Price-based Mechanisms for Climate Change Mitigation and the Role of Results-based Climate Finance?[1]

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Abstract

Price-based mechanisms (PBMs) are important vehicles to reduce greenhouse gas emissions. Examples of PBMs include carbon taxes, emission trading systems, other taxes on fossil fuels, feed-in-tariffs and the removal of fossil fuel subsidies. PBMs are gaining momentum worldwide and have been included in the packages of policy instruments considered by most of Paris Agreement parties to achieve their nationally determined contributions. However, PBMs face numerous political, financial, and technical barriers, and they have yet to be implemented at the scale needed to achieve the emissions reduction goals of the Paris Agreement. Results-Based Climate Finance (RBCF)— a result- or outcome- based development financing instrument specifically designed for financing climate change mitigation and adaptation activities—could help lower some of these barriers. This study explores potential ways in which RBCF can help facilitate successful implementation of PBMs in developing countries.

Key Words: Climate change, Result-based climate finance, Price-based mechanism, carbon pricing, Carbon tax, Emissions trading system, fossil fuel taxes, Feed-in-tariff, Fossil fuel subsidy removal

JEL Classification: Q54

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[1] The author would like to thank Carolyn Fisher, Klaus Oppermann, Stephanie Rogers, Jon Strand, Paolo Agnolucci and Mariza Montes de Oca Leon for their valuable comments and suggestions. The Transformative Carbon Asset Facility under the World Bank provided financial support to the study. The views and interpretations are of authors and should not be attributed to the World Bank Group. The author acknowledges Sunil Malla for compiling historical data on various PBMs.

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Price-based Mechanisms for Climate Change Mitigation and the Role of Results-based Climate Finance

1. Introduction

The price-based mechanisms (PBMs) are defined, for the purpose of this study' as "pricing instruments that follow the polluter-pays principle and that change relative prices in a consistent fashion, raising the cost of high-carbon-emitting processes or products compared to low-carbon-emitting processes or products, thereby incentivizing emission reductions." [3] PBMs include (i) fossil fuel/carbon taxes or comparable pricing instruments such as emissions trading systems; (ii) feebates: charges or rebates where less-emitting products are rewarded, and more emitting products are penalized; (iii) subsidy roll-back: reform of energy, agricultural or other subsidies that increase emissions; and (iv) policy driven changes in financial parameters: differentiated capital requirements and/or risk weightings.

Some PBMs, particularly carbon taxes, have a long history of implementation. Scandinavian countries (Denmark, Finland, Norway and Sweden) introduced carbon taxes in early 1990s when international negotiations on climate change just started. These countries were followed by many economies over the last 30 years around the world. The European Union introduced a regional emission trading system (ETS) in 2005 which is followed by several nations and sub-national jurisdictions. At present, more than 120 economies have introduced carbon pricing instruments, either ETS or carbon tax or both thereby covering about 22% of global greenhouse gas (GHG) emissions (World Bank, 2021a). It is estimated that carbon pricing initiatives around the world generated US$53 billion in revenue in 2020 (World Bank, 2021a).

Feed-in-Tariff (FiT) is one of the main PBM used to incentivize renewable energy, particularly solar and wind power. At present, around a hundred countries around the world have introduced some forms of FiT (REN21, 2021). Tax credits, subsidized finance, production

[3] The definition of PBMs vary across studies. For example, World Bank (2021a) include regulatory policies such as vehicle mileage standards as implicit carbon pricing and interpreted as PBMs. One can also interpret carbon offset mechanisms, such as clean development mechanism (CDM) and joint implementation (JI), the pricing instruments under the Kyoto Protocol are also price-based mechanisms. Indeed, they are. However, we have excluded them because they do not have direct relationship to government policies as such.

subsidies are also commonly used to promote renewables in many countries and are also part of PBMs (Timilsina et al. 2012). Removal of fossil fuel subsidies is one of the key vehicles to reduce greenhouse gas (GHG) emissions. A recent Global Subsidy Initiative (GSI) study reports that removal of fossil fuel subsidies in 32 countries that account for 77% of global CO_2 emissions would reduce 6% of their emissions from the baseline in 2030. (Kuehl et al., 2021).

PBMs represent some of the main policy instruments included in the Nationally Determined Contributions (NDCs) pledged by almost 200 countries under the Paris Agreement. Various levels of government (national, provincial, municipal), global corporations, industries all are increasingly giving attention to PBMs to reduce their GHG emissions. Thus, momentum is building at the international level towards further scaling-up of PBMs.

However, wider introduction and implementation of PBMs face many barriers, including political resistance and public reluctance. While there are several reasons for the political resistance and public reluctance to carbon pricing, particularly carbon taxes, one of the main reasons is a lack of confidence in these instruments. This is because there is no guarantee that a carbon tax causes the demand for fossil fuels to decrease at the rate expected or estimated. Even if there are no political obstacles, there does not exist institutional capacity to successfully implement PBMs, particularly in the case of ETS. Usual technical barriers, such improper design of PBMs, lack of monitoring, reporting and verification (MRV) system, inflation of baseline, potential leakage of GHG emissions, are still present.

