Chapter 10
Waste Technological Dynamics and Policy Effects: Evidence from OECD Patent Data

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Abstract This chapter examines the effect of environmental policies on technological change, in the field of waste management. This study is conducted using patent data on 28 OECD countries over the period 1980–2005 and considers five different technological fields related to the waste sector. Even though the analysis confirms that policies actually played a positive, significant role in promoting the development of green innovations, this effect is highly non-linear and strongly depends on time. As previous works have highlighted, the technological maturity of the sector, especially if compared with other areas of environmental innovation such as renewables, is reflected in a decreasing effect of policies on innovation trends. If a first wave of policies, which dates back to the 1990s, was able to promote technological change, this effect is now less evident. Nevertheless, it is reasonable to conclude that if no policy efforts had been introduced, the slowdown in the trend of patenting in waste-related sectors would have been even more pronounced.

Keywords Waste management • Patents • Policy effects • Non linearity • Technology fields

10.1 Introduction

Landfill reduction has been, in the last decades, one of the primary aims of environmental policies in European and OECD countries. According to the European waste hierarchy, landfill diversion and waste prevention are the two main priorities in the new waste management strategies. For this reason, in 1999,

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V. Costantini and M. Mazzanti (eds.), *The Dynamics of Environmental and Economic Systems: Innovation, Environmental Policy and Competitiveness*,
DOI 10.1007/978-94-007-5089-0_10,

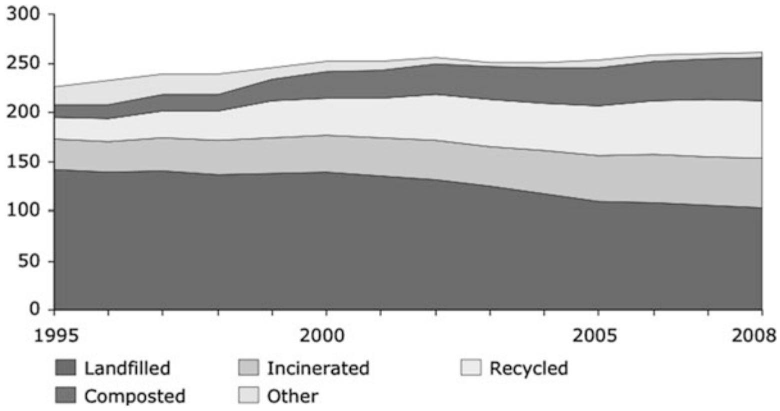

Fig. 10.1 Development of municipal waste management in EU-27 (Millon ton)

a European landfill directive was issued (EEA 2007), which can still be considered the cornerstone of European waste strategy. This policy measure, like many other European guidelines on waste, has to be accepted and implemented at country level because the goals set by the directive can only be achieved by a decentralised implementation associated with further national legislation.

Despite all the efforts, landfilling is still a very important option in the European municipal waste management but with significant differences among the European countries. The two pictures below, for example, tell us two different and important stories. Figure 10.1 shows how, at an aggregate level, the composition of waste management has changed radically from 1995 to 2008, with a declining trend in landfilling in favour of more preferred disposal options such as recycling, incineration and composting. If the general picture looks extremely positive, the second graph below (Fig. 10.2) shows how the aggregate data masks high intra-country heterogeneity. For example, there are countries, such as Germany, Sweden and Belgium, that rely on landfilling only for a very small share of the total waste management (less than 5%), and there is a second group of countries, including Italy, Finland and Spain, in which landfilling accounts for about the 50% of the total waste management. Finally, there is a last group that includes, among others, Lithuania, Greece and Bulgaria, in which landfill is still the predominant disposal choice.

Furthermore, even if the pictures above depict a positive trend of general waste management in Europe, the total amount of waste produced is continuously increasing (EEA 2010) in EU-27, driven mainly by household consumption and the increasing number of households. This increasing amount of waste production puts pressure on the management system, with a consequent increase in the amount of waste traded across borders, much of it for recycling and energy recovery.

In this context, policy stringency may play many important roles. First of all, policy may be implemented at country level in order to promote landfill diversion and to encourage the use of other forms of disposal, such as recycling and incineration. For these cases, a mix of command-and-control and economic instruments is

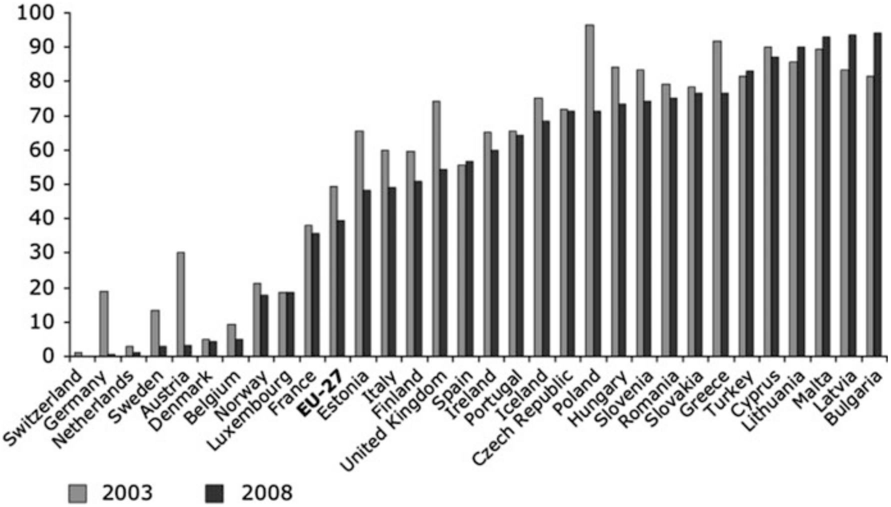

Fig. 10.2 Municipal waste landfilled in EEA countries (share of total disposal)

generally implemented. These are bans on landfilling of specific materials, technical requirements for the construction of landfill sites and incineration plants, landfill tax and specific limits on the heavy metal contained in packaging, etc. Moreover, many countries have adopted a polluter pays principle scheme (i.e., they have shifted the responsibility from the consumer to the producer) as in plastic and paper packaging. European directives, on the other hand, generally impose specific performance targets (such as a share of waste to be recycled), with flexibility in the adoption of the preferred technology. In addition to the emphasis posed by the European waste hierarchy, the focus on landfill reduction is due in part to the negative environmental impacts of landfilling (Pearce 2004) that, in many cases, are not economically justified, especially if the cost and benefit of different waste management technologies are taken into account (Dijkgraaf and Vollebergh 2004). Secondly, in a context that is evolving rapidly and in which the main technological paradigm (disposal) is switching to new and differentiated alternatives, it is interesting to understand what role policy stringency has played in promoting technical change (Johnstone et al. 2010b). The first of these two points has been the object of a consolidated strand of literature, while the second point, the relationship between policy stringency and environmental innovation, is the aim of this work. Thanks to an online database made available by the OECD,[1] we can study how waste-related technologies have changed among a selected group of 28 OECD countries in the period 1980–2005, through the analysis of patent data. In particular, the OECD online statistic service divides waste-related patents into five classes: incineration and recovery, material recycling, fertilisers from waste, solid waste collection and

