# 9 Policy Choice and Evaluation

In Chapters 7 and 8, we discussed several market-oriented and non-market-oriented energy and climate policy instruments. Each policy instrument has specific characteristics, and can thus be used to solve a market failure or behavioural anomaly. For example, in the presence of positive externalities from the use of a new energy-efficient technology, a policymaker might want to introduce a subsidy to promote the adoption of this new technology. Furthermore, in the presence of bounded rationality, the policymaker may also want to introduce nudges or standards. Finally, if market failures and behavioural anomalies both coexist in an economy (as is typical in many cases), a combination of instruments may be needed to address the multitude of problems.

In this chapter, we propose and examine some vital criteria for selecting and implementing either a single policy instrument or a mix of policy instruments.

## 9.1 Policy Evaluation Criteria

Optimal policy instrument choice and the right balance of policies are not trivial goals for policymakers. Economists have developed some criteria to help policymakers identify the policies to adopt.

From an economic point of view, as mentioned in Chapters 7 and 8, the most important rule for selecting 'desirable' policy instruments is to compare their benefits and costs, that is, to analyse whether a policy instrument increases the level of economic efficiency (productive, allocative, and dynamic) and, more generally, the welfare of society. However, it is also essential to judge policy instruments on other dimensions, such as distributional issues (impact on different socioeconomic income groups and regions), macroeconomic issues (impact on economic growth, inflation, and employment), and the level of acceptance and administrative feasibility of the instruments as well.

The following criteria can be considered when deciding the policy mix:

- **Productive and allocative efficiency**: an economic system achieves productive and allocative efficiency when, given scarce resources, it can produce goods and services by minimising the resources and optimally allocating them given consumer preferences. In such a situation, the welfare of society is maximised. A policy instrument is efficient from an economic point of view if it improves productive and/or allocative efficiency.

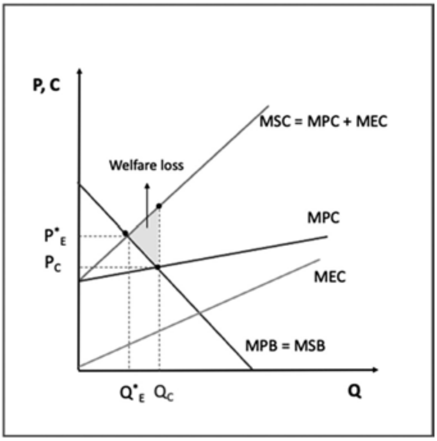


**Figure 9.1** Welfare loss without considering externalities of electricity produced by coal plant

To apply this criterion, we first need to estimate the impact of a proposed policy on these two efficiency measures. For instance, in an electricity market dominated by power plants that use fossil fuels such as coal, introducing a $CO_2$ tax will eliminate the welfare loss, as illustrated in Figure 9.1 (and already explained in Chapter 2). In this case, the $CO_2$ tax will lead to an improvement in the level of allocative efficiency, as before the introduction of the tax, the price was not set equal to the marginal social cost. Of course, this welfare gain should be compared to the implementation and enforcement costs of a $CO_2$ tax (discussed later in further detail).

- **Dynamic efficiency**: dynamic efficiency is related to the production processes of energy services and goods by firms and households. In the energy and climate policy context, a firm or household is dynamically efficient if, over time, it can introduce new production methods that contribute towards achieving sustainable development. Therefore, a policy measure is efficient from a dynamic point of view if it provides incentives to invest in research and development that can generate the optimal rate of technological change to reduce average costs, exploit renewable energy sources, improve energy efficiency, and thus ensure sustainable development. For example, R&D subsidies for firms operating in the heating sector may allow them to develop new, more efficient, heating systems based on renewable energy sources that also reduce the production cost of heating services, as depicted in Figure 9.2 (rotation of the heating cost function 1 ($HC_1$) to heating cost function 2 ($HC_2$)). Another example is the introduction of pollution or energy taxes, or performance-based pollution standards, that generally provide incentives for advancements in pollution abatement technologies.
- **Effectiveness**: the efficiency criterion assumes that energy and climate policy instruments are effective, that is, that they have a substantial impact on the variable that they are intended to change, such as energy consumption, electric car adoption, or innovation. Empirical evidence, however, suggests that energy and climate policy measures need not always be effective. Therefore, before analysing

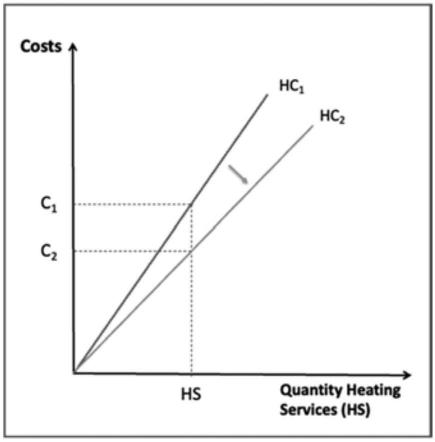


**Figure 9.2** Dynamic efficiency and heating costs

the impact of a policy measure on the level of welfare, it is essential to conduct empirical analyses to verify whether there is any effect of the measure on the outcome variable of interest. For example, a subsidy for the adoption of electric cars may not work, because not all consumers may know about the presence of the subsidy. Additionally, some consumers may be boundedly rational, and therefore may fail to consider the car subsidy in the calculation of the life cycle cost, and in doing so, they may end up purchasing less expensive, but also less efficient vehicles. For this reason, the evaluation process is an essential first step to verify the effectiveness or impact of a policy measure using empirical methods, some of which will be discussed in more detail later in this chapter.

