

Chapter 2

Consumption as a Base for Emission Accounting and as a Policy Base

Abstract This chapter introduces a number of basic concepts needed to analyze consumption-oriented approaches in international climate policy. First, the exact difference between production-based and consumption-based emission accounting is explained. Two methods to determine a country's consumption-based emissions inventory are presented—the bottom-up approach and the top-down approach relying on environmentally extended input-output analysis. Then the question how a country's consumption-based emissions inventory can be used as a base for climate policy is examined. It is argued that it is crucial to distinguish between the base to which emission reduction targets refer and the base to which the policy instrument is applied. Two options are introduced by which the policy base can in practical terms be changed from production to consumption—border carbon adjustments and a “carbon-added” scheme. Finally, various criteria for assessing different climate policy variants are discussed: economic efficiency, cost-effectiveness, environmental effectiveness, carbon leakage, welfare, and competitiveness. This discussion shows that one of the most common policy effectiveness indicators—carbon leakage—in its standard definition is actually tailored only to a production-based policy. An alternative definition is presented that allows leakage to be determined in a meaningful way also for consumption-oriented policies.

This chapter introduces a number of basic concepts that will be used throughout this study: first, the exact difference between production-based and consumption-based emission accounting will be explained, then the question how a country's consumption-based emission inventory can be used as a base for climate policy will be examined, and finally, various criteria used to assess different climate policy variants will be discussed. In the course of this discussion we will also see that one of the most common policy effectiveness indicators—carbon leakage—in its standard definition is actually tailored only to a production-based policy. To serve as a meaningful indicator for a consumption-based policy also, the formulas defining carbon leakage have to be adjusted. Additionally, it will be argued that when formulating abatement policies it is crucial to distinguish between the base to which the emission reduction targets refer and the base to which the policy instrument is applied—a distinction usually not made in the literature.

2.1 Production- and Consumption-Based Emission Inventories

2.1.1 Emission Accounting Concepts

After the UN climate conferences in Copenhagen and Cancun in 2009 and 2010, around 90 countries have offered various GHG mitigation pledges.¹ If these countries abide by their pledges, a multitude of national climate policies with quite different levels of stringency will exist side by side. No attempt will be made here to model this real-world complexity. Rather, the simplest of possible settings is used to analyze the consequences of a switch of the GHG accounting system: a world, where one region (the policy-region, called “Home” in the following) pursues a GHG abatement policy, whereas the rest of the world (the non-policy region, called “Foreign” in the following) does not. In a highly stylized representation of current international circumstances, it will be assumed that the policy region Home comprises industrialized countries, whereas the non-policy region Foreign consists of developing and emerging economies.

In a first step, this simplified framework will be used to demonstrate the difference between production-based and consumption-based emission accounting. Region Home produces goods for domestic consumption as well as for export, denoted H and $X1$, respectively (see Fig. 2.1). The sum of H and $X1$ is Home’s output. Region Foreign produces goods for its domestic consumption (F), and also goods that it exports (termed $M1$, as these goods are imports seen from the perspective of Home). Thus, Foreign’s output is the sum of F and $M1$.

Let now E_H be the GHG emissions discharged by producing H , E_{X1} those discharged by producing $X1$, E_F those discharged by producing F , and E_{M1} those discharged by producing $M1$. Then, Home’s production-based emissions inventory E_1^{PB} and Foreign’s production-based emissions inventory E_2^{PB} are defined as follows (in the following variables and parameters relating to region Home will be marked by the subscript 1, those relating to Foreign by the subscript 2):

$$E_1^{PB} = E_H + E_{X1}, \quad (2.1)$$

$$E_2^{PB} = E_F + E_{M1}. \quad (2.2)$$

E_1^{PB} includes all emissions set free to produce Home’s output, and E_2^{PB} includes those set free to produce Foreign’s output.²

¹ See UNFCCC (2011a), for an overview of the mitigation pledges of developed countries, and UNFCCC (2011b) for an overview of the mitigation pledges of developing countries.

² This study follows Peters (2008) and Peters and Hertwich (2008a, b) in its definition of the production-based emissions inventory. As Peters and Hertwich point out, their definition is close to, but not the same as the one employed by the UNFCCC in the Kyoto Protocol (UNFCCC 1998a, b). The Protocol refers to the definition given by the Intergovernmental Panel on Climate Change (IPCC): “national inventories should include greenhouse gas emissions and removals taking place

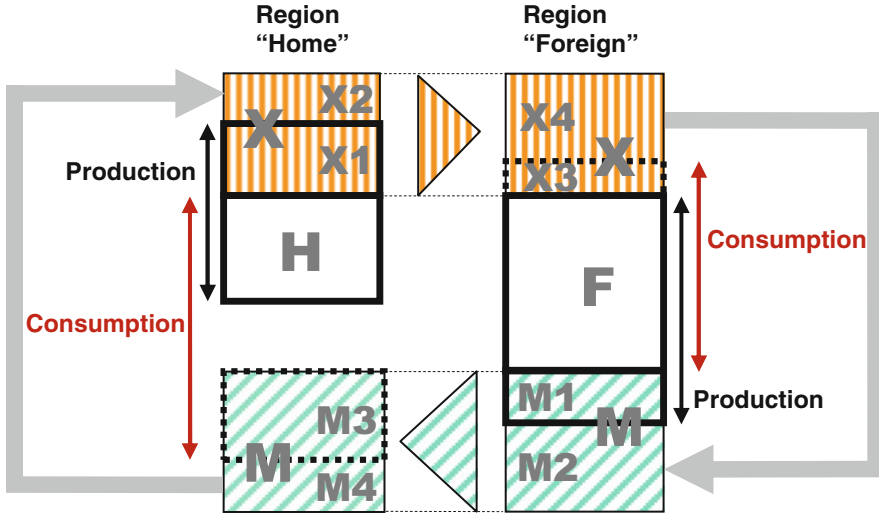


Fig. 2.1 Emission accounting concepts (see the main text for details)

Next, consider the consumption-based emissions inventory of the two regions. At the outset, two terminological issues shall be clarified: First, note that in the term “consumption-based emissions” the word “consumption” is used in a different sense than in national income accounting: it refers not only to private consumption, but also to investment and to government consumption, i.e. to all forms of domestic final demand. Second, the literature on consumption-based emission accounting uses the term “embodied emissions”—it, for example, discusses “emissions embodied in imports” or “emissions embodied in exports.” This, however, does not mean that these emissions are in some way “physically contained” in the imports or exports examined. Rather, the emissions embodied in some good are defined as the emissions set free at all different steps of the production process of that good, from raw materials extraction through to final assembly and, ultimately, the final sale of the product (Peters and Hertwich 2008b). Thus, the emissions embodied in a product also include the emissions embodied in intermediate goods used in the production of that good; and in the intermediate goods used to produce these intermediate goods etc.

within national (including administered) territories and offshore areas over which the country has jurisdiction” (IPCC 1997). Thus, the geographic rather than economic definition of a country is used. The approach may therefore be termed “territorial” emissions accounting. The problem with it, Peters and Hertwich argue, is that emissions from international transportation are not assigned to any country and that the geographic approach differs from the way in which quantities like GDP are calculated in national economic accounts. They therefore suggest employing the same allocation rules for emissions as for economic activities in national accounts, i.e. not recording emissions that occur within national territories, but rather emissions from institutional units resident in the economy. For the topics discussed in this study, however, the difference between the two definitions is inconsequential and will therefore not be elaborated.

