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ALTERNATIVE APPROACHES TO DESIGNING CLIMATE POLICY RESPONSE: AN AUSTRALIAN CASE STUDY

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Abstract

Climate change presents a significant risk to humanity. Fossil fuels combustion is the single largest source of carbon emissions, which contributes to climate change. Carbon emissions can be mitigated either at the point of production of goods and services where consumers of fossil fuels are held responsible for reducing emissions, or at the point of final consumption where responsibility to reduce emissions are shared across the economy according to the amount of carbon embedded in goods and services. Climate policy is traditionally framed on the basis of the former approach. This is mainly because of the complexity involved in the application of the latter approach, specifically in terms of accounting for carbon emissions embodied in goods and services. This paper shows that the input–output analysis can be used to understand such complexity. It encapsulates embodied energy flows and associated carbon emissions within the economy, and hence provides information on carbon footprints of goods and services. The method also captures behavioural response from changes in policy, and thus allows the assessment of the impact of climate policy throughout the economy. This paper provides a comparative analysis of the economy-wide impacts of a carbon tax based on the two approaches noted above – in the context of limiting carbon emissions from the Australian electricity sector, to 20 per cent below 2000 levels by the year 2020.

Keywords: Carbon emissions; Embodied energy flows; Input–output method; Shared-responsibility principle.

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Introduction

Global warming and associated climate change are currently the most significant environmental challenges facing humanity. The emission of greenhouse-gases from the combustion of fossil fuels is the dominant anthropogenic emission contributing to climate change (Houghton et al. 2001). The production and use of energy is the single largest source of carbon emissions. In Australia, for example, fossil fuel combustion accounted for more than 90 per cent of total carbon-dioxide emissions and around three-quarters of total greenhouse-gas emissions (DCC 2009).

While fossil fuels induce threats to the Earth's climate, they are important inputs that provide heating, lighting and motive power to households and industry, which is essential for ensuring economic growth and improved living standards (CoA 2008). Balancing between the threats of climate change and the economic as well as social benefits brought about by fossil fuel combustion is therefore a major policy challenge for the policy makers. A range of policy options are being considered worldwide to mitigate greenhouse-gas emissions. These policy options are based on a mix of regulatory and market-based approaches. In Australia, for example, the recent debate on climate policy has focussed essentially on a market-based approach, with the argument that it is the most cost-efficient mechanism to reduce carbon emissions (CoA 2008).

Further, all climate policy options are generally framed within the context of polluter-pays principle where polluters of carbon emissions are held responsible for reducing this emission. This paper argues that that application of polluter-pays principle is not appropriate as a founding principle for developing climate policy response. This paper further argues that this principle is based on less than a complete understanding of the energy–economy–environmental relationship and ignores the broader dynamics of economic interdependencies. There is, therefore, a need to fully understand the complexity of economic interdependencies and its relationship with the environment, and to develop an analytical framework that captures such complexities. This paper is an attempt in that direction.

The next section of the paper discusses the complexity arising from energy, economy, and environmental interactions. It is followed by a discussion on the implications of the polluter-pays principle as a basis for designing climate policy response. An alternative to this approach, based on shared-responsibility principle is presented next. Subsequent sections of the paper provide a comparative assessment of the efficacy of the two approaches – in the context of reducing carbon emissions from the electricity sector in Australia.

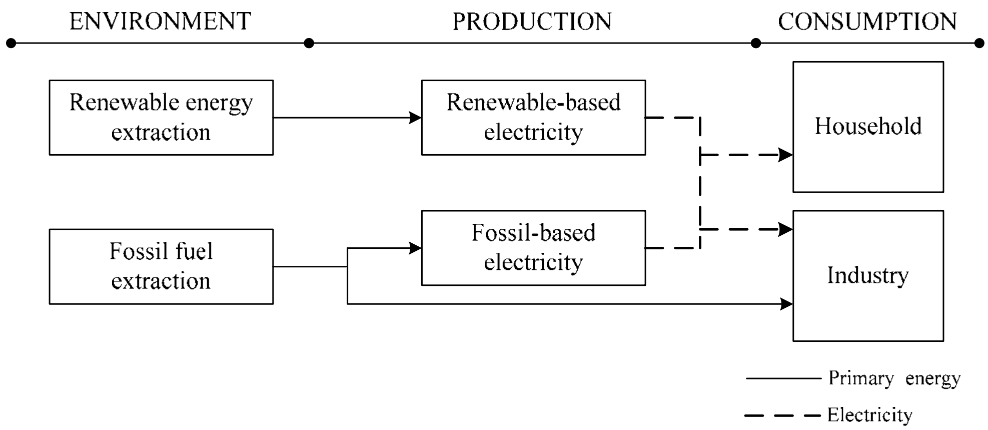
The complexity of energy–economy–environmental interactions

