basis von Öl/Gas/Kohle	☐	☐	
• dezentrale Wärme-Kraft-Kopplung (“microgeneration in buildings“)	☐	☐	
- Wasserkraftwerke	☐	☐	
- Kraftwerke auf der Basis von Öl/Gas/Kohle	☐	☐	
- Kraftwerke auf der Basis von nuklearen Energieträgern/Kernfusion	☐	☐	
- Hochspannungs-Gleichstrom-Übertragung	☐	☐	
- Verwendung von Supraleitern	☐	☐	273

b) Technologien zur Wärmeerzeugung, nämlich:

	Ja	Nein	
- Solartechnik (Sonnenwärme)	☐	☐	
- Wärmeerzeugung aus Biomasse	☐	☐	
- Geothermie	☐	☐	
- Wärmepumpen (Umweltwärme)	☐	☐	
- Wärmerückgewinnungssysteme	☐	☐	
- Fernwärmenutzungssysteme	☐	☐	279

c) Technologien zur Lagerung von CO_2

	Ja	Nein
- Carbon Capturing and Storage (CCS)	☐	☐

d) Andere Technologien, nämlich:

____

4.5 Anteil der **F&E-Ausgaben** für die Entwicklung neuer bzw. Weiterentwicklung bestehender **Energietechnologien (ET)** in der Periode 2006-2008 an den F&E-Gesamtausgaben:

☐☐☐ % 283

4.6 Schätzung des **Umsatzanteils** von neuen Produkten und von erheblich weiterentwickelten bestehenden Produkten Ihrer Firma **im Bereich der Energietechnologien** (ET):

Vor 5 Jahren ☐☐☐ %

Heute ☐☐☐ %

In 5 Jahren ☐☐☐ % 292

4.7 Unsere Firma wurde bei der Generierung von Innovationen im Bereich der **Energietechnologien** (ET) finanziell unterstützt:

	Ja	Nein	
- durch das Bundesamt für Energie (BFE)	☐	☐	
- durch Kantone und Gemeinden	☐	☐	294

Falls ja, wie stark war der **Impuls** der Förderung auf die Generierung von Innovationen im Bereich der Energietechnologien (ET)?

sehr schwach				sehr stark	
1	2	3	4	5	
☐	☐	☐	☐	☐	295

****Ende des Fragebogens****

Bitte Kontaktinformationen und allfällige Bemerkungen auf der letzten Seite ausfüllen und Fragebogen bis zum 15. Mai 2009 an uns zurückschicken. Vielen herzlichen Dank für Ihre Mitarbeit.

*** Wir danken Ihnen für Ihre wertvolle Mitarbeit ***

Kontaktperson der Firma: ______________________

Funktion/Stellung: ______________________

Telefon: ______________________

Fax: ______________________

Firmenadresse*: ______________________

E-Mail: ______________________

Homepage: ______________________

***Bitte teilen Sie uns allfällige Adress- oder Personenänderungen mit! Vielen Dank.**

Bemerkungen zur Umfrage:

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____

____

____

____

Für Auskünfte stehen wir Ihnen gerne zur Verfügung:

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