The supply chain of many manufactured goods extends across many different countries; therefore, to determine the emissions embodied in some good, we must add up the emissions discharged in all of those countries in producing that good. In the simplified setting employed in this study, there are, however, only two regions. Thus, every good is produced in Home, in Foreign, or in both Home and Foreign.

The reason why a country's consumption-based emissions inventory typically differs from its production-based one is international trade: the goods a country consumes are not all the same as the ones it produces, and so, in general, the emissions embodied in these goods will not be the same. Figure 2.1 shows the trade flows: Imports M bring additional goods to Home, but not all of them find their way into final consumption. The reason is that imports (according to the term as used in trade statistics) contain (a) final goods as well as (b) intermediate goods. The intermediate goods can be used to produce either (b1) domestic final goods or (b2) exports (Peters 2008). Only (a) and (b1) are part of Home's final demand—they are termed $M3$ in Fig. 2.1. The quantity (b2), on the other hand, constitutes through-trade: imports used to produce exports. It is termed $M4$ in Fig. 2.1, and it equals $X2$ —the part of Home's exports X , which stems from through-trade. The remainder of X is $X1$, which—as explained above—are exports produced domestically. We can now determine Home's final demand: it consists of H , goods produced domestically for domestic consumption, plus $M3$, the part of imports that is not re-exported. The emissions embodied in Home's final demand constitute E_1^{CB} , Home's consumption-based emissions inventory. E_2^{CB} , Foreign's consumption-based emissions inventory, is calculated in a similar manner:

$$E_1^{CB} = E_H + E_{M3}, \quad (2.3)$$

$$E_2^{CB} = E_F + E_{X3}. \quad (2.4)$$

Thus, the consumption-based inventory measures the emissions caused by a country's final demand, no matter where the production to meet this demand takes place.³

The relationship between a country's production-based and its consumption-based emissions inventory can be stated in various ways:

$$E_1^{CB} = E_1^{PB} - E_{X1} + E_{M3} = E_1^{PB} - E_X + E_M. \quad (2.5)$$

The second equality holds true because the terms related to through-trade cancel out. Of course, a similar relationship applies to region Foreign. Thus, the difference

³ Emissions discharged not during production but during the final use of goods (like emissions from the use of private cars or from heating private homes) should be included in the production-based as well as in the consumption-based emissions inventory of the country where these emissions are set free. This can be justified as follows: activities like heating a private home can be seen as production—the production of a pleasant room climate—and consumption—enjoying that room climate—occurring at the same time.

between the production-based and the consumption-based emissions inventory can be calculated as the difference between emissions embodied in exports and emissions embodied in imports. This difference is usually termed the “balance of emissions embodied in trade” (Peters and Hertwich 2008a) or simply the “CO₂ trade balance” (Munksgaard and Pedersen 2001). We shall label it E^{TB} :

$$E^{TB} = E_1^{PB} - E_1^{CB} = E_X - E_M. \quad (2.6)$$

One more equality can be demonstrated easily within this two-region framework: We already know that $E_{X2} = E_{M4}$ and $E_{X4} = E_{M2}$. From this we obtain $E_{X1} + E_{M1} = E_{X3} + E_{M3}$, which in turn can be used to show that global production-based emissions E^{PB} equal global consumption-based emissions E^{CB} :

$$\begin{aligned} E^{PB} &= E_1^{PB} + E_2^{PB} = E_H + E_{X1} + E_F + E_{M1}, \\ E^{CB} &= E_1^{CB} + E_2^{CB} = E_H + E_{M3} + E_F + E_{X3} = E_H + E_{X1} + E_F + E_{M1} = E^{PB}. \end{aligned} \quad (2.7)$$

This is as it should be: both emissions measures refer to the very same emissions—they are just measured at different points along the supply chain.

2.1.2 Determining a Country’s Consumption-Based Emissions

Determining a country’s production-based emissions inventory (or more exactly: its territorial emissions inventory, see Footnote 2) is a well-established procedure: it is done by all industrialized countries at least once a year, *inter alia* to meet their emission reporting requirements under the Kyoto Protocol. Establishing the emissions embodied in an individual good or the consumption-based emissions inventory of an entire country is however a more difficult task: consumption-based emissions cannot simply be “measured at the chimney” where they are set free. Currently, two approaches are used to determine embodied emissions, both of which have certain advantages and disadvantages (Ismer and Neuhoﬀ 2007): in the bottom-up approach, production processes and the emissions associated with them are assessed for individual products (or narrowly defined product categories). The emissions measure thus determined is sometimes termed the “carbon footprint” of a product. It is the same quantity as the emissions embodied in that product defined above (Hertwich and Peters 2009). This method requires a lot of information (often from suppliers of intermediate products spread across the globe), it is time-consuming, but it can deliver exact results on the carbon content of individual products. If this carbon content for all goods that make up the final demand of a

country were to be added up, this would, theoretically, enable the country's consumption-based emissions inventory to be established (which, in analogy, is sometimes termed the "carbon footprint" of that country).

But this would be a tedious procedure, and therefore in determining consumption-based emissions for a whole country in practice the second approach mentioned above, the top-down approach, is employed. This approach has been continuously refined, starting in the late 1990s, in what has become known as the literature on emissions embodied in trade (see Chap. 6). It is based on environmentally extended input-output analysis. Simply put, such an analysis does not establish the carbon content of individual goods, but works with sector averages. For every sector it is determined how many inputs from other sectors directly or indirectly (via a longer supply chain) are required to produce one unit of output of the sector examined. These data are combined with data on the aggregate emissions discharged by every sector (or alternatively its energy consumption) in order to provide the amount of emissions embodied in the output of the sector studied. Lenzen et al. (2004) give an overview of different types of such international input-output models: The simplest type, *autonomous trade models*, assumes that imported commodities are produced with the same technology and production structure (and thus the same emissions) as domestic goods. The second type of models, *unidirectional trade models*, trace imports one step back to the region producing them. Every such producing region is characterized by its own technology and production structure (and thus its own emission intensities). Finally, the most sophisticated type of models, *multidirectional trade models*, trace back the whole supply chain of imports, often involving many different regions (each with its own technology and production structure).