Market-based environmental policy is traditionally formulated based on standard neoclassical economic theory of externalities, including *Pigouvian tax* and *Coasean theorem*. A Pigouvian tax refers to an additional cost in the form of tax levied on each unit of emission, in an amount just equal to the marginal damage it inflicts upon society, in order to achieve the environmentally and economically efficient level of output (Pigou 1978). The Coasean theorem, in the context of climate policy, refers to the allocation of permits to release carbon emissions and, through the process of buying and selling these permits, to a market-based redress of the environmental problem (Coase 1960). These theories, in essence, define the core of what is known as the polluter-pays principle (PPP). Following the adoption of this principle by the Organisation for Economic Co-operation and Development in 1972 and the European Community in 1975, it has occupied a prominent place as a background principle for developing environmental policy measures around the world (Steenge 1999).

According to PPP, a polluter is defined as an agent who is primarily responsible for taking measures to maintain desired environmental quality levels (OECD 1994). The polluters of carbon emissions are treated as consumers of fossil fuel (called direct energy) where combustion takes place. By implication, they are considered to be solely responsible for pollution and hence for controlling pollution.

In the PPP approach, the magnitudes of (direct) energy consumption and associated carbon emissions are traditionally determined from an energy-balance perspective. A schematic of this perspective is shown in Figure 1. The figure shows that there is a unidirectional relationship between energy, economy, and the environment. Further, in this perspective the flow of energy is relatively straightforward, beginning with the primary energy extraction from the environment (renewable and fossil fuels), energy conversion (such as electricity generation), and ending with end-use consumption (such as by household and industry).

Figure 1: Energy-balance



Clearly, carbon price, determined from this perspective, tends to penalise big polluters such as fossil-fuel industries. The impact on these industries would be directly proportional to the carbon content of each fossil fuel consumed. In this perspective, the electricity sector is considered as the consumer of primary energy (this energy is used for electricity production). This means that a coal-fired power station would be penalised more than a gas-fired power station. It also means that a renewable resource-based technology is considered a zero emissions technology because it does not consume any fossil fuel. Therefore, electricity generated from renewable energy is not penalised. Further, the end-users, such as households and industries, are considered to be only responsible for a small amount of direct fossil energy consumption and associated carbon emissions, although they are large consumers of electricity produced from fossil fuels.

Although the PPP has been widely adopted as the background principle for developing a range of climate policy responses, it has some shortcomings. For example, the PPP approach is based on purely economic theories. It does not adequately reflect the real world contexts, for example, the conceptualization of the real physical world in term of a complete materials balance – in the context of this paper (see, for example, Ayers 1978; Ayers 1999; Ayers and Kneese 1969; Boulding 1966; Fritsch et al. 1994; Georgescu-Roegen 1971; Kneese et al. 1970). The materials-balance perspective holds that all materials (that is, energy and non-energy) extracted from the environment and used in the economy are accounted for by either remaining in the economy as durable goods or disposed of in the environment as emissions (Pearce and Turner 1990; Perrings 1987; Pethig 2003; Ruth 1993). This perspective therefore implies that environmental problems are a part of economic processes and all goods and services produced in an economy are (directly and indirectly) associated with energy use. In other words, energy is consumed in any economic activity in two ways – directly in the form of primary energy, and indirectly in the form of energy embodied in materials (called indirect energy). This indirect use of energy, according to Spreng (1988, p. 138), includes:

> *… (1) energy embodied in materials consumed during operation of the process; (2) energy embodied in the capital facilities of the system (including the energy embodied in all the manufactured components as well as the energy directly consumed during construction of these components); (3) energy embodied in the capital facilities that produce the materials and components and in the equipment used during construction; and (4) energy required to produce the fuels and electricity consumed directly.*