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[1] OECDStatExtract, available at http://stats.oecd.org

general waste management. Starting from this data, five innovation indicators have been created at country level for the analysed period, and they will be used in the following section as proxies for environmental innovation at country level. Moreover, a series of country fact sheets on environmental regulation, made available by Eionet,[2] have made it possible to create a policy indicator that will be used to test the effect of regulation on environmental innovation. This chapter is structured as follows: the first section illustrates the main characteristics of the two strands of relevant literature, that is, waste management and disposal options, and the drivers of environmental innovation; the second section illustrates the data and the methodology used in the analysis; the third one presents the main results of an econometric analysis conducted on the data and their economic interpretation; and the final section concludes.

10.2 Waste, Environmental Policies and Technological Innovation

An important part of the waste literature is related to waste management and the evaluation of the externalities involved with the different instruments of waste recovery, with many focusing on cost-benefit analyses of different waste management strategies, often accompanied by policy indications and evaluations. A good survey of this branch of literature can be found in Goddard (1995) and Choe and Fraser (1998). In addition to these studies on waste management, another much smaller (in terms of number of publications) body of literature has been built up in the last decade with the aim to understand the evolution of waste generation and disposal over time. Even though these kinds of studies are not directly correlated with this analysis, this work strongly refers to this branch of literature for the identification of the possible determinant of waste management development. These studies, based on Kuznets-type models, aim at understanding how waste generation and waste disposal evolve when income rises, usually by regressing the environmental (waste) indicator variable against GDP and squared GDP, with the purpose of testing for the presence of delinking between environmental impact and economic growth. A common result of this literature is that there is still no evidence of an inverted U-shape in relation to waste generation (the amount of waste generated is increasing with respect to income) but a general change in the composition of waste management is usually registered. What usually happens, in fact, is that, with respect to GDP, landfilling generally decreases (i.e., we have absolute delinking) or increases less than proportionally (the so-called relative delinking) with respect to income, whereas incinerating and recycling usually increase with respect to income. Cole et al. (1997) was one of the first studies of this kind, and the

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[2] EIONET is a partnership agency of the EEA and its member countries; it is fundamental to the collection and organisation of data for the EEA. See www.eionet.net

authors found a monotonically increasing relationship between income growth and waste accumulation in relation to municipal solid waste using a data set of 13 OECD countries over 15 years (1975–1990); Seppala et al. (2001) in a study on industrialised country over the period 1970–1994 found the same result. Regarding waste disposal, Fischer-Kowalski and Amann (2001) found evidence of absolute delinking for landfilled waste but only a relative delinking for generated waste by analysing OECD countries over the period 1975–1995. Kaurosakis (2006) obtained similar results by conducting a similar analysis on 30 OECD countries including some socio-economical and policy-oriented variables. Finally, Mazzanti and Zoboli (2005) found no evidence of either absolute or negative delinking in Europe during the period 1995–2000. More recently, Mazzanti et al. (2009a) in an analysis at EU level confirmed that municipal solid waste is constantly increasing with respect to income, while a more reassuring picture is emerging from landfilling and recycling. Environmental policy in the field of waste is in fact driving a transaction towards a progressive reduction in landfilling and a consequent promotion of recycling and incineration, even if disparities are still present among countries. Finally, in an analysis of the Italian case conducted at provincial level, Mazzanti et al. (2012) found that here too, we are in the presence of absolute decoupling for landfilled waste, but the total amount of waste is still increasing with income. Summarising the results of this first strand of literature, the waste management in OECD countries is characterised by a flow of total generated waste that is monotonically increasing with respect to income, whereas landfilling is, on average, decreasing and incineration and recycling are increasingly becoming more important. As the above-mentioned literature tells us, this transaction has been partially driven by policy stringency, as well as other socio-economic factors. Nevertheless, these results leave an open question. The policy adopted in OECD countries may have had an effect on the innovative performances of the waste management sector, generating an incentive for a continuous search for more economically efficient ways of meeting the new target posed by the regulation. Debates of this kind are not new in environmental economics, even though they have rarely been applied to waste management studies. Up to 20 years ago, the economic discipline was dominated by the idea that since firms are profit maximising, any attempt by environmental regulation to abate pollution would lead to an increase in internal costs for the compliant firm. In this framework of analysis in fact, if profitable opportunities existed to reduce pollution, optimising firms would certainly already have taken advantage of them. Moreover, many theoretical studies during the 1970s give support to the idea that a country comparative advantage could have been affected in a negative manner by stringent environmental regulation. For instance, the works of Pethig (1975), Siebert (1977) and McGuire (1982) stress how environmental policies increasing firms' internal costs affect countries competitiveness by decreasing exports, increasing imports and lowering the general country's capacity to compete in an international market. Moreover, in the long run, if production factors are free to move across countries, more stringent environmental regulation can produce movement of the manufacturing capacity from more regulated countries to less regulated ones (which are often called "pollution havens" in modern environmental and trade studies). From this perspective, command-and-control regulation, for example, that restricts the choice of technologies or inputs in the production process would increase the constraints a firm has to face, while taxes and tradable permits, charging production by-products (wastes or emissions), generate costs that did not exist before the regulation. Nevertheless, in the last two decades, many scholars have challenged this main idea. In different contributions, Porter and van der Linde (1991, 1995) strongly criticised this approach, underlining that the consolidated paradigm did not consider all the aspects of the environmental regulation/competitiveness relationship. Moving from the static approach in which technology was held constant to a dynamic context, the authors showed how in practice some of the loss of competitiveness related to the environmental regulation was compensated for by an increase in innovation driven by the policy itself. According to Porter and van der Linde in fact, a proper design policy framework may put pressure on firms, pushing them to develop new innovations and promoting technological change. From this point of view, this additional policy-driven innovation may offset the loss of competitiveness due to the additional costs of regulation. In particular, Porter and van der Linde show how regulation can act through six different channels (1995). First, regulation signals likely resource inefficiencies and potential technological improvements to companies; second, regulation focused on information gathering can achieve major benefits by raising corporate awareness; third, regulation reduces the uncertainty in environmental pollution activities; fourth, regulation, posing pressure on firm cost function, motivates cost-saving innovations; and fifth, regulation makes free riding behaviour in the transition phase through an innovation-based equilibrium more difficult. Based on this seminal work, Jaffe and Palmer (1995) distinguished three different implications of the Porter hypothesis, proposing a taxonomy, that is helpful in discerning the different lines of research that have further developed. The first idea, also called narrow Porter hypothesis, shows that certain types of environmental regulations are able to stimulate innovation, based on the idea that policy design matters and command-and-control policies are generally (with exceptions) less efficient than economic instruments in promoting innovation and technical change. A second version of the Porter hypothesis, called weak, states in a nutshell that a well-designed environmental regulatory system may stimulate certain kinds of innovation. Finally, the stronger version of the Porter hypothesis says that regulation is not only able to spur innovation but also that this gain in efficiency is able to completely offset the loss in competitiveness due to compliance costs. In other terms, this last approach suggests that more stringent and well-designed regulation promotes competitiveness.