All these types of models have been used in recent years to estimate consumption-based emissions inventories for most countries and regions of the world—see Chap. 6. They are an excellent tool for depicting the interconnectedness of production between different regions in today's globalized economy. Still, one should not forget that these models work with aggregate or average data relating to whole sectors. Any individual good may be produced using a supply chain or a technology that is quite different from that sector average. Thus, the emissions embodied in that good will, typically, also differ from the values characterizing the whole sector. The top-down approach to the estimation of consumption-based emissions is therefore suitable for determining the emissions inventories of whole countries or regions, but the data it will provide for individual goods are less accurate. This contrasts with the bottom-up approach, which can give more precise data for individual goods, but, if applied on a larger scale, is a tedious and time-consuming procedure.

2.2 Consumption-Based Emissions as a Policy Base

Leaving the practical problems of determining consumption-based emissions aside for the moment, let us examine the formulation of a consumption-oriented policy. Basically, just as a country's production-based emission inventory can be used as a base for an abatement policy, so its consumption-based emissions inventory can be used as a policy base, i.e. policy targets and policy instruments can be tied to the country's consumption-based emissions. In the following these two options will be referred to as "production-based policy" and "consumption-based policy."

2.2.1 *Target Base vs. Tax Base*

Steininger et al. (2012) observe that the question of the policy base of a certain policy actually consists of two questions: the "target base question," i.e. the question whether an emissions reduction target should be interpreted as a target to lessen a country's production-based emissions inventory or its consumption-based emissions inventory. Similarly, if instead of targets "emission-budgets" (see Sect. 1.2) are used to define the stringency of an abatement policy, these budgets may refer to either a country's production- or its consumption-based emissions inventory. The second question is the "tax base question," i.e. the question whether a country's production- or its consumption-based emissions inventory should be used as the base for an emission tax.⁴ A change of the target base from production to consumption has quite different effects from changing the tax base from production to consumption. So far this has not been discussed in the literature in any detail. But, as a clear understanding of this difference is essential when comparing production- to consumption-based policy approaches, the main arguments shall be outlined here.

To simplify somewhat: a change of the target base alone affects the distribution of the costs of an abatement policy between different countries or regions, but will not affect the effectiveness of the policy. Consider, as an example, the following scenario: A global conference agrees that every country should reduce its emissions by 20 %. This agreed target is defined in terms of production-based emissions. At some point, however, it is decided to redefine it in terms of consumption-based emissions. What consequences does this switch of the target base have, for example, for the EU? To answer this question, it is necessary to determine what the

⁴ "Instrument base" would be a more comprehensive term than "tax base," as a climate policy cannot be pursued only by means of an emission tax, but also through quantity instruments like, for example, a cap-and-trade scheme. Still, here the term "tax base" will be employed for the most part—simply because it is also used in other fields of economics and is therefore well-established. But note that all the results discussed in this study equally apply when, instead of a tax, a different policy instrument is used.

percentage target means for the absolute amount of emissions to be abated (e.g. in Gt CO₂ equivalent). For the EU, this absolute amount is larger if the 20 % reduction target refers to emissions in consumption rather than to emissions in production, as the EU's consumption-based emissions inventory is larger than its production-based one (see Sect. 6.1). Thus, for the EU a switch to a consumption-based policy means an increase in the absolute abatement requirement and, as a consequence, an increase in the cost of the abatement policy. Countries or regions that have a larger production-based than consumption-based emissions inventory will, on the other hand, experience a reduction of the costs of the policy as the result of a switch of the target base. Thus, overall, this switch redistributes policy costs between regions.⁵

As opposed to a switch of the target base alone, a switch of the tax base alone will influence both the distribution of the costs of the policy between regions and the environmental effectiveness as well as the cost-effectiveness of the policy. The direction and size of these distributional and effectiveness effects are the central questions of this study. As we will see in the following chapters, it is impossible to draw conclusions on these effects without knowing the values of all relevant parameters. Nevertheless, as regards distributional consequences, for a scenario where only industrialized countries abate, in many cases these countries will be able to reduce the costs they incur by switching to a consumption tax base. Now, if both the target base and the tax base are switched from production to consumption at the same time, then there will be two counteracting effects on costs (and thus income or welfare) of industrialized countries: the switch of the target base increases costs (recall the example above of the effects of such a switch on the EU), but the switch of the tax base decreases costs—again the overall effect will depend on parameter values.

This study will mostly analyze exactly such a scenario where the target base and the tax base are switched at the same time. Peters and Hertwich (2008b) examine a similar setting. But, as Table 2.1 shows, the different strands of the literature generally discuss quite different scenarios:

The literature on border carbon adjustments typically assumes a (partial) switch of the tax base by means of adjustments towards a consumption-orientation (see Sect. 1.3). But the target base is typically not altered—it is assumed that the (industrialized) countries introducing the border measures continue to pursue targets defined in terms of production-based emission as, for example, the targets

⁵ The claim that a change of the target base does not influence the effectiveness of the policy is a simplification. As described in the main text, the choice of target base influences the international distribution of the costs of the policy and consequently affects international income distribution. Insofar as this income distribution has an influence on policy effectiveness, effectiveness is not independent of the choice of target base. On this question, see also the discussion of the “income leakage channel” in Sect. 9.2. Secondly, if the target base, but not the tax base is switched, typically in every region an adjustment of the stringency of the policy at the very least will be needed to meet the altered target. Now, if the effectiveness of the policy is related to its stringency, then the choice of target base may have an effect on policy effectiveness. But all these effects are rather indirect—and will not be discussed here in greater detail.

Table 2.1 Target base vs. tax base

		Target base (affects burden sharing)	
		Production-based	Consumption-based
Tax base (affects burden sharing, policy effectiveness)	Production-based	Current UNFCCC system (Kyoto Protocol)	Most of literature on emissions embodied in trade
	Consumption-based	Literature on border carbon adjustments	• Peters and Hertwich (2008b) • This study

of the Kyoto Protocol. Such a policy may seem inconsistent—should it not be easier to meet a given target if the tax base matched the target base? Note, however, that the literature on border adjustments typically does not assume a “full” switch of the tax base. And additionally, the aim of the introduction of the border measures is often not to improve the effectiveness of the policy, but to protect the domestic industry of the country introducing the measures.

The other strand of literature discussed in this study, the literature on emissions embodied in trade, typically does not draw a distinction between changes in the target base and changes in the tax base. However, many of the proposals on assigning “responsibility for emissions” seem to discuss a switch of just the target base without a corresponding switch of the tax base—see Sect. 6.3.1.

2.2.2 *The Tax Base: Production vs. Consumption*

Tax incidence analysis tells us that under the assumption of flexible prices the effects of a tax do not depend on the question on which economic agent a tax is levied, but only on the tax base. For instance, to cite a standard textbook example, a uniform sales tax is equivalent to a uniform income tax as both have the same tax base. It is true that the two taxes are collected from different economic agents, but the tax burden is passed on and—after all price adjustments have taken place—the tax burden borne by each economic agent is the same for the two taxes. These principles, of course, also hold for emission taxes (or any other policy instrument used for abatement policy). Thus, from the fact that the production-based and the consumption-based emissions inventories are equal on a global scale (see Eq. 2.7) it follows immediately that if the world were to follow a uniform abatement policy (i.e. apply a uniform tax rate—or carbon price—to all emissions), it would make no difference whether production-based or consumption-based emission were taxed: the tax base is the same in both cases—all emissions world-wide.