- **Macroeconomic effects**: the introduction of energy or climate policy instruments such as taxes or standards can lead to economic effects on the markets directly affected by these instruments, as well as result in economic effects at the economy-wide level such as changes in employment, or in gross domestic product (GDP) growth. Therefore, in choosing a policy measure, it is important to also consider these effects.
- **Fairness**: introducing a policy instrument may engender costs and benefits that vary across geographic regions or segments of the population. It is, therefore, essential to analyse the heterogeneity in the effects of a policy instrument among all economic agents and to judge if these distributional effects align with the general level of fairness and equity that is acceptable to society. Of course, in the application of this criterion, one should also consider the intergenerational equity dimension (namely, the distributional impacts of a policy measure across generations).
- **Acceptance**: generally, it is important that proposed energy and climate policy measures are accepted and supported by citizens. In a direct-democracy system, consideration of an instrument that does not have the support of citizens may lead to a referendum, and thus to a possible rejection, which implies a lengthening of the time frame for policy implementation. In an indirect democratic system, an

unpopular instrument may lead to citizens taking to the streets to protest publicly in authorised or unauthorised forms, or to go on strike. In this context, public communication campaigns play an important role in providing information on the introduction of the measure, as well as on its possible distributional effects. For example, suppose that the distributional effects of introducing a $CO_2$ tax are not adequately communicated, both while levying the tax and while distributing the tax revenue. In such a scenario, the proposal to introduce a $CO_2$ tax is likely to create significant opposition. For instance, in the case of the introduction of a $CO_2$ tax where the revenues of the tax are redistributed to the households and firms, it is essential to explain and communicate the re-distributional effects of the system. Due to the importance of this criterion from a practical point of view, we will discuss the relationship between distributional effects and social acceptance in further detail in Section 9.2.

- **Enforceability and administrative practicality**: the identified policy measure should be transparent and easy to implement and administer. Moreover, it should also be feasible to monitor its performance (and check for compliance), while minimising possible evasion and avoidance behaviour.

## 9.2 Distributional Issues and Acceptance of Policy Instruments

The introduction of energy and climate policies can produce different effects among consumers and firms on the level of negative externalities experienced, on income and wealth, and on the level of access to energy sources.

We know from the literature that air pollution and greenhouse gas emissions generally affect individuals differently, both within a country and across countries. This implies an unequal distribution of the burden across individuals, regions, and countries. For instance, a household living in an urban area close to a road with heavy traffic is generally more affected by local air pollution, compared to a household living in a more suburban area. Given that low-income urban households generally tend to live in areas where land or real estate may be cheaper, but that are likely to be more polluted, air pollution will disproportionately tend to affect these households compared to richer households, who tend to live in less polluted areas. Furthermore, at the international level, we have seen in Chapter 1 that some low-income countries are more affected by climate change than high-income countries. Therefore, we can say that air pollution and climate change are natural sources of inequity. These inequities are more stark at the global level, whereas they are weaker within the urban areas of a city or region.

This implies that the implementation of energy and climate policy instruments can affect individuals both within a country and across countries in different ways. For instance, the implementation of a pollution tax can reduce the level of pollution and, therefore, decrease some inequality in the distribution of pollution. On the other hand, a pollution tax increases prices that may have an impact on income and wealth distributions. For instance, introducing a carbon tax on gasoline without redistributing the revenues will disproportionately affect households that spend a more significant fraction of their income on gasoline, who tend to be, in general, low-income households or households living in rural areas where public transport infrastructure may be lacking. Of course, if the revenue from implementing such a tax is redistributed to the households and firms in a revenue-neutral manner, such as within the framework of ecological tax reforms, then these distributional implications may even be absent. Also, keep in mind that the introduction of the gasoline tax will also likely promote the adoption of more energy-efficient cars that can lead to further reductions in air pollution in heavily polluted areas where low-income households tend to reside.

Subsidies are another interesting example of an energy and climate policy instrument with income and wealth distributional effects. For instance, subsidies for the installation of solar panels have important distributional effects. Indeed, this type of subsidy will mostly be used by owners of single-family houses belonging generally to the middle- and high-income classes. In this case, the subsidy will tend to be regressive. Of course, in an analysis of the distributional effects of this subsidy, we should also consider the financing of this measure, that is, how the government collects funds for the subsidy. For instance, in case the government decides to use general tax revenues, then the distributional effects of the subsidy will depend on the progressiveness of the tax system. On the other hand, if the government decides to use a tax on electricity consumption to finance the implementation of the subsidy, then non-owners of houses will subsidise owners of houses, and this has clearly some distributional effects.

In general, some market-based instruments such as pollution and energy taxes do not enjoy high levels of social acceptance (in comparison to subsidies, for example). This is mostly due to their effect on the individual as well as regional income distributions, and the increase in the prices of several base products. Moreover, the effects of these types of instruments are salient to economic agents. Therefore, in the design and implementation of these types of taxes, such distributional effects should be considered to both avoid opposition and achieve equitable outcomes in terms of reduction of pollution, as well as in terms of costs.

Non-market-based instruments, on the other hand, can also have distributional implications. For instance, an energy consumption standard in the building sector, defined in terms of energy consumption per square metre, may increase the building cost of a house, due to the increase in the level of insulation. This cost increase, which need not be salient to economic agents, is more likely to affect low-income households, given that high-income households may be more price-inelastic in their preferences for the sizes of their homes.

Direct control measures have been known to exacerbate prevailing inequalities: for example, license plate-based driving restrictions result in a stronger negative welfare effect for lower-income households who may not be able to afford to own more than one car. Another example of a policy that may have had important distributional effects is a ban on using incandescent light bulbs. Poor households are likely to have been affected by this policy much more adversely, especially given that the replacement technologies (such as light-emitting diode (LED)-based bulbs) were more expensive, at least initially. In such situations, combinations of policies (such as providing a subsidy, while imposing the ban) may have important welfare effects, even if they may not necessarily be efficient policies by themselves.

Energy and climate policy measures, both market and non-market-based, are also likely to have vital distributional implications on energy access, particularly in developing countries. A good example to illustrate this is the liquefied petroleum gas (LPG) subsidy that was provided for all households in India. LPG is used as a clean cooking fuel by many households, and the Indian government was heavily subsidising its use to particularly encourage low-income and rural households to switch to it from using firewood. However, setting a uniform subsidy meant that relatively richer households, who could afford to pay more for LPG, received the same subsidy as poorer households and, thus, benefitted relatively more from receiving these subsidies. Many rural households, for whom acquiring firewood was relatively easy, still did not end up using LPG on a regular basis.