Porter's original idea has been strongly criticised, especially by Oates et al. (1995) and Palmer et al. (1997). These authors suggest that the entire Porter reasoning was based on wrong assumptions that were not compatible with the concept of profit-maximising firms. Nevertheless, this is the exact point stressed by Porter himself. In his view, firms operate in a dynamic and uncertain framework, where the agent behaves according to Simon's idea of bounded rationality. In such a context, the rationality of firms is moved by managers who may have different objectives from the firm or do not have the competence to innovate at an adequate level. Following this line of reasoning, some theoretical works explained the Porter hypothesis as being due to managers who are risk adverse (Kennedy 1994), resistant to costly changes in their routines (Ambec and Barla 2007) or rationally bounded (Gabel and Sinclair-Desgagné 1998). Ambec and Barla (2002), on the other hand, argue that whenever managers have private information on the outcome of R&D investments and the government does not, a problem of asymmetric information may rise from which managers may derive a rent. On the contrary, if a government enacts stringent environmental regulation, it can deprive managers of their advantage and overcome this problem. Obviously, the presence of this inefficiency supports the presence of the Porter hypothesis.

In addition to the discussed theoretical contributions, the core debate regarding the Porter hypothesis has been developed through a number of different empirical studies. Following the survey conducted by Ambec et al. (2010),[3] these works can be divided into three different macro sections, representing the three different connotations of the PH, respectively: weak, strong and narrow.

With regard to the first group of works, referring conceptually (and often not explicitly) to the so-called "weak" version, one of the first contributions is Jaffe and Palmer (1997), which tested for the presence of a Porter hypothesis using pollution abatement expenditure as a proxy for environmental regulation, and total firm R&D expenditure and the total number of patent applications in a panel of US manufacturing industries in the period 1973–1991 as a proxy for innovation. Their findings support the idea that compliance expenditure has a positive and significant effect on innovation measured as R&D whereas they did not find significant results in the patent-related specifications. This last unexpected result may be due to the nature of the dependent variable: the authors used total patent counts, instead of using environmentally related ones. In another work in the same line, Brunnermeier and Cohen (2003) used US manufacturing industry data and empirically analysed the determinants of environmental technological innovation, using the number of environmental patent applications as an innovation proxy, and both pollution abatement expenditures and the number of air and water pollution control inspections as regulation proxies. They found a significant impact of the first variable and a not significant impact of the second one. Among other covariates, they found that international competition stimulates environmental innovation. Another work on patent data at firm level is Popp (2003), which by analysing 186 plants in the USA from 1972 to 1997 found that the tradable permit scheme for the reduction of SO2 has been able to promote technical change, increasing SO2 removal efficiency and decreasing operating and removal costs. Moving to cross-country studies, De Vries and Withagen (2005) studied the effect of SO2 environmental regulation on national patent counts in relative technological classes and found some evidence of a link between policy stringency

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[3] Ambec, S., Cohen, M. K., Elgie, S., Lanoie, P., (2011). The Porter Hypothesis at 20: Can Environmental Regulation Enhance Innovation and Competitiveness. Paper presented at Montreal, 2010 EAERE conference

and environmental innovation. More recently, a second example of a cross-country study is Johnstone et al. (2010a), who studied the effect of many different policy instruments on the innovative performance of the main renewable technologies (solar, wind, geothermal, ocean, biomass and waste), for 15 OECD countries, over the period 1978–2003. They found strong evidence of a Porter hypothesis. In most of their specifications, different policy instruments are positively and significantly related to technological change, and more interestingly, they observed the effect of different policy designs on different technologies. Subsidies and feed-in tariffs are, for example, more suitable for inducing innovation on more costly technologies such as solar power, while tradable certificates show a stronger effect on technologies that closely compete with fossil fuel, such as wind power. Finally, Nicolli and Mazzanti (2011) studied the effect of environmental policies on innovation in the specific waste streams of paper and plastic packaging waste, end-of-life vehicles, composting and aggregate waste for OECD countries from 1970 to 2007. They found two important results on which this work is based: first, in specific waste streams, regulation does seem to play an important role in the promotion and diffusion of innovation, and second, they outlined how the waste sector seems to have reached a degree of technological maturity and is now experiencing a decreasing trend in patenting activities. These results seem to suggest that there have been two different policy eras in waste in OECD countries, a first and older wave of policies (end of the 1980s, beginning of the 1990s) that produced a technological shock in the system and a second and more recent wave of policy which seems to have had less impact on environmental innovation. Summarising the previous works, the literature tells us that there is a positive but variable link between stringent environmental regulation and innovation.

The second strand of literature refers to the “strong” version of the Porter hypothesis, that is, testing to see if there is a link between environmental regulation and competitiveness of the firms. A review of this literature can be found in Jaffe et al. (1995), where most of the papers reported there found a negative impact of environmental regulation on productivity. Nevertheless, more recent works by Berman and Bui (2001) and Alpay et al. (2002) found respectively that refineries in the Los Angeles area and Mexican food-processing industries experience an increase in competitiveness associated with increased regulation stringency. Moreover, Lanoie et al. (2008), in a study on 17 Quebec manufacturing sectors, have found a modest but significant effect of regulation on competitiveness once the dynamics of the process are taken into account. The original critique moved by Porter and van der Linde was in fact motivated by a lack of dynamics that affected these studies at that time. Lanoie et al. (2008) show that this lack of dynamics is still present in empirical studies, especially when competitiveness at time 0 is regressed against environmental regulation at the same point in time. This may have produced biased results because the effect predicted by Porter, if present, might have taken time to develop. For this reason, in their study, they introduce a lag of 3 or 4 years between regulation and productivity, showing how regulation reduces productivity after 1 year. However, this effect is reversed after only 2 years and becomes increasingly more evident as the lag increases. Finally, Costantini and Mazzanti (2012) test the effect of environmental regulation on export competitiveness of the manufacturing sector, using a gravity model for the EU15 group over the period 1996–2007. They find that generally policies do not seem to be harmful to export competitiveness, and specifically, some energy tax policies positively influence trade patterns.