In the remainder of this study, however, situations will be examined where just one region abates and the other does not—in that case, the policy bases of a production- and a consumption-based policy will differ. And, to repeat the central point, it is this difference in policy bases that is the cause of differences in the

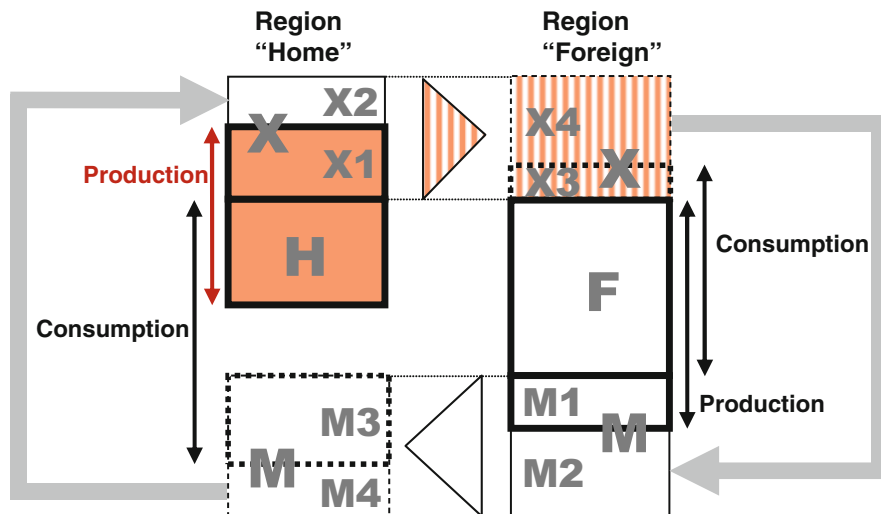


Fig. 2.2 Production as policy-base

effectiveness and distributional impacts of the two policies—and not the fact that one tax is collected from producers, while the other one might be collected, for example, directly from consumers or at the border between the regions.

In Fig. 2.2 the policy-base for a policy in Home targeting production-based emissions is highlighted. One can see that also Foreign is affected by this policy: part of its imports (the part that does not constitute through-trade for Home) are subject to the policy (and will therefore usually become more expensive).

In Fig. 2.3 Home follows a policy targeting consumption-based emissions. Now, the policy also affects Foreign's export production; or more precisely that part of export production which will not become through-trade in region Home.

2.2.3 Implementing a Consumption-Based Policy

Most countries currently abating their GHG emissions follow some form of production-based policy. In practical terms, this means imposing the carbon price (e.g. a tax or the costs of emissions permits) on those firms that actually discharge the GHGs. Consumption-based policies are currently not followed by any country on a wider scale. The academic literature however discusses several options how they might eventually be introduced (see e.g. Droege 2011; Droege et al. 2009).

The only one of these options that could be realized relatively quickly appears to be *border carbon adjustments*. Border adjustments usually start with a mitigation policy that uses production as the policy-base. Then, in the case of full adjustment, all imports are taxed at the border for the emissions associated with their production

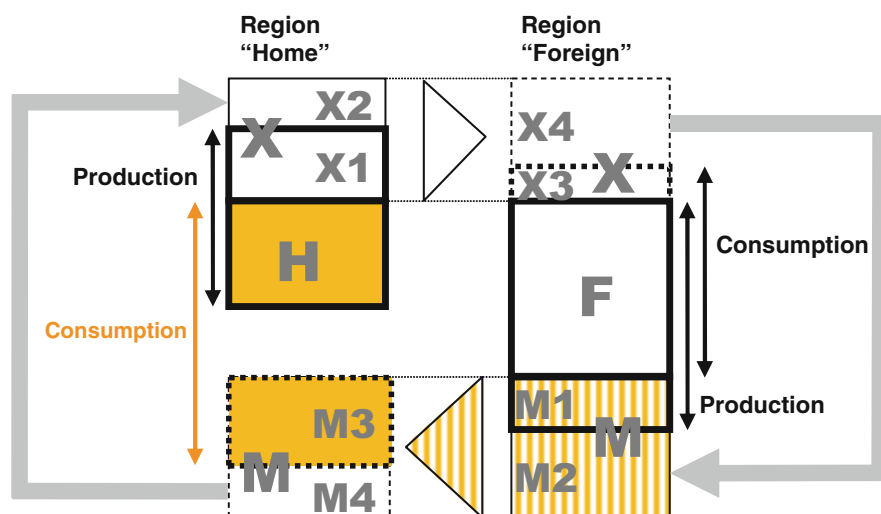


Fig. 2.3 Consumption as policy-base

(i.e. the emission embodied in these goods) in the same way as domestic goods, and exporters receive a tax rebate on exports for the full amount of emissions taxes paid. In this way, the tax base is changed from production to consumption (through-trade is not taxed, as import taxes and export rebates cancel out). Border adjustments cannot be imposed for emission taxes only—equivalent measures also exist for quantity-based policy instruments, for example importers may be required to purchase emission allowances for the emissions embodied in imports. In this study, in order to keep the argument simple and without loss of generality, border adjustments will however be discussed in the form of taxes.

There exists a vast literature on border carbon adjustments (see Chap. 5). Most of the adjustments discussed in that literature however do not qualify as “full adjustments,” i.e. they will not bring about a full switch of the tax base from a production-based to a consumption-based one: For example, they do not extend to both imports and exports; or they include only energy-intensive, but not all sectors of the economies studied; or they only encompass direct emissions or direct emissions plus indirect emission from electricity, but not all emissions discharged along the complete international value added chain for all products; or they only count combustion emissions, but disregard process-related emissions; or they apply a carbon price that differs from the domestic carbon price. In this study, on the other hand, we examine the effects of a “full switch” of the policy base towards consumption.

It is however not clear whether such a “full switch” can indeed be achieved by means of border adjustments. The discussion in Sect. 2.1.2 has already shown that establishing the emissions embodied in a good is a tedious procedure that requires a lot of information on production processes and supply chains in foreign countries. It

is far from clear whether this information can indeed be available “at the border.” Several methods of calculating border taxes are discussed in the literature (see Chap. 10)—but most of these methods will not bring about a full switch of the tax base. Still, even though it is thus doubtful whether border carbon adjustments are indeed an appropriate means to introduce a consumption-based policy in real-world situations, the idea of such adjustments can serve as a convenient “tool” in theoretical discussions: phrasing one’s arguments in terms of border adjustments can sometimes help to envision the effects of a policy, notwithstanding the fact that the policy, if ever implemented, might actually be pursued through other policy instruments.