On the other hand, economic studies have also shown that carbon pricing can be progressive in poorer countries, particularly due to different patterns of energy expenditure. For instance, in countries where biomass is used extensively by poorer households, poor households will remain relatively unaffected by policies that tax carbon. The implementation of direct control measures such as bans on incandescent light bulbs can also have a positive effect in improving the adoption of energy-efficient technologies such as light bulbs among poorer households in developing countries, as long as they are enforced. However, it remains important to conduct a welfare analysis to understand the full impact of such policy measures on households and firms.

**Regional impact of $CO_2$ tax on gasoline**

In a study based on data from Switzerland, Filippini and Heimsch (2016) [52] evaluated the effects of a hypothetical $CO_2$ tax on gasoline, by estimating a demand function using spatial econometric approaches. The authors found that the short-run elasticity of gasoline demand at the aggregate level was about −0.27, whereas the average long-run elasticity was about −0.82. Regarding the distributional implications, the authors found that the tax burden of a hypothetical $CO_2$ tax was likely to be higher in rural areas, compared to urban areas. This finding can explain opposition to such taxes, such as the notable protest movement against the introduction of a similar tax in France (called 'Gilets Jaunes'), which was also rooted in this rural-urban divide.

## 9.3 Policy Evaluation Methods

In Section 9.1 of this chapter, we illustrated the most important criteria to consider in choosing an energy or climate policy measure. For applying the first two criteria, that is, productive/allocative efficiency and dynamic efficiency, it is essential to perform a policy evaluation from an economic point of view. Policy evaluation is an analytical and scientific tool that uses the methods and models of the economic sciences to evaluate the economic effects, that is, the costs and benefits produced by the introduction of a public policy.

Generally, the economic effects of an energy or climate policy instrument are estimated *ex-ante*, that is, before the policy measure is introduced, using different economic and econometric models that we will shortly introduce in Section 9.3.1. In doing this economic analysis, generally researchers implicitly assume that the policy measure has a significant and notable effect on economic variables. For instance, researchers may assume, in evaluating *ex-ante* the economic effects of a subsidy for the adoption of electric cars, that it is likely to be effective, that is, that the adoption rate of electric cars will significantly increase once the subsidy is implemented. However, this assumption may, on occasion, be too optimistic. For this reason, as already mentioned, it is important to perform empirical analysis to understand the level of effectiveness of a policy measure. If it turns out that the policy is less effective than was initially assumed, the *ex-ante* analysis would not have been accurate. In these cases, the policy measure must be reevaluated, that is, the causes of ineffectiveness must be identified and corrected. Therefore, in Section 9.3.2, we present some important empirical methods of policy evaluation.

In conclusion, designing and implementing energy and climate policy measures should be considered an interactive, dynamic process, where the results of studies on the impact of a policy instrument can be used to confirm or reevaluate the effects of a policy measure and to 'update' its economic effects.

### 9.3.1 Modelling the Economic Effects

In this subsection, we summarise the most important economic models that can be used to evaluate the effect of energy and climate policies. The goal of this summary is to sketch a general preliminary idea of some of the most commonly used models in energy economics and policy. Overall, these models provide a framework for economists and policymakers to take more informed decisions about energy and climate policy. Note that these models can be specified and used to evaluate a policy measure's impact on a society's overall welfare, on the welfare gains/losses in a single market, and/or on other economic outcome variables such as employment or GDP.

When studying economic behaviour, economists often start by building an economic model. This type of model provides a simplified representation of the functioning of markets, economic systems, or the behaviour of economic agents. Therefore, they may not be able to accommodate all the details and context of reality. However, good models can capture and explain economic phenomena in a realistic manner. Once a model is built, economists have a tool that can be used to analyse the effect of policies.

The models that we present are interesting and informative, however, they have some limitations due to the need to represent markets, economic and energy systems in a simplified way. Therefore, in the interpretation of the results provided by these models, it is always important to keep in mind the assumptions and limitations of the models that partially arise because of the need to simplify the representation of the real world. We believe that these models are very useful for economic policy discussions; however, it is important to not use these results at face value.

- **Applied general equilibrium models**: these models represent economic systems by modelling the functioning and interaction of different markets, such as the energy and labour markets. Moreover, this type of model represents the endogenous origin and spending of income. Therefore, general equilibrium models do consider the effects of income flows on the market as well as the effects of price changes on that market. In these models, each market is characterised by consumers and firms whose behaviour is captured through mathematical functions of supply and demand, derived from economic theory. Some of the parameters of these mathematical functions, in particular the price and income elasticities and the elasticity of substitution of production inputs, are generally defined based on the results of empirical studies published in the literature. In contrast, other parameters are calibrated to reproduce the economic equilibrium in the market that was observed in one specific year.

  Researchers have also developed applied general equilibrium models that include a detailed description of the energy system to analyse the economic effects of energy and climate policy measures. This type of model, also called a hybrid model or 'top-down' model, integrates an energy system model, which provides a technology-rich representation of the energy system based on energy technologies and their associated costs. Important hybrid models have been obtained, for instance, by linking the energy system model TIMES with the applied general equilibrium models EMEC and GEM-E3. Hybrid models make it possible to analyse the *ex-ante* economic impact of energy or climate policy measures on both energy markets and other markets. For instance, implementing a carbon tax won't only raise energy costs, but it may also have an impact on the supply and demand of other goods.
- **Partial equilibrium models**: these models generally encapsulate the functioning of a single market. In the basic version of this type of model, the market is represented by consumers and firms whose behaviour is modelled using the mathematical functions of aggregate supply and demand functions. Some of the parameters of these mathematical functions are defined based on the results of empirical studies published in the literature (e.g., elasticities of substitutions and price elasticities). In contrast, as for the applied general equilibrium models, other parameters are calibrated to reproduce the economic equilibrium in the market that was observed before the introduction of the energy or climate policy. Unlike applied general equilibrium models, these models: (1) do not consider the effects of an energy or climate policy measure on other markets; (2) consider the effects of a policy on the price changes on a market but not on the income flows on the market.

  This enables detailed consumer and producer behaviour modelling within this single sector and the technological options available for producing and transforming energy sources. Using partial equilibrium models, it is possible to analyse, ex-ante, the impact of suggested energy and climate policies on economic indicators, such as prices, quantities and consumer surplus, and producer surplus.