Finally, a third approach is based on the narrow version of the Porter hypothesis, that is, flexible regulatory policies are more likely to promote innovation than more prescriptive forms of regulation. This approach follows Porter's idea that the design of the policy actually matters and discerns the effect of command-and-control regulation (CAC) and economic instruments. In particular, Porter and van der Linde (1995) argue that CAC in particular have to respect three principles in order to be able to spur innovation:

1. They must leave the approach to innovation to firms and not to the regulating agency.
2. The stringency of CAC instruments must improve continuously and avoid locking in any particular technology.
3. The regulatory process must be certain and time consistent. Any uncertainty of the policy lever would increase the risk that investors face in the market, slowing down innovation.

On the other hand, market based and flexible instruments, such as emission taxes and tradable certificates, are more favourable since they leave firms freer to find the best technological solution to minimise compliance costs. A summary of this strand of literature would be beyond the scope of this work—a good review can be found in Driesen (2005), who concludes that environmental taxes provide a stronger incentive for innovation than other policy types.

10.3 Research Hypothesis, Data and Methodology

As mentioned earlier, Nicolli and Mazzanti (2011) found evidence of a close relationship between innovation and environmental policies in the field of waste, especially in composting, end-of-life vehicles and plastic and paper packaging. This work was a first attempt to address the relationship between regulation and innovation in the field of waste through narrative examples and opened discussion for a more general analysis. In particular, in the present study, an empirical analysis through the use of econometric estimation is conducted with the aim of estimating the effect of policies and other factors on innovation. The main relationship that we want to test is the following one:

$$(\text{patent}_{it}) = \alpha_{it} + \beta_1\,(\text{policy}_{it}) + \beta_2\,(\text{totpatent}_{it}) + \beta_3\,(\text{GDP}) + \varepsilon_{it} \tag{10.1}$$

where $i = 1,\ldots, 28$ indexes the cross-sectional unit (country), $t = 1980,\ldots, 2005$ indexes time and α_{it} is a constant term that controls for country fixed effect and for time effect. The dependent variable, patent counts, is measured as the total number of patent applications in each of the five areas of waste technologies (incineration and recovery, material recycling, fertilisers from waste, solid waste collection, general waste management). The explanatory variables include the policy variable (β_1), the total number of patents per year per country (β_2), and the last term is the country GDP (β_1). ε_{it} captures all the residual variation. Following previous works in this field (for instance, Johnstone et al. (2010a)), we used negative binomial and Poisson models[4] to estimate this relationship, given the count nature of the dependent variable (see also Maddala 1983; Cameron and Trivedi 1998). In particular, in this work, an event count is the number of patent applications, and we suppose here that the number of patents (PATENTSi,t) follows a negative binomial distribution.

10.3.1 Patent Data

It is well known in the economics debate that a good indicator of a country's innovative output is hard to find. For this reason, researchers have used many different imperfect proxies in previous works such as research and development expenditure (Jaffe et al. 2007), the number of scientific workers and patent counts (Johnstone et al. 2010a). Of these measures, patent applications are particularly appealing to researchers for many reasons. First of all, patent counts display overall good availability both in terms of time and country coverage, and secondly, they can be easily and efficiently divided into technological fields. Each single patent in fact is classified through an International Patent Classification (IPC) code, developed at the World Intellectual Property Organisation. This tree-like classification allows technological fields to be created with different levels of detail in a way that is similar to NACE classification. For example, Section "D" contains all patents related to "textiles and papers", while the subcategory "D 21" refers more specifically to "papermaking and production of cellulose", "D 21 F" refers to "papermaking machines and methods of producing paper thereon" and, at the maximum level of detail, "D 21 F 11/06" refers to the hyper-specific field of patents related to "processes for making continuous lengths of paper, or of cardboard, or of wet web for fibreboard production, on papermaking machines of the cylinder type". This coding allows very specific technological subcategories to be created that can identify specific fields of interest. For all these reasons, patent data have been long considered a useful proxy of innovation for economic research (Griliches 1990). Moreover, as Dernis and Kahn (2004) suggest, generally all economically relevant innovations are patented, and for this reason, patents can be used as a valuable proxy for a country or firm level of innovation. Nevertheless, patents also suffer some well-known criticalities. First of all, it is difficult to discern the value of

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[4] In the text, only negative binomial results are reported, but Poisson estimations generally confirm the presented results.

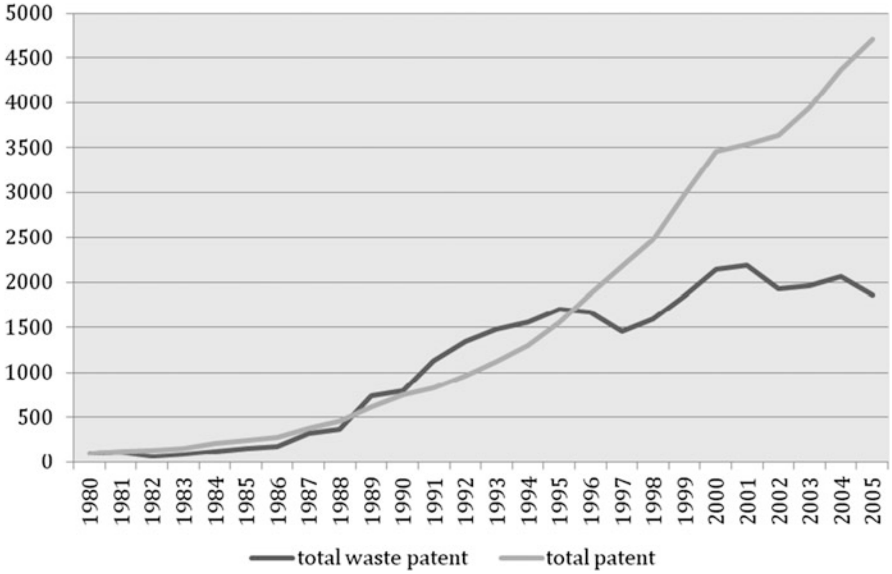

Fig. 10.3 Number of patent application filed under the PCT (total patent and waste, 3-year moving average)

different patents. An indicator created as the sum of patent counts per year per country certainly includes patents with a high commercial and/or technological impact and patents with a lower value. Second, patent regimes and patent attitudes across country may be different. This may be due in part to legislative differences between countries and in part to a different general propensity towards patenting (in some countries, firms might be more likely to patent new inventions than in others for several different reasons. For example, in the presence of a monopoly, firms might not need a patent system to protect innovation).