The indirect energy thus comprises a chain of direct energy requirements leading upstream to raw materials in the ground. Therefore, in order to complete the materials flow and hence accurately represent energy–economy–environmental interactions, both direct and indirect energy should be accounted for. This issue has also been emphasised by Owen (2004, p. 131) in the context of environmental impact of energy use. For example,

> *… a life cycle approach must be adopted in order to identify and quantify environmental adders associated with the provision of energy services. This approach provides detailed and comprehensive evaluation of energy supply options (based upon both conventional and renewable sources).*

A carbon price based on PPP does not explicitly consider the environmental consequences arising from this indirect energy. Non-fossil-fuel-consuming sectors are not considered as “polluters”, even though they use technologies whose manufacture might produce carbon emissions. In the case of renewable technologies, while PPP considers them as zero emission technologies, they may in fact consume significant amounts of energy through the use of materials over their entire operating life. This includes, for example, the construction of power plants requiring steel (from the iron and steel industry), copper (from the non-ferrous metal industry), and cement (from the construction industry). Moreover, the operation of these technologies may require electronics (from the electronics industry), plastics (from the chemical industry), and so on (Proops et al. 1996, p. 230). The production of these materials requires the burning of various types of fossil fuels, and hence the release of carbon emissions. In addition, they consume electricity produced from fossil fuels. If this indirect energy is explicitly considered and the responsibility for this part of emissions is appropriately allocated, there could be different economy-wide implications of a climate policy as compared with the one that is based on PPP.

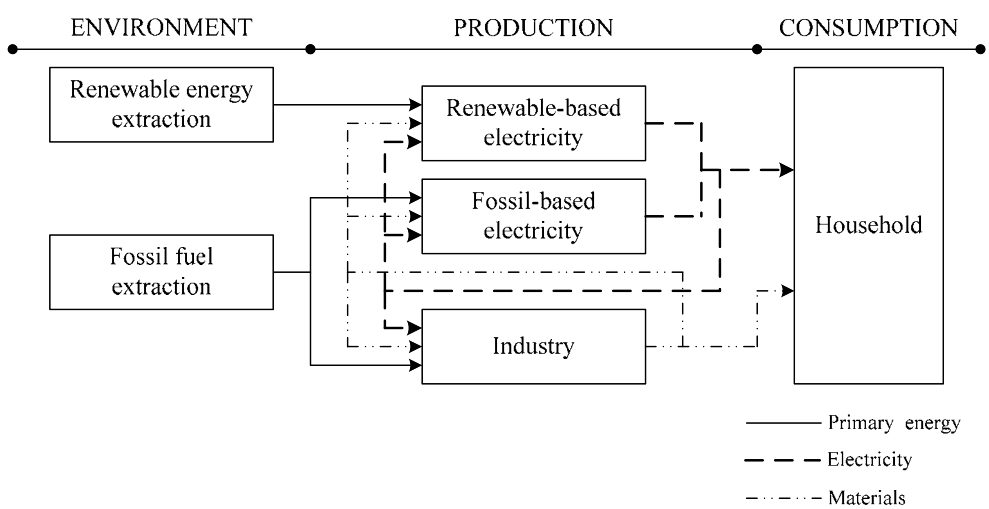
Another shortcoming of designing climate policy response based on PPP is the issue of equity. Because PPP does not consider indirect emissions, the responsibility of controlling pollution rests solely upon fossil-fuel consumers. In this principle, renewable industry and other non-fossil-fuel consuming sectors remain sheltered from environmental responsibility, even though they may be large consumers of indirect energy. Accordingly, this could place an unfair burden on fossil-fuel industries. The message here is that the climate change problem should not be considered as the responsibility of only the fossil fuel consumers (or "polluters" as they are defined in the PPP); it should be the concern of the whole economy. In addition, involving consumer of indirect energy directly in climate change responses appears to be prudent because consumers are considered as the root cause of carbon emissions. As Adam Smith (1776) put it: "*Consumption is the sole end and purpose of all production; and the interest of the producer ought to be attended to, only so far as it may be necessary for promoting that of the consumer*". Demand for products by consumer leads, directly and indirectly, to higher demand for fossil fuels and associated carbon emissions.