- **Energy system models**: energy system models, often also referred to as bottom-up models, offer a detailed representation of the energy system with a special focus on technologies. For instance, these models consider individual energy technologies, such as wind turbines, solar panels, and natural gas power plants, and then aggregate the use of these technologies into a larger energy system to identify the best combination of the various technologies to satisfy a given energy demand. This type of model is based on (linear) optimisation methods and tries to find the optimal mix of energy technologies that satisfy the energy demand while minimising the discounted net present value of energy system costs (including investments in supply technologies, operational expenses, and fuel costs). These models adopt a centralised approach, that is, assume that a social planner decides to identify the cost-minimising technology mix to meet the demand. Therefore, these models do not represent markets and do not capture prices, and the reactivity of demand to price changes. Therefore, they are unable to model decentralised economic behaviour when agents respond to economic incentives or prices.

  These models can also be used to evaluate the ex-ante impact of different energy and climate policies on the cost-minimising technology mix; however, they are not able to provide information on the welfare effects on energy markets or, more generally, wide-scale economic effects. Of course, the advantage of using these models is that they allow us to analyse the costs and feasibility of different energy technology pathways.

  Energy system models, such as the well-known TIMES model, are informative tools that can be used to understand the effects on the system cost of various combinations of energy technologies and the effects on the system cost of energy and climate policy instruments.

- **Microeconometric structural models**: these models are designed to represent the behaviour of consumers or firms by estimating econometric models that are formulated based on the principles of formal theoretical economic models (generally of a neoclassical nature). The parameters of the models are estimated using econometric methods, after collecting the necessary data. For example, a firm's supply curve depends on the parameters of its cost functions. By observing and collecting data on costs and production levels, it is possible to estimate a cost function by adopting a functional form as the trans-logarithmic form and then deriving the parameters necessary to specify the supply function. Given this supply function, it is then possible to simulate the economic effects of the introduction of an energy policy, such as a subsidy for the adoption of energy-efficient production technology.

  Another example of a simple structural model is estimating a system of equations representing the demand for different energy sources in the residential sector, based on the almost ideal demand system model as that discussed by

Deaton and Muellbauer (1980) [121]. This empirical model is derived from an indirect utility function characterised by a specific functional form. Starting from this, it is possible to obtain a set of equations modelling expenditure shares, whose parameters are estimated using econometric methods, after having collected the necessary data. Given the estimated parameters, price and income elasticities are derived, and the welfare impact of a $CO_2$ tax on the households can be simulated ex-ante. A commonly used approach for modelling demand is the model proposed by Berry, Levinsohn, and Pakes (1995) [122], which is based on using a discrete choice modelling approach. Structural microeconometric approaches can also be used to model the interaction of demand and supply, either in a competitive or a non-competitive market.

- **Economic growth models**: these models analyse the factors that influence long-term production and consumption increases such as technological progress, investment, human capital, and institutional factors, and can be used to assess the impact of energy and climate policies on economic growth. These models represent economic systems with the help of mathematical functions and identities, after making assumptions in a very simple and aggregated way.

  At the heart of these models exists a single aggregate production function for the economic system, with capital and labour as production factors and a parameter representing the level of technological progress. With this production function and some assumptions on the savings rate (which can be endogenous), the depreciation rate, the growth rate of technology and of the population, and the assumption that markets are always in equilibrium, these models allow the analysis of the role of capital accumulation, population growth, and technological improvement on economic growth.

  Over time, these approaches have incorporated additional modelling possibilities; for example, the technological progress that was considered to be exogenous in the early models is mostly modelled as being endogenous. Moreover, in addition to the classical factors of production such as capital and labour, some economists working with these models have begun to be concerned with environmental issues and constraints and, therefore, have introduced another factor into the production function, namely natural resources. These models are oriented towards analysing the factors of economic growth, by focusing on the production activities in an economic system. Finally, and most importantly, from an energy and climate policy point of view, the possibility of connecting economic growth models to climate models has emerged in the economic literature in the form of integrated assessment models (IAMs).
- **IAMs**: IAMs are used to analyse the effects of the functioning of an economic system on the environment and to evaluate the effects of policy measures on the economic and environmental systems. These models tend to be interdisciplinary in nature and based on different models developed across scientific fields such as climatology, ecology, economics, and sociology. The main goal of IAMs is to link together different models that represent, for instance, the climate, the economic

system, and the biosphere. Thus, these models provide a comprehensive representation of the interactions between these systems.

Related to energy and climate issues, IAMs combine a description of the economy along with a formulation of the climate system to help us understand the effects of climate change across economic sectors and agents and enable us to learn about the implications of energy and climate policies. Several IAMs are currently available, many of which combine a neoclassical growth framework with a climate model. However, some models may also use other economic models, such as a general equilibrium framework. An important example of an IAM is the DICE (Dynamic Integrated Model of Climate and Economy) model, which is based on neoclassical economic growth theory, and in which economic agents undertake investments in capital, education, and technology to increase consumption in the future. Other examples include RICE (the Regional Integrate Model of Climate and Economy, which assumes different regions of the world) and the MERGE (Model for Estimating the Regional and Global Effects of Greenhouse Gas Reductions) model, which includes a damage assessment module in addition to a general equilibrium economic module and a climate module.

- **Agent-based models (ABMs)**: When it comes to energy systems, computational models called ABMs can be quite useful. These models simulate the actions and interactions of economic agents in an energy system. Here, each agent is represented as an independent decision-maker who interacts with other agents according to a set of rules or heuristics. These rules can be simple or complex and are based on various factors that influence the agent's behaviour, such as economic incentives, social norms, and technological constraints. Unlike other approaches, ABMs are suited to modelling rational as well as boundedly rational agents and can also be used to model adaptive heterogeneous agents such as investors or consumers that change their behaviour depending, for instance, on the behaviour of other economic agents. Monte Carlo simulations can also be used to determine the probabilistic distribution of the outcomes in these models. ABMs can be used to simulate the behaviour of households and firms under different policy scenarios, such as the introduction of subsidies for renewable energy sources or energy-efficient technologies, or to assess the reliability and resilience of the energy system under different scenarios.