For this specific analysis, we used the total amount of patents in the waste sector, divided in five different technologies, as a dependent variable. The study was carried out using patents filed under the Patent Cooperation Treaty (PCT), according to the applicant's country of residence (and not the inventor's country of residence). As a robustness check, we also conducted the same analysis using only patent data filed at the EPO, and the results did not change. The work was conducted on a group of 28 OECD countries, many of them European, from 1980 to 2005. The countries were Australia, Austria, Belgium, Canada, Czech Republic, Denmark, Finland, France, Germany, Greece, Hungary, Ireland, Italy, Japan, Luxembourg, Mexico, the Netherlands, New Zealand, Norway, Poland, Portugal, Slovakia, Spain, Sweden, Switzerland, Turkey, the United Kingdom and the United States. All data are taken from the OECD online patent statistics, and their trend is summarised in the two pictures below.

Figure 10.3 underlines the different development paths that total patents and waste patents exhibited from 1980 to 2005. If, on the one hand, the total patent

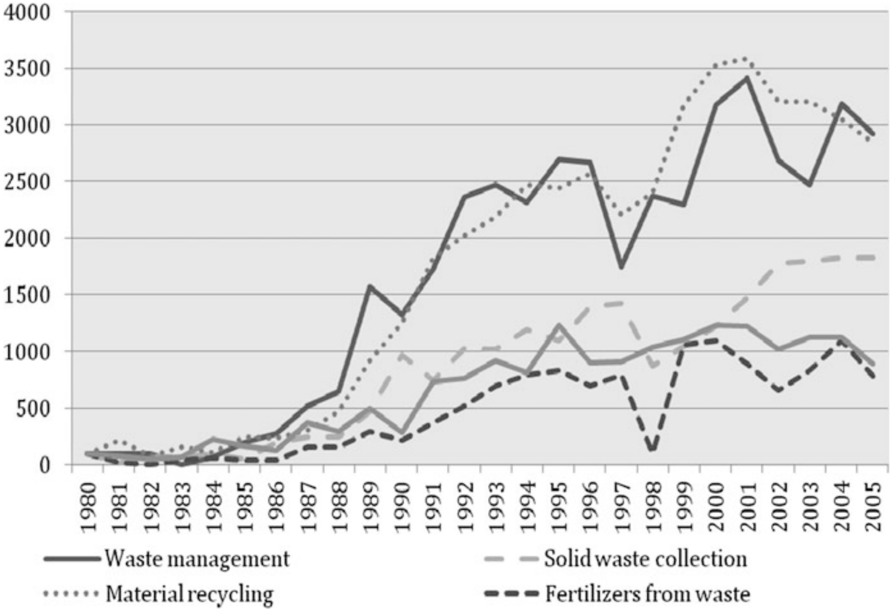

Fig. 10.4 Number of patent application filed under the PCT (specific waste technologies, 3-year moving average)

count constantly increases through time, on the other hand, waste-related patents increased at the same pace until 1995 and then slowed down considerably. A waste technology seems more stable and less dynamic than the general trend of innovation, as already found by Nicolli and Mazzanti (2011). If we decompose the total waste patents in the five different groups (following the division made by the OECD online statistics), we can gain more insight into this trend (Fig. 10.4). Although the total amount of patents in waste-related technologies is stable, differences can be found among the different groups, with material recycling and waste management being more dynamic than the other three categories.

Figure 10.5 compares total patent applications in a selection of OECD countries that have demonstrated significant levels of waste-related innovation. The United States, Japan and Germany in particular are the three countries that present the highest number of patents, both generally and in relation to waste. Nevertheless, their trends are different. Germany and the United States show a trend for waste patents that, although different in intensity, is similar to the general one (increase until mid-1990s and than stabilisation) whereas Japan shows a completely different path of development, increasing slowly until 1999 and then registering a jump in the total number of patents filed in the field of waste.

Finally, in Fig. 10.6, we simply normalise total waste patent counts by the national GDP to obtain a measure of patent intensity that is not biased by differences in income. This procedure does not alter the ranking presented much, except for the interesting case of Italy which achieves a high level of innovation per unit of input, but is only tenth in the previous ranking based on patent counts.

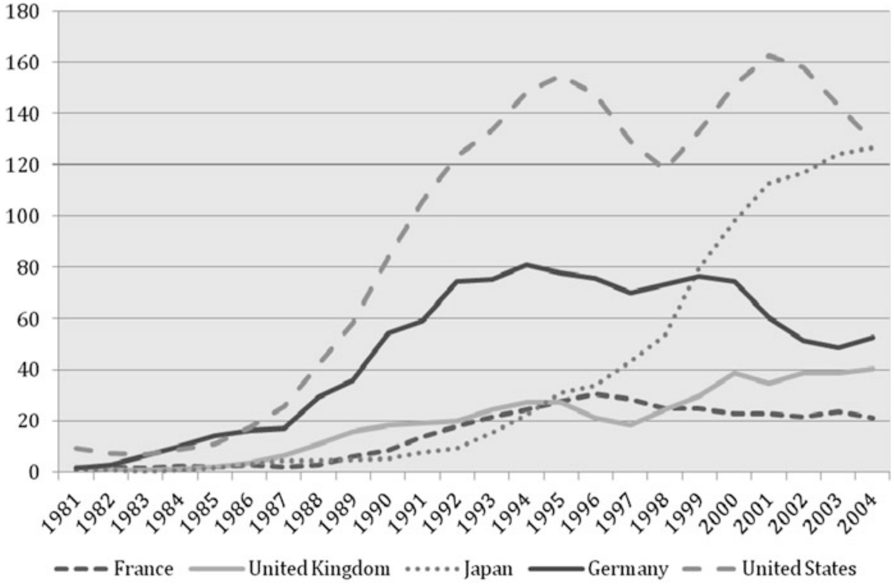

Fig. 10.5 Number of patent application filed under the PCT (total waste patents for selected countries, 3-year moving average)