In light of these shortcomings, a number of principles have been developed as alternatives to PPP. These include user-pay, polluter-and-user-pay, and victim-pay (Steenge 1999). However, like the PPP, all these principles also have some shortcomings. For example, in the complicated networks of industrial complexes and economic interdependencies, it is difficult to identify who should be considered as the polluter, user, or victim (Steenge 1999, p. 165). If the liability of maintaining environmental standards is set as the responsibility of any single party, it would inevitably pose an unfair burden on that particular party.

In addition to the above, there is another principle that has been mentioned in the European Union Fifth Action Program – the shared-responsibility principle (EC 2001). Though this principle was discussed in the context of public participation to achieve a sustainable development, the concept of shared responsibility can be adopted as a founding principle for environmental policies. The shared-responsibility principle (SRP) seeks to alter production and consumption patterns in the economy. Such alteration is driven by environmental considerations (for example, carbon emissions) of various production and consumption patterns (Steenge 1999). In other words, this principle (proportionally) assigns responsibility for carbon emissions to both fossil-fuel consumers and consumers of other products whose production may have consumed carbon-emitting fossil fuels.

The task of estimating indirect energy (and associated carbon emissions) for each economic activity in a society is, however, complex. Reasonably robust estimates could however be developed by adopting a materials-balance perspective. A schematic of materials-balance is shown in Figure 2.

Figure 2: Materials-balance



The energy-economy-environmental interactions shown in materials-balance are relatively more complex. Take renewable technology as an example. It is considered as a zero emission technology under the energy-balance perspective. However, under the materials-balance perspective, some emissions are also attributed to this technology, in proportion to the consumption of materials. The increase in demand for electricity generated from renewable technology will result in increased demands for these materials. The production of these materials would require additional energy, which inturn would produce carbon emissions. In contrast to the energy-balance, here the electricity generated from renewable energy is also responsible for creating carbon emissions. Using the materials-balance perspective, the environmental impact from the consumption of energy (and carbon) embodied in materials can also be captured. Hence, the responsibility for carbon emissions could be appropriately assigned, based on both direct as well as indirect energy consumption.

The application of climate policy response based on SRP, rather than PPP, provides a fuller understanding of energy–economy–environmental interactions. Furthermore, the SRP provides a basis for allocating emissions to each economic activity in the economy in a manner that truly reflects environmental impacts of that activity.

Methodological framework

In the previous section, a case was made for considering a climate policy based on the shared-responsibility principle (SRP). It was argued that such a principle is applicable within a materials-balance perspective. This section provides some discussion about the methodology that can be adopted to represent energy–economy–environmental linkages from a materials-balance perspective.

In its most basic form, the materials-balance can be represented in the form of physical flows of energy and materials, with flows expressed in their original (that is, physical) units. The motivation for the physical flow approach is that the economy is underpinned by a physical world of stocks and flows of energy and materials. These stocks and flows are used to determine the economic choices and social behaviour (Poldy 1998). In order to be better informed about this dimension of the physical world, it is essential to understand these flows in their original forms. This approach is favoured by environmentalists and ecologists, as it represents the physical indicators of sustainable development, which cover a "*broader set of social values and amenities and do not have an integrative power of monetary aggregates generated in environmental accounting systems*" (Bartelmus & Vesper 2000). While the methods based on a physical flow (such as material flow analysis and life cycle analysis) is useful for assessing specific technical options where the scope is relatively small at a product or at most a sector level, it is not a suitable approach for the analysis that covers a whole economy (Sandu 2007).

Another approach to materials-balance is to employ an embodied energy approach, rather than the physical flow of materials. The embodied energy methods started to be applied in the late 1970s, mainly in an effort to address the problem of fossil fuels depletion following the 1973 energy crisis, which was the main concern at that time. A number of studies (for example, Bullard & Herendeen 1975; Chapman 1975; Wright 1975) considered energy flows in the economy, rather than monetary flows, to analyse the energy used for the production of energy and materials. The embodied energy approach is defined as "*the computation and measurement of energy flows in society, and, in particular, as the quantification of the volume of energy resources sequestered, directly and indirectly, in various commodities*" (IFIAS 1978). The embodied energy comprises energy required directly for the main process (for example, coal used for electricity production) and the indirect energy embodied in the material inputs to the process (for example, energy used for readying coal needs for electricity production and energy used for the construction of power stations). The embodied energy approach can be used as a substitute for the physical flow approach in that the flows of materials are interpreted as flows of indirect energy embodied in the materials.