### 9.3.2 Modelling the Impact of Policies

Now, we will briefly review some of the methods that can be used to evaluate the impact of energy and climate policies on different economic outcome variables. As mentioned previously, one of the criteria to consider in the choice of a policy measure is its level of effectiveness, that is, if the policy measure has a significant impact on the economic variables of interest.

Identifying the impact of a policy measure on an economic variable is inherently difficult. One must isolate the policy's effect from all other factors that can potentially affect the economic variable considered in the evaluation analysis. For example, before it can be said that a subsidy for the purchase of electric cars led to an increase in sales of this type of car, it is necessary to understand what would presumably have happened to car sales in the absence of the subsidy. For instance, it may be that an observed increase in electric car sales can be attributed to other economic factors, for example, increased income, and not only to the subsidy. For this reason, from a methodological point of view, it is essential to base the evaluation on a counterfactual approach to identify the true impact of a policy measure. This implies that one must somehow reconstruct what would have happened without the intervention to determine the real effect of public policy. It is, therefore, a question of distinguishing a causal relationship (the occurrence of one event causing a second event) from a correlational relationship. A correlation (or association) between two variables does not imply a causal relationship.

Generally, to argue that a policy measure A causes a change in the outcome variable B, we must verify three conditions: (1) the introduction of the policy measure A must precede the effect observed on variable B; (2) cause and effect must be correlated; and (3) we need to exclude other factors/explanations that could account for the effect on variable B.

We can distinguish two main broad types of approaches for policy evaluation. The first set of approaches is experimental studies. In this case, researchers introduce an intervention or a policy using random assignment and study its effects using the methodology of randomised control trials. These effects could be analysed using a stated choice approach, or a revealed choice approach. In a stated choice approach, participants are asked to make a choice in a hypothetical situation, whereas in using the revealed approach, we look at the impact of the policy on actual choices.

Experimental studies are normally done *ex-ante*, that is, before the introduction of the policy measure. For this reason, this method is very attractive for undertaking policy evaluation. However, the implementation of experiments may not always be possible due to financial, ethical, or organisational reasons. The second set of approaches is quasi-experimental and does not involve random assignment of policies. Instead, by applying methods such as difference-in-differences or regression discontinuity, it is possible to derive causal estimates of a policy using observational data. This type of analysis is usually performed *ex-post*.

- **Randomised controlled trial (RCT)**: this methodology involves evaluating the impact of a policy measure by organising an experiment in which some observational units (individuals, households, firms, etc.) randomly chosen from a sample are 'treated', that is, they are subjected to the energy or environmental policy measure. In contrast, another group is not treated and is considered to be a

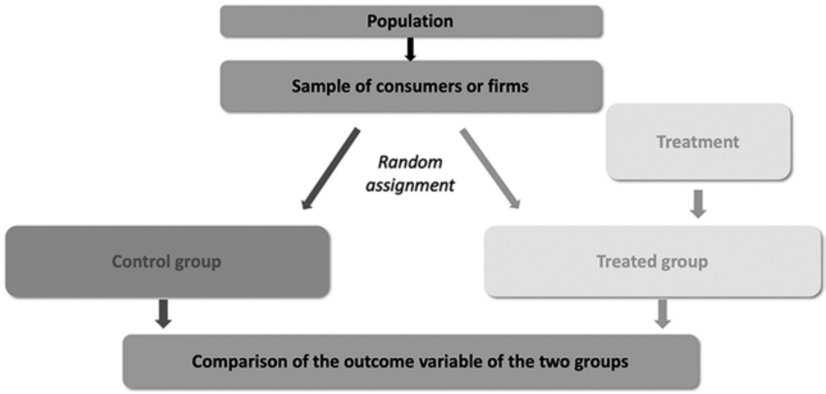


**Figure 9.3** Randomised controlled trial

control group. This group approximates the counterfactual situation we need to perform the policy evaluation. After introducing the policy for the treated group (and, in some situations, allowing some time to pass), the researcher evaluates the impact of the policy by comparing the change in the outcome of interest between the treated and control groups. The random selection of the observations into each of the two groups participating in the experiment assures us that the two groups are similar to one another, in terms of both observable and unobservable characteristics. This type of experiment is called a **RCT** because it is based on the randomisation of the treatment or the intervention, and this process is controlled by the researcher, that is, the researcher has complete control over the introduction of the policy measure and the random selection of units into the treatment and control groups.

Figure 9.3 summarises the elements of conducting an RCT.

For instance, if policymakers are interested to know the impact of introducing a subsidy to promote the adoption of electric cars *ex-ante*, then they can collaborate with a research institution to organise an RCT. In this case, the researcher would start by selecting a sample of people interested in buying a car in the next six months (as an example). He or she would then conduct a baseline survey to obtain important information on this group (such as socioeconomic information) and then use randomisation to define the group of people that will have access to the subsidy (the treated group) and the control group that will not have access to it while ensuring that the two groups are similar to one another in terms of observable covariates. The next step would involve the researcher cooperating with the government on the practical aspects of the experiment, that is, in defining and implementing the procedure to obtain the subsidy from the government. The researcher could then organise another survey after six months and collect information on the cars that participants bought. The last step in the analysis would involve comparing the share of electric vehicles bought by the two groups. Suppose the percentage of electric cars purchased by the treated group is significantly higher (in a statistical sense) than the share of the control group. In that case, the researcher can provide evidence to the policymaker that the subsidy has been effective.

This RCT can also be organised in a stated choice framework, whereby participants are asked to choose a car hypothetically. However, it is important to keep in mind that this approach may result in participants not revealing their true preferences, also known as hypothetical bias. Therefore, from a methodological perspective, it is better to organise an RCT on revealed choices whenever possible.

### Can information about energy costs affect consumers' choices? Evidence from a field experiment

In this paper, Boogen, et al. (2022) [123] investigated the impact of providing households living in Switzerland who were customers of two electric utilities with information on the potential monetary savings that could be achieved by replacing their current light bulbs or major appliances such as washing machines with new (and more energy-efficient) light bulbs and new appliances available on the market. A **RCT** was conducted in which the treated group of households received a letter with detailed information about potential monetary savings. After 1 year, the households were re-contacted. Both treated and control households, that is, those who didn't receive the letter, were asked to indicate which appliances and light bulbs had been replaced. The level of energy efficiency of the appliances and light bulbs purchased during the year by the two groups of households was then compared. The main result of this study was that providing information on monetary savings led households to purchase more energy-efficient light bulbs and appliances. Figures 9.4 and 9.5 illustrate the overall organisation of the study, as well as an example of the information that the households received about the efficiency of washing machines.