A second option as regards how a switch to a consumption-based tax base might be accomplished is discussed by Droege et al. (2009) and Droege (2011). It is termed “*carbon-added proposal*” and has certain similarities to a value added tax (VAT): for every good the emissions discharged are recorded at every step of the value added chain through which the good passes. The emissions measures of the individual steps are added and passed on with the good whenever it is sold. At every production step their sum gives the emissions already embodied in the good at that step; at the end of the production chain, the “carbon footprint” (or the overall embodied emissions) of the good will be obtained. In that way information on the carbon content of all goods, no matter whether they are intermediate or final goods, will be available.

Under the “carbon-added proposal” governments can use this information to tax any good according to its embodied carbon. They are free to decide for or against the application of such a tax; all they are required to do is to ensure a correct recording of emissions. An emerging economy might, for example, decide to apply the emissions tax only to its exports, but not to its domestic consumption (this would amount to an export tax as discussed in Sect. 10.1.3). An industrialized country, on the other hand, might decide to apply the tax to all goods. Similar to value added taxation, where VAT is charged on the basis of total sales, but companies can offset their tax dues against the tax paid by other companies at earlier stages of the production chain, the carbon-added tax would also be calculated according to the total carbon embodied in the goods under question, but again it would be possible to offset the tax dues against tax already paid. For a company importing some good from an emerging economy that means that this company would have to pay tax on all emissions embodied in that good if no previous tax had been collected in the exporting country. There would thus be a “border tax.” If, on the other hand, an emissions tax had already been paid in the exporting country, the importer would be able to reduce the tax dues by the amount of that tax.

The introduction of such a “carbon-added” scheme would require the cooperation of (nearly) all countries—a credible system of emissions monitoring and recording would have to be established on a global scale. Such a scheme could therefore not be introduced quickly; establishing it would be a long-term project. But once established, a “carbon-added” scheme would have the advantage that it would enable a “full switch” to consumption-based accounting—as accurate information on the emissions embodied in every good would be available.

2.3 Evaluating Different Policy Variants

Evaluating different climate policies is by its very nature a normative exercise—it must be decided which criteria to use to determine whether one policy variant performs “better” than another (Venmans 2012). A vast number of different criteria are mentioned in the literature, of which different authors employ different ones. Some guidance on criteria choice is provided by the Fourth Assessment Report of the IPCC (2007): It lists environmental effectiveness, cost-effectiveness, distributional considerations, and institutional feasibility as principal criteria. As stated in the introduction, this study will concentrate on the question of policy effectiveness. Policy effectiveness is not a very precise term—but it is probably best operationalized by either of the first two criteria in the list above, environmental effectiveness or cost-effectiveness. Still, as this study also intends to provide proposals for climate policies that can actually be implemented, concentrating on effectiveness alone is not sufficient—we also need to discuss those criteria that dominate the political debate. Thus, the other two criteria recommended by the IPCC will also be used—we will come back to distributional questions at various points in this study; the criterion of political feasibility will be considered at length in Chap. 10. Additionally, two other criteria that are often used in the academic literature as well as in the public debate will be introduced: carbon leakage and competitiveness. But to begin this overview of policy evaluation criteria, a criterion that is employed almost exclusively in theoretical models will be briefly discussed, the criterion of economic efficiency.

2.3.1 *Criteria to Evaluate a Policy’s Effectiveness*

Some of the theoretical models that will be discussed in Chap. 4 employ the criterion of *economic efficiency* to compare different policies. Efficiency is the most comprehensive of the criteria reviewed in this subsection—it not only assesses the effectiveness of reaching a given environmental goal, but also the process of selecting this goal, i.e. it helps to identify, for example, the “optimal level” of emissions reduction. To that end, however, different environmental outcomes must be valued, which is a difficult and controversial exercise. Therefore, economic efficiency is a criterion well suited for purely theoretical analyses; in studies closer to real-world circumstances most researchers prefer to avoid valuing environmental outcomes and instead employ other criteria, such as environmental effectiveness or cost-effectiveness.

Cost-effectiveness is a criterion that evaluates both the costs and benefits of a policy, but does not require a valuation of environmental outcomes. This is achieved by comparing policies with the same environmental outcome (i.e. the same benefits). Then the policy with the lowest costs is the most cost-effective one. Or, alternatively policies involving the same costs are compared—then the one with

the best environmental outcome (i.e. the greatest benefits) is the most cost-effective one. Determining which environmental outcome is best can be done by just ranking the outcomes on an ordinal scale—a valuation of the outcomes is not required.

As climate change is triggered by the global concentration of GHGs, the environmental effect of a climate policy—the benefits of the policy—must also be measured on a global scale. In this study, benefits will be represented by the reduction in CO₂ emissions; and therefore it is the global reduction of these emissions that counts and not the reduction of the emissions in a single country or a group of countries—even if the policy is pursued unilaterally.⁶ Equally, the costs will also always be defined on a global scale, i.e. we are interested in the question whether a policy is desirable for the world as a whole, and not just for one region. In contrast policy makers, when introducing the policy, tend to be more interested in the costs incurred by their region or country. However, a policy with minimal global cost also allows minimal cost for the region introducing the policy to be achieved for given costs to the rest of the world. This argument, of course, assumes that it is possible to redistribute costs between world regions. We will come back to the question of redistribution when discussing proposals for a future climate policy.

Environmental effectiveness, as opposed to cost-effectiveness, is a criterion that looks only at the benefit side of a policy: the IPCC (2007) defines it as the extent to which a policy meets its intended environmental objective. As stated above, in this study the environmental objective is the reduction of global CO₂ emissions. As no information on the costs of the policies examined is required, as a criterion environmental effectiveness may be more convenient to apply in practical circumstances than cost-effectiveness; this convenience, however, comes at a price: the informative value of comparing only the environmental effectiveness of two policies is, of course, less. Therefore—whenever possible—economists typically prefer to analyze the cost-effectiveness of a policy, rather than its environmental effectiveness.

Furthermore, to achieve a meaningful comparison of environmental effectiveness, the two policies being compared must be similar at least regarding some of their aspects: this study will in the following compare policies that either (i) achieve the same emission reduction in the region that abates or that (ii) apply the same carbon price. As we will see in Sect. 8.7.1, option (ii) can actually be interpreted as a simple cost-effectiveness analysis.

⁶ This study thus discusses just one of the GHGs, CO₂—albeit the currently most important one in terms of its contribution to global warming. Also, to simplify the analysis, benefits are defined in terms of the “intermediate goal” of global emission reduction, and not in terms of a reduction of global GHG concentrations or even of climate change impacts avoided.

2.3.2 Carbon Leakage

Carbon leakage is a criterion that is widely used in the academic literature and has also found its way into the public discussion. Loosely speaking, it describes an effect that may occur if not all regions of the world abate: emissions may not be reduced on a global scale, but merely shifted from abating to non-abating regions. Two main versions of the concept of carbon leakage exist: first, “policy-induced” or “strong” carbon leakage, and second, “consumption-induced” or “weak” carbon leakage (Peters and Hertwich 2008a; Droege 2011).