Input–output method can be used for carrying out embodied energy analysis. The method was first developed by Wassily Leontief in 1936 as a tool to represent the structure of an economy by explicitly representing the interdependencies of economic sectors and industries (Duchin 1998). It traces the flow of commodities and raw materials across various sectors in the economy. This method can be adapted to analyse embodied energy flows by converting the economic relationship into estimates of associated direct and indirect energy intensities (Bullard & Herendeen 1975). This application allows for the calculation of embodied energy for any sector in the economy.

Input–output analysis has been applied by many researchers for empirical analysis of embodied energy. For example, Wright (1975), Bullard and Herendeen (1975), Proops (1977), and Shariful Islam and Morison (1992) employed this method to examine direct and indirect energy requirements for various economic sectors. Many of these studies found that most of the energy flows are associated with indirect use, to produce goods and services required in the economy. Further, Common and

Salma (1992), Proops et al. (1996) and Lenzen (1998) employed this method to examine direct and indirect emissions associated with energy use. While many of the above studies focused on the flows of direct–indirect energy to meet end-use demands for final consumption, only Proops et al (1996) and Lenzen (1998) have focused on these flows to also meet the demand required for capital investment. The input–output method has not only been used to account for direct–indirect energy requirements and associated emissions; Proops et al (1993) and Cruz (2002) have applied this method for future scenario analysis to reduce carbon emissions. Some of the scenarios focused on analysing technological improvements through changes in energy and material inputs. However, owing to the fact that the input–output method is characterised by fixed coefficients, both studies noted above have arbitrarily adjusted input coefficients to reflect the changes in input structure, without any economic rationality.

The underlying production function of the traditional input–output method is characterised by Leontief production function. This type of production function assumes “zero” elasticity of substitution, which does not allow one input to be substituted with another input. This limits the use of input–output method for analysing the economy-wide impacts of market-based climate policy and instead supports the application of a general equilibrium framework for this purpose. But one can also argue that the general equilibrium framework is after all basically supported by input–output representation of the economy! As noted by Dixon et al. (1992, p. 19) that, “*The prototype for modern applied general equilibrium models is Leontief’s input–output model*”. Moreover, input–output coefficients can be endogenously determined rather than exogenously given as fixed parameters (that is, changes from Leontief to other type of production function). Such modification enables the input–output framework to incorporate economic rationality in terms of substitution in response to price changes, as is the case in a general equilibrium framework.

To date, it appears that there is no study that uses the input–output method in the context of materials-balance perspective, and employing alternative production function specifications for the analysis of climate policy. However, some studies have adopted more flexible production functions in incorporating the materials-balance perspective in different contexts. For example, Gross and Veendorp (1990) adopted the Cobb-Douglas production function that satisfies the materials-balance to show that such a function sets a limit to growth for the case of an economy that obtains its material inputs from non-renewable resources. Weir (2000) studied the use of plastic, cement and steel in the Danish construction industry, by employing an econometric model to evaluate the substitution possibilities between different materials, in response to changes in material prices. Own- and cross-price elasticities were used to represent the potential for substitution between different materials. The study shows that there are substantial substitution possibilities in the construction sector, particularly between the use of concrete and metal. Other studies have used alternative production functions to estimate elasticities of substitution between aggregate variables – material, energy, capital and labour (for example, Berndt & Wood 1975; Burney & Al-Matrouk 1996; Hudson & Jorgenson 1974; and Truong 1985). These studies employed *Translog* type of production function to estimate substitution possibilities. It was found that, at an aggregate level, material inputs can be substituted with almost all other factor inputs. These results implied that assumed "zero" substitution possibilities for input coefficients in input–output analysis are inappropriate and other flexible types of production functions should be employed.

An advantage of adopting approaches based on input–output analysis is that they could make use of readily available input–output tables; statistical offices in most countries periodically produce such tables. Although such tables may not contain information at the level of individual companies or processes (IAEA 1994), they can provide sufficient detail at disaggregate levels for the whole economy. The inclusion of embodied energy flows at such disaggregated levels ensures that all emissions are accounted for in the economy. Further, the input–output method is flexible in the sense that it allows longer-term analysis, by replacing Leontief with other forms of production function. The replacement of production function does not capture only changes in the behaviour of the agents in response to changes in prices; it can also capture changes in the input structures of technologies used for production.