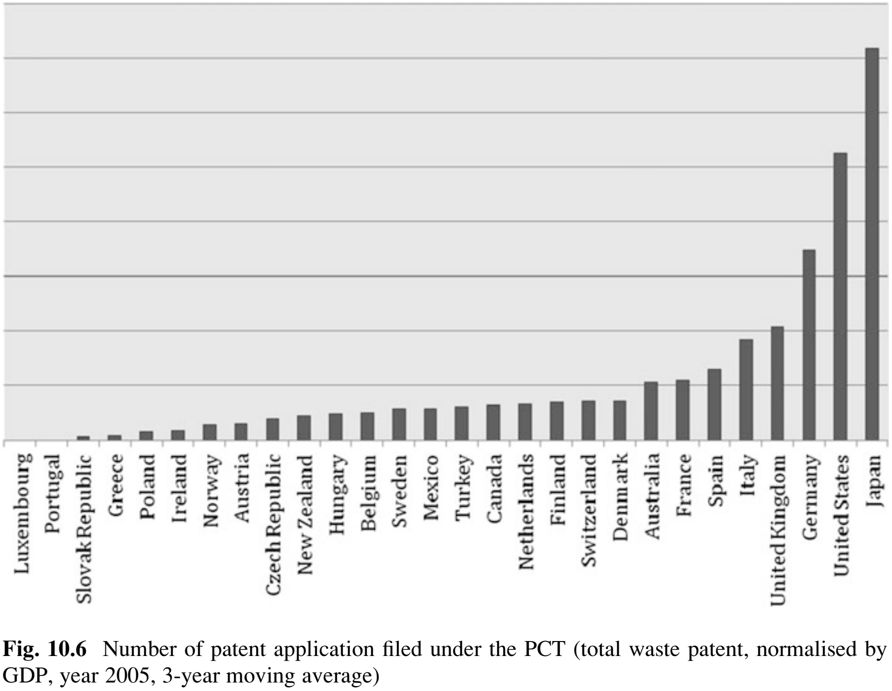

Fig. 10.6 Number of patent application filed under the PCT (total waste patent, normalised by GDP, year 2005, 3-year moving average)

10.3.2 Relevant Policies

In order to assess the role of policy stringency on innovation, a policy indicator is constructed in this chapter based on country fact sheets on waste management available at EIONET,[5] plus some additional information made available on the Ministry of Environment websites (especially for non-EU countries). Starting from this information, we constructed a series of binary variables for the different policy types in the different fields of waste. The variables take on a value of 0 prior to introduction of the policy and 1 thereafter. The variable constructed reflects the following policies:

1. Special waste: the first variable refers to the introduction, at country level, of prominent legislation in the field of special waste such as electrical waste, photographic material and pharmaceutical waste. An example of such legislation is the introduction of the EU Directive 91/157, which aimed, on the one hand, to reduce the heavy metal content of batteries and accumulators and on the other, to increase the separate disposal of spent batteries. Another example is the Directive 2002/95/EC, which supported the creation of collection schemes where consumers could return their used electronic waste free of charge. The aim of these schemes was to increase recycling and/or reuse. Moreover, this directive intended to promote the use of safe components in electrical products in order to reduce the negative externalities associated with the disposal of electrical material (it refers in particular to substituting lead, mercury, cadmium and hexavalent chromium and flame retardants such as polybrominated biphenyls or polybrominated diphenyl ethers).
2. Packaging waste: a second variable refers to packaging specific regulation. By packaging, we refer here to materials used to contain, protect, handle, deliver and display goods, that is, empty glass bottles, used plastic containers, food wrappers, cans, etc. Common examples of packaging regulation are plastic and paper policies, generally aimed at improving the share of reuse or recycling of these specific materials. At European level, the first directive regarding packaging waste was Directive 85/339 concerning containers of liquids for human consumption. This directive covered all liquid beverage containers, and its objective was to encourage the reuse and the recycling of these containers. Ten years later, in 1994, a second and more stringent directive was enacted (94/62) that imposed new targets for recovery and recycling (ranging between 55 and 60% depending on the country) and specified new targets for the concentration of heavy metals in packaging. At country level, for example, in 1990, Germany issued a decree that imposed very stringent regulation, based on the polluter pays principle. This law placed responsibility with the producer in the form of deposit and take back systems, unless the industry established

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[5] EIONET is a partnership agency of the EEA and its member countries; it is fundamental to the collection and organisation of data for the EEA.

alternative collection and recycling schemes that met precise collection and sorting goals. Outside Europe, in 1990, a Japanese law set recycling targets to between 40 and 60% for different types of packaging waste.

3. End-of-life vehicles: this refers to all the policies related to cars and light trucks at the end of their life cycle that need to be disposed of. In this specific case, policies generally focus on two different aspects: first, the parts of old cars that can be recycled and reused and second, the hazardous components of ELV waste that have to be disposed off in specific landfill sites. Consequently, policy in this field generally tends to set precise targets regarding the type of materials manufacturers may or may not use in car production (for instance, lead and mercury) and to promote the recycling of old scrap vehicles. Moreover, ELV regulations are generally based on the producer pays principle, shifting the responsibility from the consumer to the producer. Examples can be found in the EU Directive 2000/53/EC, which is based on the concept that carmakers are responsible for the cost of taking back used cars and lorries, including those already on the market. Moreover, the directive sets recycling and reuse targets that became more stringent through time (the first target for 2006 was for 85% recovery and 90% recycling). Outside Europe, Japan had three different waves of regulation in the ELV field, a first one in 1990, a second one in 1996 and a third one in 2002 that specified new technical requirements for both dangerous materials and recycling.
4. Landfill: with regard to landfill, that is traditionally the most famous disposal choice in OECD countries, environmental regulation generally has two different aims. On the one hand, it tends to regulate the type of waste that goes to landfill, expressing specific bans for material that may not be landfilled or that have to be landfilled in specific sites, while on the other, considering the negative externalities generally associated with landfill sites (Pearce 2004), environmental regulations often impose a tax on the amount of waste that goes to landfill in order to discourage this practice. An often quoted example of regulation in this field is the EU landfill directive (99/31/EC) which wanted to prevent and reduce the adverse effect of landfill sites by introducing stringent technical requirements, including a list of waste that may not be accepted in landfill sites (liquid waste, flammable waste, explosives, used tyres, etc.). Another type of legislation frequently adopted by OECD countries and included in this work is the presence of a specific tax on the total amount of waste that goes to landfill, also known as landfill tax. For example, in the UK, landfill tax is in force since 1996, and rates in 2005 were £2 per tonne for inert waste and £16 per tonne for active waste.[6]
5. Composting refers to biodegradable waste, such as wood and garden waste. Traditionally, this waste stream is considered municipal solid waste, but some specific regulations have been enacted in order to regulate this sector. For example, the above-mentioned landfill directive sets very specific targets for

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[6] Source EIONET, UK Fact Sheet

bio-wastes and obliges member states to reduce the amount of biodegradable waste that is landfilled to 35% of 1995 levels by 2016.