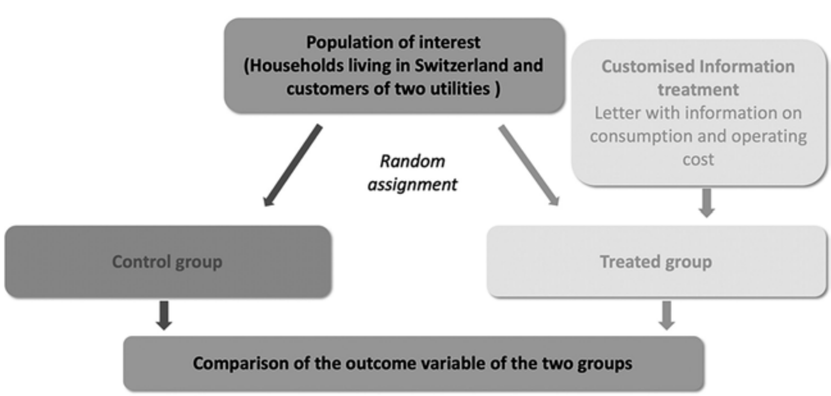


**Figure 9.4** Elements of the RCT on monetary information

## Washing machine

Characteristics of your appliance: Producer: Bosch, Width: 60cm, Height: 90cm, Year of Purchase: 2007

-----------------------------------------------------------------------------------------------

| | Your appliance | Alternative appliance on the market (load capacity: 8kg) | |
|---|---|---|---|
| | | A++ | A+++ |
| Consumption per cycle | 1.050 kWh | 1.170 kWh | 0.470 kWh |
| Cost of one cycle | 0.210 CHF | 0.234 CHF | 0.094 CHF |
| Annual operating cost[ii] | 46 CHF | 51 CHF | 21 CHF |
| Approximate price range of new appliance | | 725-2309 CHF | 440-4099 CHF |
| Estimate of potential annual savings on operating costs (compared to current appliance) | | No savings | 25 CHF |

[ii] The annual operating costs for the washing machine are estimated using 220 cycles.

- You can save an estimated CHF 25.- per year in electricity costs by replacing your washing machine with a new A+++ appliance.

**Figure 9.5** Information sheet on the efficiency of washing machines

### Nudging adoption of electric vehicles: Evidence from an information-based intervention in Nepal

Filippini, Kumar and Srinivasan (2021) [124], in their study, shed light on some of the market failures, and especially behavioural anomalies, that hinder the adoption of electric motorcycles in Kathmandu, Nepal. Using survey data on about 2,000 potential motorcycle buyers and a stated-preference RCT, the authors showed that informational interventions related to the health and environmental benefits of electric motorcycles had an impact in determining the stated choice of respondents. Moreover, these effects varied across respondents, based on gender, education as well as health status. This study shows that information provision, a potentially less costly policy option, especially in developing countries, can influence vehicle choice (even if it is the stated preference) [124].

- **Difference-in-difference analysis (DiD)**: this method is quasi-experimental in nature. As with an RCT, this method also assumes that some economic agents are treated, while others aren't. However, compared to an RCT, in a quasi-experiment, the treatment assignment is not random, and it is not organised by a researcher. DiD analysis is based on collecting data on the treated group and the control group that are observed both before and after the treatment. In a simplistic version of the DiD analysis, we compute the difference in the economic variable of interest for the two groups before and after the treatment and then compare this difference across the two groups. In this methodology, treatment assignment is based on some

**Table 9.1** Introduction of a subsidy for energy-efficient renovation of buildings in some regions

| Region | Year 1 | Year 2 |
|---|---|---|
| A | No policy | Policy |
| B | No policy | Policy |
| C | No policy | Policy |
| D | No policy | No policy |
| E | No policy | No policy |
| F | No policy | No policy |
| G | No policy | No policy |

other criteria, such as administrative or spatial rules, which result in some units receiving treatment, whereas others do not. For example, we can imagine a situation in which one city introduces a subsidy for purchasing solar panels, while other cities do not. In this case, we would have treated people in one city and untreated people in other cities, but the assignment to the respective groups was not randomised. For this reason, DiD analysis is considered to be a quasi-experimental method, since the treatment assignment is not organised and controlled by the researcher, but is observable in reality. In general, DiD analyses are conducted after the implementation of policies, and thus they are *ex-post* in nature.

A typical situation in which it is possible to apply a DiD approach is the one illustrated in Table 9.1. Let us assume that we have several regions in a country that, in year 1, have not implemented any energy and climate policy measures to promote energy-saving renovations of buildings. Then, some regions choose to implement a policy measure to promote energy-saving renovations in year 2. In this case, we have a quasi-experiment with treated economic agents (owners of buildings) in some regions and untreated economic agents in other regions. The owners of buildings in the treatment groups have the possibility to apply for the subsidy (but they are not obliged to do so), whereas owners in the non-treated regions do not have this possibility.

This type of situation allows the researcher to exploit the variation in the policy over time and between regions to analyse the impact of the policy, by comparing the number of energy-saving renovations in the treated and untreated regions. Because the data observed are over multiple time periods, we can calculate two types of differences in the outcome variable (the number of energy-saving renovations), and not only one as in the typical RCT. The first difference is obtained by subtracting the outcome variable in year 2 from the outcome variable in year 1 for each region, whereas the second difference is obtained by subtracting the first difference of the outcomes of the untreated from the first difference of the treated. Using a mathematical expression, we can say that the DiD estimate compares the variations over time of the treated group outcome ($Y_2^T - Y_1^T$) with the variations over the same period of the control group outcome ($Y_2^{NT} – Y_1^{NT}$). The magnitude of this estimate is also shown in Equation 9.1.

$$DiD = (Y_2^T - Y_1^T) - (Y_2^{NT} - Y_1^{NT}) \tag{9.1}$$

It is possible to obtain more precise DiD estimates by using a regression-based approach that allows researchers to incorporate other variables that may influence the outcome variable. It is particularly interesting to use a regression model that includes fixed effects because this allows one to control for unobserved variables that are time-invariant. For example, a simple difference-in-difference regression model based on the use of panel data can take the following form:

$$\ln Y_{it} = \beta_0 + \beta_1 POLICY_i + \beta_2 POST_t + \beta_3 POLICY_i * POST_t + \lambda_t + \epsilon_{it} \tag{9.2}$$

where $Y_{it}$ is the outcome variable, $POLICY_i$ is the treatment or policy variable, $POST_t$ denotes a post-treatment indicator, $\lambda_t$ denotes dummy variables for time periods, and $\epsilon_{it}$ is the idiosyncratic error term.