Allocation of carbon emissions in the Australian economy

This section presents an example of the use of input–output method in allocating carbon emissions from energy-balance and materials-balance perspectives – for seven key sectors in the Australian economy.

Carbon emissions from fossil fuel combustion in the Australian economy in 2007 were 364 Mt (DCC 2009). From an energy-balance perspective, the sectoral responsibility for this emission can be easily allocated using equation 1.

$$E_{energy-balance} = e \cdot C \cdot X \qquad (1)$$

where
$E_{energy\text{-}balance}$ = vector of carbon emissions from each sector (Mt);
e = vector of fixed carbon emission factor for each fuel type (Mt per PJ);
C = matrix of sectoral energy intensities (PJ per \$); and
X = vector of sectoral output (\$).

The result shows that, in 2007, the electricity sector accounted for more than half of total carbon emissions (Table 1). The table also suggests that the big fossil-fuel consumers (for example, the electricity, transport and manufacturing sectors) were responsible for most of the emissions in the economy. On the other hand, the commercial sector was responsible for just over one per cent of total carbon emissions, as it consumes only a small amount of fossil fuels. It is also worth noting that the allocation of carbon emissions from an energy-balance perspective, as shown in Table 1, is same as those reported in the official statistics (see DCC 2009).

Table 1: Carbon emissions from fossil fuel combustion in Australia

(Year 2007)

Rank	Energy-balance			Materials-balance		
	Sector	Mt	%	Sector	Mt	%
1	Electricity	198.7	54.5	Commercial	122.8	33.7
2	Transport	76.5	21.0	Manufacturing	82.3	22.6
3	Manufacturing	48.3	13.3	Electricity	76.7	21.1
4	Coal, oil and gas	22.2	6.1	Transport	40.4	11.1
5	Agriculture	7.3	2.0	Coal, oil and gas	20.4	5.6
6	Mining	6.2	1.7	Mining	13.0	3.6
7	Commercial	5.1	1.4	Agriculture	8.9	2.4
	Total CO_2 emissions	**364.4**	**100.0**	**Total CO_2 emissions**	**364.4**	**100.0**

Source: DCC (2009) and Author's estimates.

From the materials-balance perspective, the sectoral responsibility of total emission can be calculated from equation 2.

$$E_{materials-balance} = e \cdot C \cdot \left[I - \left(A + \overline{B}\right)\right]^{-1} \cdot Y \qquad (2)$$

where
$E_{materials\text{-}balance}$ = vector of carbon emissions from each sector (Mt);
I = identity matrix;
A = matrix of input–output technical coefficients;
$\overline{B}$ = matrix of weighted mean capital coefficients; and
Y = vector of sectoral demand (excluding demand for capital investment).

The result from the materials-balance perspective (as shown in Table 1) suggests that, in contrast to the energy-balance, the electricity sector contributed only 21 per cent of total carbon emissions. In this case, the commercial sector is ranked first: it is responsible for around one-third of total carbon emissions. Although the commercial sector does not consume fossil energy directly, it consumes significant amount of electricity, as well as other materials. These materials and electricity, in turn, are produced from carbon-emitting fossil fuels.

Clearly, the results presented in Table 1 shows that if carbon price is introduced in Australia, the decision on how it is imposed – based on PPP or SRP – would have different implications for the Australian economy. That is, penalizing sectors according to their consumption rather than production would have different impacts across the economy. This is because the burden to reduce carbon emissions shifts from producers to consumers and, as a result, each would respond differently.

Reducing carbon emissions from Australia's electricity sector

This section of the paper provides an assessment of the economic impacts of introducing carbon price when carbon emissions are allocated on different environmental principles – PPP and SRP. The impacts of both principles are compared against a base case (BC) – i.e., no carbon tax case. This assessment is carried out in the backdrop of a scenario that envisages to limit carbon emissions from the electricity sector to be 20 per cent below 2000 levels by the year 2020. For example, in 2000, carbon emissions from the electricity sector were 175 Mt (DCC 2009). To achieve the specified target, the emissions would therefore be limited to 140 Mt in 2020 – a reduction of carbon emissions by 30 per cent from the 2007 levels.