6. Incineration: for example, the European Directive 2000/76/EC replaced the previous directives on the incineration of hazardous waste (Directive 94/67/EC) and household waste (Directives 89/369/EEC and 89/429/EEC) and proposed a common framework for the incineration of waste in the European Union. In particular, it sets emission limit values and monitoring requirements for pollutants to air such as dust, nitrogen oxides (NOx), sulphur dioxide (SO_2), hydrogen chloride (HC_l), hydrogen fluoride (HF), heavy metals and dioxins and furans.

Starting from this data, we constructed a policy index as the average level of the single policy variables (the binary variables) in a given year in a given country. The resulted value was then normalised in order to range between 0 and 1. Thus, in any given year, each country was associated with an index, where 1 was the maximum potential value (assuming that all the policies considered were present) and 0 the minimum. Furthermore, in the construction of the single dummies, we differentiated between the presence of a simple strategy (low value) and an effective regulatory policy (high value). The latter was assigned a bigger weight in order to roughly account for the stringency of different instruments (0 for no policy, 1 for strategy only, 2 for a policy, as if two binary variables with value equal to 1 were present for the same country in a given year). The result was a single indicator of policy stringency at country level that varied across year and across country. Such an indicator can be a good proxy of the overall adoption of policy at country level and thus a good candidate for a main policy variable in the empirical analysis. Prominent examples of overall environmental policy performance indices, for several countries, based on a synthesis of diverse policy performances can be found in Eliste and Fredriksson (1998). Cagatay and Mihci (2006, 2003) provide an index of environmental sensitivity performance for 1990–1995, for acidification, climate change, water and also waste management. The following graph shows the level of the policy indicator across the analysed country in three different points in time, 1980, 1993 and 2005, at the beginning, middle and end of our time period. As can easily be seen (Fig. 10.7), the indicator increased significantly in the analysed time span, especially in the later period. Many countries, like Greece, Spain and Hungary, present a value equal to 0 for the first two time periods and higher values later. This graph also shows how there is considerable heterogeneity across countries in the number of waste policies adopted, with leader countries such as Germany, Japan and the United States.

10.3.3 Other Explanatory Variables

In addition to the above variables, other variables are included as a control. First, we included the total number of patents filed under the PCT as a control for the different propensity to patents across countries and sectors. For the reason

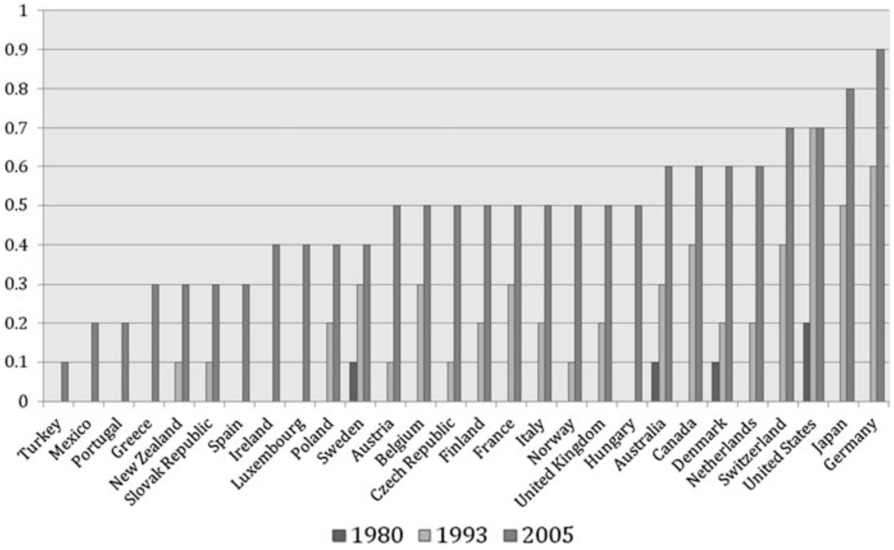

Fig. 10.7 Policy index (year 1980, 1993 and 2005)

explained in the previous section, countries may have a different attitude towards patenting due to legislative and economic reasons, and this may generate a bias in our dependent variable. Controlling for the total amount of patents can consequently control for this element. We expect this variable to exert a positive and significant effect on innovation. Moreover, we also included a demand related variable, such as average country GDP per capita, in the estimation. Innovation could in fact be driven by increasing pressure on disposal imposed by the increasing amount of waste generated (that may differ across countries), that is, driven by an increasing demand for disposal. Considering the lack of OECD panel data on waste generation, we used GDP as a proxy. This is perfectly in line with waste Kuznets curve literature that shows how waste generation is strictly positively correlated with waste generation (Mazzanti and Zoboli 2008). Moreover, GDP obviously also controls for different income level across countries, another factor that may influence innovation. Some descriptive statistics for the above-mentioned variables are summarised in the table below.

10.4 Empirical Results

Results of the empirical analysis conducted in this chapter are summarised in Tables 10.1 and 10.2. In Table 10.1, we pooled all the five different technologies, creating a single data set in which the individuals are patent counts in the different

Table 10.1 Descriptive statistics

Acronym	Variable description	Mean	Min	Max
Patent pct	Total waste-related patent filed under the PCT	2.229	0	91.5
Waste management	Total patent classified in the category "waste management—not elsewhere classified", filed under the PCT	2.388	0	51.5
Solid waste collection	Total patent classified in the category "solid waste collection", filed under the PCT	1.22	0	28
Material recycling	Total patent classified in the category "material recycling", filed under the PCT	4.9346	0	91.5
Fertilisers from waste	Total patent classified in the category "fertilisers from waste", filed under the PCT	0.916	0	13
Incineration and energy recovery	Total patent classified in the category "incineration and energy recovery", filed under the PCT	1.677	0	28.5
Tot pct	Total patent counts, filed under the PCT	1604.69	0	49709.42
Pol ind	Policy index, normalised from 0 to 1	0.224	0	0.9
Gdp	GDP per capita	23939.48	0	71160.5
Time trend	Time trend, goes from 1 to 26 for every country	13.5	1	26

technologies by year per country. The result is a panel from 1980 to 2005 for 140 individuals (28 countries times five technologies). One interesting feature of this approach is that once a fixed-effect model is applied, it controls for country-specific and technologic-specific fixed effect.