For applying the DiD approach, it is very important that the regions that we are analysing are comparable to one another. Particularly, before the introduction of the policy, the evolution of the outcome variable of interest should be similar for treated and non-treated groups over time. This assumption is known as the 'parallel trends' or 'common trends' assumption. In Figure 9.6, we graphically present the mechanism of the introduction of a subsidy for energy-efficient renovation of buildings. In this graph, we plot time on the horizontal axis and the share of energy-efficient renovations on the vertical axis. We can observe two lines that describe the development of the share of energy-efficient renovations in two regions over time, and the vertical dotted line denotes the onset of the treatment. The line on top indicates the share of energy-efficient renovations in the untreated region, whereas the line on the bottom denotes the share in the treated region. From this figure, it is clear that before the introduction of the subsidy, the two lines were parallel, that is, the shares of energy-efficient renovations were growing at the same rate for both groups. This indicates that the parallel trends assumption was satisfied. After the introduction of the subsidy,

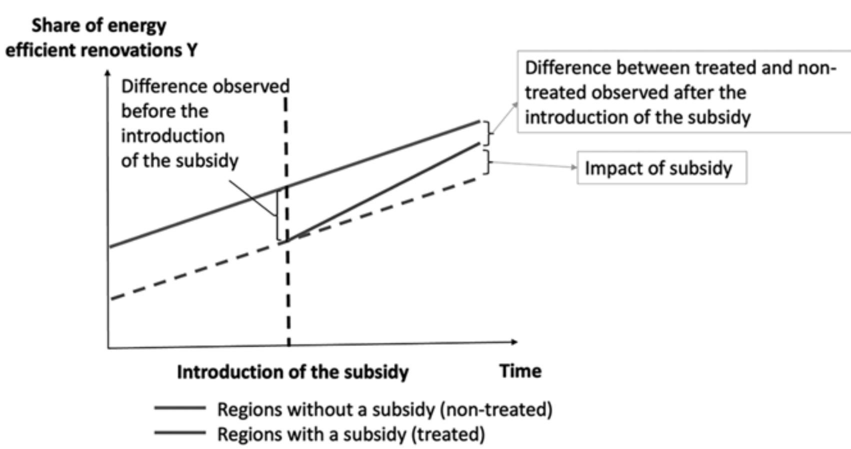


**Figure 9.6** Introduction of subsidy for energy-efficient renovations

the dashed part of the line on the bottom indicates an increase in the rate of change of the share of energy-efficient renovations in the region that adopted the policy. This visual analysis indicates that the subsidy had an impact on increasing the number of renovations in the treated region.

If in a natural experiment setting, we observe that the treated and untreated groups are very different from one another in terms of socioeconomic variables, it is possible to use a method that focuses the analysis on comparable subgroups within the sample. This method is called matching, and the comparable subgroups can be obtained using different matching algorithms. The researcher usually selects some important socioeconomic characteristics of the household, or economic characteristics of a firm, on the basis of which to find a suitable match for each observation in the data. This implies that observations in both treated and untreated groups that do not find a match are excluded from the analysis. Once this matching is complete, the researcher performs a DiD estimation on the matched sample. It is important to keep in mind that the matching approach can also be used by itself to analyse the impact of policy measures. In this case, the researcher simply compares the outcome variable after matching observations in the treated and untreated groups. However, this approach suffers from certain shortcomings; for instance, it is not possible to account in any way for unobserved variables that may influence the outcome variable.

**Application of DiD for the evaluation of rebates for energy efficient appliances**

In this paper, Datta and Filippini (2017) [125] estimated the impact of rebate policies on the quantity of ENERGY STAR household appliances sold using data from the United States. The authors of this study exploited a natural experiment, given that only some of the US states introduced subsidies to increase the adoption of energy-efficient appliances with an 'ENERGY STAR' label. Therefore, no state had introduced a rebate for ENERGY STAR appliances in the pre-treatment period, whereas in the post-treatment period, some states introduced a rebate for them. The empirical analysis, using a classical DiD regression model, was performed using socioeconomic and sales data for washing machines, dishwashers, refrigerators, and air conditioners at the state level for the period from 2001 to 2006. The empirical results showed that rebates have a positive impact on the share of ENERGY STAR electrical appliances. The authors estimated the following econometric model:

$$ES_{ait} = \alpha_0 + \beta RebatePolicy_{it} + \gamma X_{it} + \delta_i + \lambda_t + \epsilon_{it} \tag{9.3}$$

where the subscripts 'a', 'i' and 't' denote appliance type, state, and year, respectively. In the model, the authors considered four types of appliances, that is, washing machines, dishwashers, refrigerators, and air conditioners. $ES_{ait}$ is the share of each of the ENERGY STAR appliances sold, $RebatePolicy_{it}$ is a dummy variable for the presence of the rebate policy in a state in period 't', $X_{it}$ is a matrix of all other explanatory variables, $\delta_i$ denote the individual fixed effects, $\lambda_t$ are the time fixed effects, and $\epsilon_{it}$ captures the idiosyncratic error term.