The economy-wide impacts are analysed using an energy-environment-oriented input–output framework (see Sandu 2007). These impacts, which include economic, energy, environmental, and social aspects, are calculated from the following set of equations.

$$
\begin{aligned}
X &= \left[I - \left(A_t + \overline{B}\right)\right]^{-1} \cdot Y \\
F &= C \cdot X \\
E &= e \cdot C \cdot X \\
L &= l \cdot X
\end{aligned}
\qquad (3)
$$

where
X, I, B, Y, C, E and e are defined earlier;
A_t = an updated matrix of input–output technical coefficients;
F = vector of primary energy requirement of each sector (PJ);
L = vector representing the level of employment for each sector (persons); and
l = matrix representing people employed per unit of output in each sector.

The impacts of introducing carbon price based on PPP and SRP are presented in Table 2. A review of the table suggests that, in order to limit carbon emissions from the electricity sector to 140 Mt by 2020, the impacts of introducing a carbon price based on SRP is milder than when price is imposed based on PPP. Without a carbon price, total carbon emissions from the electricity sector would reach 250 Mt by the year 2020.

A much higher level of carbon price would be needed in the case of PPP ($51 per tonne) as compared with SRP ($26 per tonne) – in order to reduce carbon emissions to 140 Mt by 2020. This is because, in the case of PPP, most of the responsibility for carbon emissions is attributed to a few large fossil fuel consumers (in this case, the electricity sector). A higher level of penalty is therefore needed to trigger a behavioural change by these consumers. In contrast, in the case of SRP, indirect fossil fuel consumers are also considered as a responsible party for carbon emissions. These consumers are small and scattered throughout the economy (see Table 1). A carbon price based on SRP, prompts a collective response by these consumers to mitigate emissions. The level of required penalty is therefore relatively small, as compared to the case of PPP.

Table 2: Impacts of carbon price to achieve an *a-priori* emission target in the electricity sector

	BC	PPP		SRP	
Carbon price ($/tonne)	0	51		26	
CO_2 emissions† $ (Mtonnes)	250	140	*(-20)*	140	*(-20)*
Electricity technology mix† ξ (per cent)					
Coal-fired	84.2	66.0	*(2010)*	66.0	*(2010)*
Combined-cycle	3.6	6.2	*(2014)*	11.4	*(2014)*
Renewable	10.2	25.8	*(2015)*	20.6	*(2017)*
Cost of electricity† # (¢/kWh)	5	31	*(461)*	24	*(343)*
Share of primary energy for electricity production† #					
Black coal	45.9	35.5	*(-10.4)*	34.0	*(-11.9)*
Brown coal	28.6	22.1	*(-6.5)*	21.2	*(-7.4)*
Oil	0.9	0.8	*(-0.1)*	0.7	*(-0.1)*
Gas	14.4	15.9	*(1.5)*	23.5	*(9.1)*
Renewable	10.2	25.8	*(15.6)*	20.6	*(10.4)*
Economic Impact ($Bn 1990)					
GDP‡ #	6,325	6,177	*(-2.3)*	6,140	*(-2.9)*
Carbon tax Revenue‡	0	78		143	
Electricity sector‡ §	0	42	*(54)*	41	*(29)*
Commercial sector‡ §	0	1	*(2)*	46	*(32)*
Net economic growth‡ #	***6,325***	***6,255***	*(-1.1)*	***6,282***	*(-0.7)*
Net economic cost		***-70***		***-43***	
Sectoral output‡ # ($Bn)					
Electricity	58	55	*(-4.6)*	55	*(-5.6)*
Coal-fired	49	46	*(-7.7)*	45	*(-8.5)*
Renewables	6	6	*(14.8)*	6	*(2.7)*
Combined cycle	2	2	*(14.6)*	3	*(40.8)*
Coal, oil and gas	121	100	*(-17.0)*	99	*(-17.7)*
Commercial	3,457	3,415	*(-1.2)*	3,413	*(-1.3)*
Agriculture	121	118	*(-2.8)*	117	*(-3.6)*
Mining	114	111	*(-2.6)*	111	*(-2.9)*
Manufacturing	2,122	2,102	*(-1.0)*	2,092	*(-1.4)*
Transport	332	324	*(-2.6)*	320	*(-3.7)*
Employment† #					
Electricity (persons)	47,399	39,494	*(-16.7)*	41,563	*(-12.3)*
Coal-fired	40,713	25,045	*(-38.5)*	26,578	*(-34.7)*
Renewable	4,925	11,969	*(143.0)*	10,110	*(105.3)*
Combined-cycle	1,760	2,480	*(40.9)*	4,875	*(176.9)*
Total ('000 persons)	9,444	8,719	*(-7.7)*	9,090	*(-3.8)*