2.3.2.1 Policy-Induced Carbon Leakage

In this study, it is mostly the first variant, policy-induced leakage, which will be discussed. As the name already indicates, it measures an effect directly triggered by climate policy, or more precisely, an unintended global effect of unilateral climate policy—a possible increase in emissions in the non-policy region caused by the introduction of the abatement policy in the policy-region.⁷ In its most simple form, this can be stated in absolute terms, i.e. in tonnes or gigatonnes of CO₂ of additional emissions in the non-policy region. In our two-region framework, if Home introduces a policy using emissions in production as the policy-base, then this policy-base consists of all emissions discharged in the production of $H + X1$, i.e. all emissions set free in production taking place inside the policy region. The emission discharged in production taking place in the non policy-region, on the other hand, are those set free in the production of $F + M1$. The absolute policy-induced leakage for a policy targeting production, L^{PB} , then equals

$$L^{PB} = \Delta E_F + \Delta E_{M1}. \quad (2.8)$$

Δ denotes the change in a variable compared to a reference state with no abatement policy. Absolute leakage therefore is a measure of the (unintended) “side-effect” of the policy, an increase of emissions in the non-policy region, in absolute terms.

However, more common than this absolute leakage measure is a relative measure—the leakage ratio (denoted here by the lower-case letter l). It is defined as the increase of emissions in the non-policy region divided by the reduction in the policy region:

⁷ The IPCC defines carbon leakage as “the part of emission reductions in Annex B countries that may be offset by an increase of the emissions in the non-constrained countries above their baseline levels” (IPCC 2007, 811). This definition refers to the split of countries into abating and non-abating ones as introduced by the Kyoto Protocol. But obviously, the concept of carbon leakage can also be used for other coalitions of abating countries.

$$l^{PB} = \frac{\Delta E_F + \Delta E_{M1}}{-(\Delta E_H + \Delta E_{X1})}. \quad (2.9)$$

Thus the leakage ratio sets the undesired effect of the policy—the increase of emissions in the non-policy region—in relation to the desired effect, the reduction of emissions in the policy-region.

Note that policy-induced leakage thus measures one aspect of a policy's global environmental effectiveness: if a reduction of emissions in the policy region is accompanied by an increase of emissions in the non-policy region, then clearly the global reduction in emissions is smaller than the reduction in the policy region—the effectiveness of the policy is thus reduced by the unintended effect in the non-policy region. Thus, leakage is an undesirable phenomenon that reduces the global effectiveness of a unilateral climate policy.

Nevertheless, carbon leakage cannot be used as a measure of the overall effectiveness of a climate policy: the overall effectiveness depends on the impact of the policy in both the non-policy and the policy region—but carbon leakage only assesses impacts in the non-policy region. To give an example: assume policy *A* leads to a little less leakage than policy *B*. But policy *B* is much better in lowering emissions in the policy region than policy *A*. Taken together, policy *B* results in a larger reduction in global emissions and is therefore the environmentally more effective one, even though, in terms of leakage, it performs worse. In one specific setting it is however indeed possible to infer the environmental effectiveness of a policy directly from its leakage ratio: if one compares two policies that bring about an equal emissions reduction in the policy region, then the policy involving less leakage leads to a larger reduction in global emissions and is therefore the environmentally more effective one.

When analyzing a policy with consumption instead of production as its policy base, there is a change in the split-up of the impacts of the policy into intended and unintended effects: A consumption-based policy followed by region Home targets emissions embodied in goods $H + M3$. Thus emissions embodied in $H + M3$ constitute the policy base—a “consumption policy base”—and the intended effect of the policy is a reduction of exactly these emissions. The unintended effect of the policy, on the other hand, is a possible increase of emissions not targeted, i.e. of emissions outside the “consumption policy base”—and these are the emissions embodied in goods $F + X3$. Now, if one wants to use carbon leakage again as a measure of the unintended effects of the policy (and thus of the loss of effectiveness associated with these unintended effects), the leakage formula has to be adapted accordingly (Steininger et al. 2014). Absolute leakage and the leakage ratio for a policy with consumption as the base are then defined as follows:

$$L^{CB} = \Delta E_F + \Delta E_{X3}, \quad (2.10)$$

$$l^{CB} = \frac{\Delta E_F + \Delta E_{X3}}{-(\Delta E_H + \Delta E_{M3})}. \quad (2.11)$$

When comparing policies, it is therefore necessary to decide whether to calculate leakage using the “production formulas” (2.8) and (2.9) or using the “consumption formulas” (2.10) and (2.11). The choice between these formulas should be guided by the objective pursued by a country’s climate policy, and not by the base of the actual policy followed, i.e. the emissions reduction target that a country wants to reach defines what is an “intended” and what an “unintended” effect (Steininger et al. 2014): assume, for example, that a country, bound under the current UNFCCC system by mitigation targets referring to emissions in production, decides to introduce border carbon adjustments to protect its domestic industry. The border adjustments in effect represent a (partial) switch to a consumption-based policy. Now the country is interested in knowing whether leakage under its former production-based or its new consumption-based policy is larger. In this case, the country should calculate leakage for both policies with the “production formulas” (2.8) and (2.9), as with both policies it aims to reach a mitigation target stated in terms of production. This also is the scenario usually assumed in the CGE literature on border carbon adjustments (see e.g. Boehringer et al. 2010, 2012; Burniaux et al. 2010; Fischer and Fox 2012). Note, however, that a leakage measure calculated in this way provides information only about how well the policy performs in achieving the country’s internationally agreed mitigation target, but not about whether the policy also helps to reduce global emissions. Thus, carbon leakage in that case is no longer an indicator of the policy’s global effectiveness. This is an important point that so far has not been discussed in the literature on border carbon adjustments.

The situation, however, changes if a country examines the effects of changing both the tax and the target base—either because a switch of the global accounting system is considered or because the country is interested in how, by pursuing a unilateral policy, it best furthers mitigation efforts at the global level. Then, leakage for the production-based policy should be determined by formulas (2.8) and (2.9), and leakage for the consumption-based policy by formulas (2.10) and (2.11). For much of the remainder of this study, exactly such a setting will be analyzed: a switch of both the target and the tax base. Then, by applying the correct leakage formulas, one can compare the unintended effects of the two policies as seen from a global perspective.