In Table 10.2, five different analyses are conducted on the five different available technologies taken singularly. As a general result, the policy variable is statistically significant and associated with a positive coefficient, confirming our hypothesis that increases in policy effort have spurred innovation at country level. Among the covariates, GDP generally performs as expected (even if it is associated with a very low coefficient), whereas the total patent count is not statistically significant. This result is not completely unexpected. If we look at the descriptive graphs presented in the previous section, we can see how the trend of the two patent-related variables is significantly different, with the total count increasing through time and the waste patents showing a more stable path. This different trend can motivate this result, going against other patent-related studies (Johnstone et al. 2010a). With regard to pooled panel analysis, the second and third specifications present regression results once accounting for time dummies (column II) and secondly including an area-based trend (time trend specific for different geographic area, column III). Results seem to be robust at this further check; the policy index is still significant once the time dynamics and the differences across areas are taken into account. Interestingly, the coefficient associated with the policy variable decreases significantly in both cases, meaning that the temporal dimension plays

Table 10.2 Pooled panel estimations

Specification	I	II	III	IV	V	VI
Pol ind	2.6105***	0.5411***	1.2551***	2.5102***	5.6437***	7.211***
Gdp	0.00003***	0.00003***	0.00004***	0.00003***	−0.00008***	−0.00001**
Tot pct	3.20e-06	2.24e-06	−0.00001***	4.08e-06	0.00003***	0.00002***
Policy* waste management				−0.2211		
Policy* solid waste collection				−0.0642		
Policy* material recycling				0.4729**		
Policy* fertilisers from waste				0.0574		
Policy* time trend					−0.3173***	
Time trend					0.2309***	
Policy squared						−5.23***
Country and tech FE	Yes	Yes	Yes	Yes	Yes	
Year FE	No	Yes	No	No	No	
Area trend	No	No	Yes	No	No	
N	3,430	3,430	3,430	3,430	3,430	

Dependent variable: pooled panel of patent counts in the five available technologies

Negative binomial estimations. *,**,*** indicate significance at, respectively, 10, 5 and 1% level

Table 10.3 Specific technology estimations

Specification	Waste management	Solid waste collection	Material recycling	Fertilisers from waste	Incineration
Pol ind	2.771***	1.376***	2.9775***	2.7566***	2.656***
Gdp	0.00002	0.00009***	0.00002**	0.00002	0.00002
Tot pct	1.54e-06	3.68e-06	8.69e-06*	0.00001	−3.34e-06
Country FE	Yes	Yes	Yes	Yes	Yes
Year FE	No	Yes	No	No	No
N	721	676	721	669	643

Dependent variable: patent counts in the five available technologies
Negative binomial estimations. *,**,*** indicate significance at, respectively 10, 5 and 1% level

a significant role in explaining patent activity. Column IV also presents a set of interaction effects between the policy variable and the five technological sectors analysed, where incineration is the benchmark. Interestingly, "material recycling" is the only sector associated with a significant interaction term: the effect of policy in this specific field seems stronger than in the other cases. This result is expected if we consider that a huge emphasis at both EU and OECD levels has been placed on landfill diversion and recycling (see Mazzanti and Zoboli 2008), with recycling being the most preferred disposal technology. Moreover, as shown in the graphs above, "material recycling" is the technological class with the highest number of patents. Finally, the fifth specification includes both a time trend and an interaction term between the policy variable and the trend itself. Here too, regression results confirm the important role played by time heterogeneity, especially if it is interacted with the policy index. The negative effect of the interaction means in fact that the effect of the policies depends on time and decreases as it passes, confirming the results of Nicolli and Mazzanti (2011). Moreover, in the last column, the squared value of the policy variable is included as a robustness check. As expected, its coefficient is statistically significant and negative, confirming that the effect of the policy lever decreases with time.

Finally, in Table 10.3, the dependent variables for the five proposed specifications are patent counts in the different specific fields. Interestingly, we can see how the policy index is significant in all the analysed cases, showing how this result is constant among technologies. Here too, the total patent count is not statistically significant, except for a weak significance in material recycling. Again, this result is counter-intuitive but expected, considering that the trend of waste patents is completely different and independent of the total patent count.

10.5 Conclusions

This chapter examines the effect of environmental regulation on technological innovation, on a sample of 28 OECD countries over the period 1980–2005. For the analysis, a complex policy index was developed in order to account for both cross-country and time variability. This index was constructed starting from available country fact sheets on waste management strategies at country level, plus some information from Ministry of the Environment websites, and included evidence about all the major waste-related regulations adopted both at national and European (directive) level. With regard to the dependent variable, that is, technological change, we used the total patent count filed under the PCT in waste-specific fields as a proxy.

Nevertheless, patenting in waste management-related technologies is not increasing constantly through time as expected, and after a rapid expansion at the end of the 1980s and beginning of the 1990s, it has slowed down in the last 15 years, showing a flatter path of development than total patenting. On the other hand, environmental regulation has become always more stringent and complex since the promulgation of the first waste-related regulation more than 20 years ago. As a result, many OECD countries nowadays have a regulatory framework that includes regulation on landfills, recycling and hazardous and packaging waste, with the general aim of promoting more efficient waste disposal strategies (generally recycling) and setting increasingly more stringent technical targets regarding available waste disposal choices. This work is intended to merge these two elements together in order to test if these policies have been able to redirect the demand of waste disposal technologies towards more innovative and environmentally friendly technologies. The evidence presented here, in line with results obtained in previous analyses (Nicolli and Mazzanti 2011), suggests that policies have been able to promote innovation, but their effect has not been constant through time. A first wave of policies, at the beginning of the 1990s, has spurred an important amount of patents in waste-related fields, driving technological innovation, but this effect is now weaker, confirming the previous idea of sectorial technological maturity. Nevertheless, this work seems to suggest that this slow patenting growth (or even decline in some cases) might have been more pronounced if no policy measures had been introduced. This last conjecture is indeed supported by the result obtained for the specific "material recovery" sector in which the induced innovation effect of policies is stronger. This is an expected and reassuring result, considering that the final aim of the majority waste regulation at OECD level is to improve the share of recycling, in the more complex disposal mix that characterises a country waste management service.

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