Application of DiD for the evaluation of a demand side management strategy

In this paper, Boogen, Datta, and Filippini (2017) [126] estimated the impact of demand side management (DSM) measures introduced by some Swiss electricity companies on residential electricity consumption. The authors of this study exploited a natural experiment, given that only some of the Swiss electricity distribution companies introduced DSM measures to promote energy savings. Therefore, no company had introduced a DSM programme in the pre-treatment period, whereas in the post-treatment period, some of the companies decided to introduce a DSM programme. The empirical analysis is based on a classical DiD estimation, and it is performed using socioeconomic and residential electricity consumption data from thirty companies observed for the period from 2006 to 2012. The empirical results showed that DSM programmes had an impact on reducing the demand for residential electricity. A 10 per cent increase in DSM spending resulted in a 0.14 per cent decline in electricity consumption. This implies that the cost of saving 1 kWh of electricity was around 0.04 cents, while the price of 1 kWh for a household was around 20 cents. The authors estimated the following econometric model:

$$\ln EC_{it} = \beta_0 + \beta_1 DSM_{it} + \gamma X_{it} + \delta_i + \lambda_t + \epsilon_{it} \tag{9.4}$$

where the subscripts i and t denote indices for electric utility and year, respectively. $EC_{it}$ is the residential electricity consumption, $DSM_{it}$ is the DSM policy variable, $X_{it}$ is a matrix of all other explanatory variables that include the electricity price, the average taxable income per taxpayer, the household size, and the heating and cooling degree days. $\alpha_i$ are the utility fixed effects, $\lambda_t$ are the time fixed effects, and $\epsilon_{it}$ is the idiosyncratic error term.

**Regression discontinuity design (RDD):** the RDD is an empirical method that can be used to analyse policy measures determined by thresholds, that is, instruments in which eligibility for treatment may be based on a cut-off condition related to some socioeconomic variables. For instance, the South African government has implemented the Indigent Programme to provide poor households (below an income threshold) with free electricity of up to 50 kWh per month. In this case, income (the variable on which assignment to treatment is based) is known as the 'running variable'. From a policy perspective, it may be interesting to verify if this measure has had an impact on households switching from using more polluting fuels (such as kerosene or firewood), to cleaner sources such as electricity, and thus to understand whether this policy reduced health costs from the indoor air pollution in developing countries.

The regression discontinuity approach, which is also quasi-experimental, evaluates the impact of a policy measure by comparing the outcome variables of interest for the treated and untreated units that are very close to the cut-off. For instance, in the example above, this approach compares the electricity consumption of households that have an income that may be 5–10 per cent higher than the cut-off (the untreated group), with the electricity usage of those 5–10 per cent below the cut-off (the treated group). If this difference is statistically significant, it implies that the policy has had an impact on electricity consumption, and thus indirectly on the health outcomes of households, within this bandwidth or interval.

In order to apply the RDD approach, we have two prerequisites: first, we need a continuous running (or eligibility) variable, and second, a clearly defined cut-off point. Moreover, this approach is based on the following two assumptions:

- No manipulation of the running variable, that is, no clumping of individuals just above or below the cut-off, and
- Similarity of households and firms around the cut-off.

The second assumption implies that we would then compare very similar groups in the econometric analysis.

regression discontinuity design (RDD) can be applied to both cross-sectional (as in the example above) and spatial contexts. In the latter case, the researcher exploits the spatial variation in a policy. For instance, one region can introduce a bonus to adopt energy-efficient cars, while another nearby region may not. In this case, the researcher can compare the shares of energy-efficient cars sold in the vicinity of the border between the two regions. Recently, in energy and environmental economics, researchers have begun to estimate RDD-based methods along the time dimension as well. For instance, one could consider the moment when an energy price shock occurs to be a threshold point. In this case, the researcher is comparing the outcome variable (let's say, energy consumption) just before and after the shock. However, RDD-based models with time as a running variable are not very easy to implement, and the results can be biased, because of the difficulty in controlling for unobserved factors varying over time that may also affect energy consumption.

In Figure 9.7, we present a typical situation in which the state decides to give a subsidy for energy-efficient electrical appliances only to low-income households. This policy is enacted with the objective of improving the level of consumption of energy services by low-income households. Therefore, its effectiveness can be measured using the RDD approach. The figure plots income on the horizontal axis, which

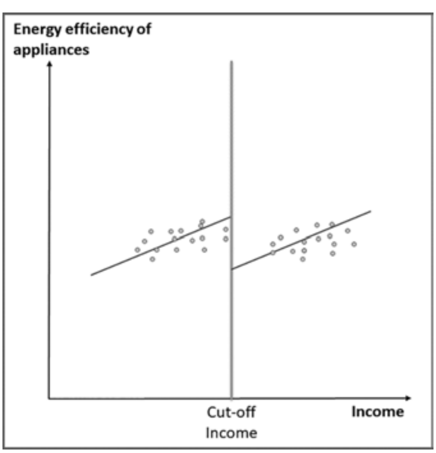


**Figure 9.7** Regression discontinuity design (RDD)

is the running variable in this case, as well as the cut-off that determines eligibility for the programme. On the vertical axis, we plot the level of energy efficiency of the electrical appliances. In the same figure, we can also see scatter points that represent the combination of income and energy efficiency for both households that are eligible for the subsidy (left of the cut-off) and not eligible for it (right of the cut-off). We can observe that close to this threshold, the level of energy efficiency of the electrical appliances by households that are eligible for the subsidy is, on average, higher than the level of energy efficiency of similar households ineligible for the programme.

Application of RDD for evaluation of labels

In this paper, Filippini and Wekhof (2021) [127] employed the RDD approach to analyse the effect of culture, captured through language, on the average level of energy efficiency of cars. Switzerland is an interesting case study to evaluate the impact of culture on economic and environmental decisions, due to the presence of different cultures/language regions that share the most important institutions at the federal level, but that are also spatially separated. In fact, Switzerland has different cantons in which the primary language varies from Italian to French, to German. Furthermore, variations exist in language and culture even within some cantons, where some regions within the canton have French as the primary language, and others have German. Such situations provide a natural experiment to analyse the impact of culture on economic decisions, by exploiting the variation in languages across the borders of regions as a threshold in the spatial RDD approach and using the distance of each municipality to the language border as a running variable. The empirical results of this study indicated an important effect of French-speaking culture on the energy efficiency of cars, that is, French-speaking car owners tended to buy more efficient vehicles.

### 9.3.3 Review Questions and Problems

The online question bank contains review questions and problems for this chapter, including solutions (see https://wp-prd.let.ethz.ch/exercisesfortextbookeep/).