2.3.2.2 Consumption-Induced Carbon Leakage

The second leakage concept, “consumption-induced” or “weak” carbon leakage, is defined as the emissions embodied in imports of the abating region from the

non-abating region.⁸ In terms of the two-region framework introduced in this chapter, consumption-induced leakage thus equals E_M (or alternatively E_{M3} , if one subtracts imports that are re-exported). In other words, it is the amount of emissions discharged in the non-policy region in order to produce goods that are consumed in the policy-region. Note that, as opposed to the definition of policy-induced leakage, the definition of consumption-induced leakage does not assume any specific cause why a certain amount of emissions is embodied in the imports of the abating region; in particular, the definition does not require that weak carbon leakage is triggered by the introduction of a climate policy (it can be, but it need not be). Therefore, weak carbon leakage is not an indicator of the effectiveness of a specific policy. Some authors writing on emissions embodied in trade (see e.g. Peters and Hertwich 2006, 2008a, b) however regard a high or increasing level of consumption-induced leakage as an indicator of a situation that is deemed (at least implicitly) problematic for the environment or for international climate policy, the reason being that production to meet the consumption demand of countries with binding mitigation targets takes place in countries without binding mitigation policies (Peters and Hertwich 2008a).⁹ Chapter 6 will discuss empirical findings on the amount of and trends in weak carbon leakage. At this point, just note that, while a high level of weak leakage may indeed be a sign of a situation problematic for the environment, this is not necessarily the case. It is, for example, problematic if abating countries “outsource” their production to non-abating countries which then produce the same goods with a more carbon-intensive technology. But in general, differing carbon trade balances (and high levels of “weak” carbon leakage) may (and typically will) also exist in situations that are economically efficient and where there are no external effects harmful to the environment.

⁸ The concept of “weak” carbon leakage was introduced by Peters and Hertwich (2008a). They frame their definition in terms of countries that have reduction targets under the Kyoto Protocol (Annex B countries) and countries that do not. But, of course, this definition can be generalized to any split-up of countries into a group that abates and another one that does not.

⁹ One might argue that a concept using the net amount of emissions embodied in foreign trade like the CO₂ trade balance is a better indicator of possible environmental effects of emissions “transfers” through international trade than a concept like “weak” carbon leakage, which includes only imports, but disregards exports. But Peters and Hertwich (2006), who have contributed significantly to the development of the literature on emissions embodied in trade, object: They argue that the CO₂ trade balance mostly reflects the emissions intensity of the resource endowment of a country. In fact, they are however interested in something else, the possibility that countries reduce their emissions by decreasing domestic production while increasing imports.

2.3.3 *Criteria to Evaluate the Relative Performance of Different Regions*

The policy evaluation criteria discussed so far assess climate policies or trends in the distribution of emissions between regions from a global perspective, i.e. they ask about the advantage to the world as a whole, and not only to certain countries. In practical policy making, however, the question of distribution, i.e. the question who gains and who loses if a specific policy is implemented, is often more important. When analyzing practical proposals for policies to be implemented, such distributional questions therefore cannot be neglected. This study, however, limits the discussion of these questions to distributional effects between countries or between groups of countries; the distributional consequences of climate policies within countries, for example between producers and consumers, will be mentioned at some points, but not analyzed in detail.

Two different criteria will be employed in the examination of distributional effects: the first is the international distribution of the costs of the different policy variants. As the analysis is performed on the aggregate (i.e. national or global) level, costs from emission abatement can be best thought of as welfare losses. Thus we will examine the (relative) effects of the policy on the *welfare* of countries or coalitions of countries. Section 8.7 will provide a more detailed explanation of what exactly constitutes the cost of pursuing a climate policy.

The second criterion used to evaluate the relative effects of climate policy on individual countries or regions is *competitiveness*. As will be discussed in Chap. 3, the problem of a possible loss of competitiveness for the country introducing the policy is at the center of the political debate on unilateral climate policy—compared to this debate, the question of the environmental effectiveness of a unilateral policy or of carbon leakage triggered by it is often relegated to second place; sometimes the term “carbon leakage” is even used—not entirely correctly—as a synonym for a loss of competitiveness.

However, as Alexeeva-Talebi et al. (2007, 2) observe, “the concept of competitiveness has proven hard to define and susceptible for ambiguities.” The main reason for this is that it is often seen as a quite comprehensive concept—but if it is measured by certain indicators, they will typically not encompass all that is generally meant by the term “competitiveness.” Here, a rather pragmatic approach will be adopted: the model used in the analytical part of this study is not suited to examine all aspects of the concept of competitiveness. Therefore, one aspect will be chosen and then a measure appropriate to gauge this aspect will be developed.

Alexeeva-Talebi et al. (2007) review much of the recent theoretical literature on competitiveness. They suggest differentiating between competitiveness at firm, sectoral, and national level. This study concentrates on the sectoral and the national level. At the sectoral level, Alexeeva-Talebi et al. argue that competitiveness resides in (i) the “ability to sell” and (ii) the “ability to earn.” For the “ability to earn,” for example, the profitability of an industry may be used as an indicator. The model of this study, however, analyzes a long-run competitive equilibrium, where

firms do not make any profits. The model therefore cannot be used to analyze the “ability to earn”—instead, the focus is on the “ability to sell”. Quirion (2010, 108) defines the ability to sell at the sectoral level as “the capacity (...) of a sector of a given country or region to increase its market share, both domestically and abroad.” Alexeeva-Talebi et al. (2007) discuss some complex indicators of this capacity, which compare the performance of one domestic sector to either that of all other domestic sectors or to the performance of the same industry in other countries. Most CGE studies, however, make use of simpler indicators like changes in output, in exports, in imports, or in net exports (i.e. in exports minus imports)—see Chap. 5. All of these indicators—both the complex and the simple ones—measure different components of the “ability to sell.” All in all, there are four such components: (i) the ability to sell of home sectors on domestic markets, (ii) the ability to sell of home sectors on foreign markets, (iii) the ability to sell of foreign sectors on domestic markets, and (iv) the ability to sell of foreign sectors on foreign markets (Alexeeva-Talebi et al. 2007).

According to Alexeeva-Talebi et al. (2007), at the national level competitiveness ought to be defined somewhat differently. In addition to the “ability to earn” and the “ability to sell” one may also consider the “ability to attract”—referring to the economy’s capacity to attract factors of production—and the “ability to adjust”—referring to an economy’s ability to adapt to new circumstances. Discussing these last two “abilities” is however beyond the scope of this study. The “ability to earn” is defined differently at the national than at the sectoral level: at the sectoral level it usually relates to only one type of income, profits, whereas at the national level it includes income in general. In the analytical part of this study the effects of climate policies on “welfare derived from consumption” will be compared. For small changes in income, the difference between using either income or “welfare derived from consumption” as a metric is however typically quite small (Boehringer et al. 2012). Thus, one can interpret results referring to changes in “welfare derived from consumption” triggered by climate policy as actually also signifying changes in competitiveness defined as “ability to earn.” As regards the “ability to sell”, the indicators recommended by Alexeeva-Talebi et al. (2007) for use at the national level are different from those suggested for the sectoral level—they include the current account, the terms of trade, the real exchange rate, and the world market share of the exports of the country being examined. CGE studies that look at the effects of climate policy on competitiveness at the national level or at the level of a whole region—see Chap. 5—typically report changes to the terms of trade or the same measures also used at the sectoral level, i.e. changes to output, imports, exports, or net exports (which equal the current account).