Notes: BC: Base case; PPP: Polluter-pays principle; SRP: Shared-responsibility principle.
- † Result for the year 2020
- Ŧ Result over the period 2005–2020
- ‡ Present value, for the period 2005–2020, using a discount rate of 8 per cent
- $ Numbers in brackets show percentage change from the 2000 level
- # Numbers in brackets show percentage changes from the BC
- ξ Numbers in brackets represent year in which the particular technology becomes cost efficient
- § Numbers in brackets show contributions of the sector to the total

When carbon price is imposed based on PPP, combined-cycle and renewable technologies become competitive by the years 2014 and 2015, respectively. By 2020, the share of coal-based electricity would reduce to 66 per cent (from 84 per cent in 2005). Nearly 16 per cent of this reduction will be compensated by renewable-based electricity, and the rest (3 per cent) by natural-gas-fired combined-cycle electricity. Consequently, the cost of electricity supply would increase by more than five-times as compared to the BC value (5 ¢/kWh), reaching 31 ¢/kWh in 2020. These changes in technology-mix would influence changes in demand for primary energy used for electricity production. The demand for brown coal and black coal would reduce by 7 and 10 per cent, respectively. The demand for renewable energy and natural gas resources would however increase by 16 and 2 per cent, respectively.

Further, a carbon price of $51 per tonne based on PPP would cause the present value of GDP, over the period 2005–2020, to decrease by 2.3 per cent ($148 billion), as compared to the BC scenario. However, it would generate $78 billion of fiscal revenue for the government, of which 54 per cent ($42 billion) would be collected from the electricity sector alone. This suggests that the net overall economic impact would be approximately $70 billion ($148 billion loss in GDP and $78 gain in fiscal revenue). Also, the application of PPP would cause employment level in 2020 to be 7.7 per cent below the employment level in the BC scenario.

In contrast, if carbon price is imposed based on SRP, the combined-cycle and renewable electricity would become competitive by the years 2014 and 2017, respectively. By 2020, the share of electricity produced from coal would reduce to 66 per cent (from 84 per cent in 2005). This reduction in coal-fired electricity is exactly the same as for PPP because, in both cases (that is, PPP and SRP), this technology would start to phase-out from the electricity market at the same time (in 2014) when combined-cycle technology becomes cost competitive. A reduction in coal-fired electricity would be compensated by renewable (10 per cent) and combined-cycle (8 per cent). Because of the large increase in electricity production from combined-cycle (in this case as compared to the PPP), the demand for natural gas would also increase, providing 23 per cent of total primary energy inputs for the electricity sector in 2020. Consequently, the cost of electricity would increase by almost four-times as compared to the BC scenario, reaching 24 ¢/kWh in 2020.

Further, a carbon price of $26 per tonne based on SRP would cause GDP, over the period 2005–2020, to decrease by 2.9 per cent ($185 billion), as compared to the BC scenario. The impact on GDP in this case is higher than that in the case of PPP because a carbon price based on PPP would affect economic sectors based on their direct fuel consumption only; whereas, for SRP, it would be based on direct as well as indirect fuel consumption. However, it would generate $143 billion of fiscal revenue for the government, out of which 32 per cent ($46 billion) would be collected from the commercial sector and 29 per cent ($41 billion) from the electricity sector. As a result, the net cost of this policy would be $43 billion ($185 billion loss of GDP minus $143 billion gains in tax revenue). Also, the application of SRP would reduce the employment in 2020 by 3.8 per cent, compared with the BC level.

Conclusions

This paper has argued that the polluter-pays principle is not appropriate as a founding principle for developing climate policy response. It is based on less than a complete understanding of energy–economy–environmental interactions, and hence assigns all responsibility for reducing carbon emissions to the consumers of fossil-fuels. This paper has proposed an alternative approach where the responsibility to reduce carbon emissions are fairly shared across the economy – in proportion to the amount of carbon embedded in goods and services consumed by each sector of the economy. This paper has shown – through the application of energy-environment-oriented input–output method – that the application of an alternative approach yields better overall outcomes, as measured in terms of overall economic impact, electricity price, and employment.

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