The use of output as an indicator of competitiveness is debatable. Fischer and Fox (2012, 203) suggest that one should rely instead on the change in net exports: “Arguably, this metric is more appropriate for climate concerns, because it does not include the lost production associated with reduced consumption at home.” A reduction of the consumption of carbon-intensive products at home is, of course, one of the main aims of a domestic climate policy—even though at the same time it reduces competitiveness in the sense of the “home sectors’ ability to sell on

domestic markets.” This study will follow the recommendation of Fischer and Fox and will also employ the change in net exports as its indicator of the competitiveness effects of different climate policies. This indicator can be used at the sectoral level as well as when examining the effects on competitiveness for a whole region. However it must still be decided whether to measure net exports in physical units or in value units. Fischer and Fox (2012) in a study on different anti-leakage measures (which will be reviewed in detail in Chap. 4) use physical units, while many CGE models report value units.

For the purpose of this study, however, the use of physical units is more appropriate. Consider in particular exports: taxing emissions discharged in their production will typically raise their price and thus lower the quantity demanded and produced. Whether the overall effect on the value of exports is positive or negative cannot be determined without knowing the specific values of the parameters of the demand and supply functions. At any rate, the change in the value of exports informs us only about the competitiveness effect on the economy as a whole, but not about the competitiveness effect on the industrial sector under question—or, if the analysis is national rather than sectoral, about the competitiveness effect on the production side of the economy. The reason is that the economy as a whole also receives the revenues of the emissions tax, the producers on the other hand—whether those of just one sector or of the whole economy—do not receive these revenues and therefore experience no advantage from the price increase triggered by the introduction of the tax. In this study, however, the competitiveness measure employed is meant to serve as an indicator of effects that pertain to the production side of the economy (and not to the economy as a whole) and thus the value of (net) exports is not an appropriate measure. Instead, a competitiveness measure will be employed that records only changes to the physical quantity of (net) exports, but not to the prices of exports and imports. As imports and exports are different goods, it is, however, not possible to add up their physical quantities directly. Therefore to determine the quantity that will in the following be labeled “net exports”, the physical quantities of exports and imports will be weighted with the prices that these goods have in the reference state with no policy. These prices—the weights—are assumed to be fixed. Thus, when the change in “net exports” triggered by the policy is determined, this change is due only to a change in the physical quantities of imports or exports, but not in their prices. Formally, let $X1_i$ and $M3_j$ be the physical quantities of export goods i and import goods j , respectively, and $\bar{p}_{X1_i}$ and $\bar{p}_{M3_j}$ their prices in a situation without any climate policy. Net exports N are defined by

$$N = \sum_i X1_i \bar{p}_{X1_i} - \sum_j M3_j \bar{p}_{M3_j}, \quad (2.12)$$

and the change in net exports caused by the introduction of a climate policy is given by

$$\Delta N = \sum_i \Delta X1_i \bar{p}_{X1_i} - \sum_j \Delta M3_j \bar{p}_{M3_j}. \quad (2.13)$$

2.4 A Simplified Framework for Analysis

In the analytical part of this study the framework introduced in this chapter will be further simplified: only final goods, and no intermediate ones, are assumed to be manufactured and traded. This implies that there will be no through-trade in the two regions—all imports find their way into final demand in Home, and all exports find their way into final demand in Foreign. Of course, when compared to real-world circumstances this is a substantial simplification; in fact, currently more intermediate than final goods are globally traded—but this simplification allows us depict our two-region framework by using a small model that is analytically tractable. Figure 2.4 visualizes the policy-bases of a production- and a consumption-based policy according to this simplified framework.

Within this simplified framework, the formulas given in this chapter have also become more simple. In particular, the production- and the consumption-based emissions inventories are now defined as follows:

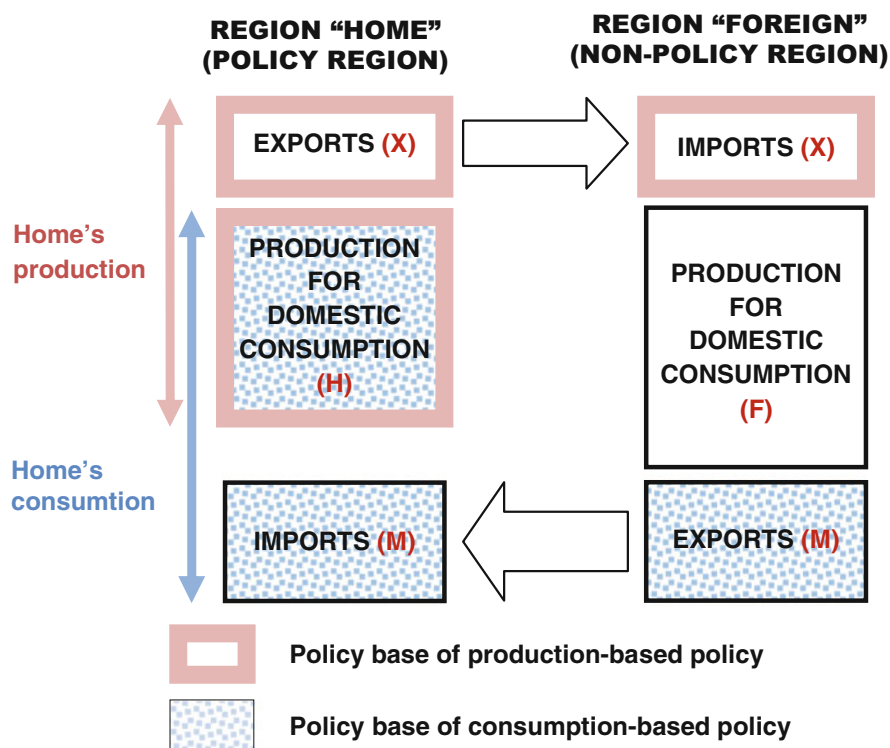


Fig. 2.4 Production and consumption as policy base—simplified framework (Reprinted in modified form from Steininger et al. (2014, 76) with permission from Elsevier)

$$E_1^{PB} = E_H + E_X, \quad E_2^{PB} = E_F + E_M, \quad (2.14)$$

$$E_1^{CB} = E_H + E_M, \quad \text{and} \quad E_2^{CB} = E_F + E_X. \quad (2.15)$$

The formulas for absolute leakage and the leakage ratio for a production-based policy simplify to

$$L^{PB} = \Delta E_F + \Delta E_M \quad \text{and} \quad (2.16)$$

$$l^{PB} = \frac{\Delta E_F + \Delta E_M}{-(\Delta E_H + \Delta E_X)}. \quad (2.17)$$

For a consumption-based policy, absolute leakage and the leakage ratio within the simplified framework are defined as follows:

$$L^{CB} = \Delta E_F + \Delta E_X \quad \text{and} \quad (2.18)$$

$$l^{CB} = \frac{\Delta E_F + \Delta E_X}{-(\Delta E_H + \Delta E_M)}. \quad (2.19)$$

Finally, the change in net exports simplifies to:

$$\Delta N = \sum_i \Delta X_i \bar{p}_{X_i} - \sum_j \Delta M_j \bar{p}_{M_j}. \quad (2.20)$$

This definition of “net exports” will be used as the measure of competitiveness in the analytical part of this study in Chap. 8.

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