Result Based Climate Finance (RBCF) is a type of Results-Based Financing (RBF), a scheme used by international financial institutions to support economic development and social welfare activities in recipient countries. Under the RBF, a donor disburses financial resources to a recipient *ex post*, based on the verified results or achievements (Kachi and Day, 2020). The World Bank launched this concept in early 2000 through its program 'Global Partnership for Results Based Approaches'[4] and has applied it to several sectors including education, health, water and sanitation. The main difference between the traditional financing mechanism and the RBF is that, in the former case, the fund is provided upfront (ex-ante) or before or during the implementation

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[4] https://www.gprba.org/index.php/who-we-are

of the project activities, whereas, in the latter case, it is disbursed ex-post or after the completion of project activities. Under the RBF, the delivery risk of the project is transferred from donors to recipients. RBCF is an RBF dedicated to climate change mitigation and adaptation activities. Mostly mitigation activities have been supported by RBCF to date. The RBCF has been utilized to finance range of climate change mitigation project activities such as REDD+, renewable energy, energy efficiency improvement, rural electrification, and clean cooking (World Bank, 2017).

The primary objective of this paper is to qualitatively explore the potential role of RBCF to facilitate introduction and successful implementation of PBMs, which are part of NDCs submitted by most of the parties to the Paris Climate Agreement. The paper, first, briefly presents current status of PBMs around the globe, particularly focusing on developing countries (Section 2), followed by a synthesis of evidence on PBMs' contribution to GHG mitigation drawn from empirical literature (Section 3). It then elaborates the key challenges or barriers faced by the PBMs (Section 4) followed by discussions on the potential role of RBCF to reduce these barriers and promote the scaling-up of PBMs (Section 5). Finally, it draws key conclusions.

2. Existing PBMs Around the World

Almost every country has introduced some forms of PBMs. Currently, 26 countries have introduced carbon tax and another five sub-national jurisdictions (states, provinces) have also introduced carbon tax (World Bank, 2021). There are 28 ETS programs operational at various levels, of which one at the international or cross-country level (EU ETS), seven are national level (China, New Zealand, Switzerland, Kazakhstan, Republic of Korea, Canada and Germany), nine provincial or state level (Alberta, British Colombia, New Brunswick, Newfoundland and Labrador, Nova Scotia, Quebec and Saskatchewan in Canada: Massachusetts and California in the US), one cross-state level (RGGI in the US) and 10 at city level (Tokyo and Saitama in Japan; Beijing, Guangdong, Shanghai, Shenzhen, Tianjin, Chongqing, Hubei and Fujian in China) (World Bank, 2021). More than 110 countries have introduced FiT schemes to promote renewables (REN, 2021) A large number of countries (28) have undergone significant reforms in their fossil fuel subsidies (Table 1 and its Footnote). Most countries around the world have different type of taxes on fuels (e.g., excise taxes, VAT, environmental levy, road maintenance surcharge). These taxes increase end-use prices of fuels. They can, therefore, be interpreted as indirect taxes to reduce CO_2 emissions. However, these taxes might be there anyway for other purposes, particularly to generate government revenues. For the purpose of this study, we interpreted any increase in weighted average[5] after tax fossil fuel prices in each year between 2010 and 2019 as compared to 2010 as indirect carbon taxes for the given year.[6] However, we find that only a few countries (see 'Fuel price rise' column in Table 1) have higher fuel prices in 2019 as compared to that in 2010. In this section, we briefly present these PBMs. Table 1 presents the countries with various PBMs.

Table 1: Countries with various PBMs at some level of jurisdiction (as of 2020)

(a) Developing countries (including Non-OECD high income countries as relevant)

Country	Carbon tax	ETS	FiT	Fossil subsidy reduction	Fuel price rise
Algeria			√	√	n.a.
Argentina	√		√	√	n.a.
Chile	√		√		
China		√	√	√	
Egypt			√	√	n.a.
Indonesia			√	√	n.a.
Iran			√	√	n.a.
Kazakhstan		√	√	n.a.	n.a.
Malaysia			√	√	n.a.
Mexico	√			√	n.a.
Nigeria				√	n.a.
Pakistan			√	√	n.a.
Russia			√	√	
Saudi Arabia				√	
South Africa	√		√	n.a.	n.a.
Thailand			√	√	n.a.
Ukraine	√		√	√	n.a.
Uzbekistan			√	√	n.a.
Viet Nam			√	√	

(b) Developed countries (including all EU member states)

Country	Carbon Tax	ETS	FiT	Subsidy reduction	Fuel price rise
Australia			√		√
Austria		√	√		
Bulgaria		√	√	n.a.	n.a.

[5] Weighted by fuel consumption (measured tons of oil equivalent) in various sectors.

[6] The selection of 2019 is based on the fact that fuel demand and prices were distorted due to COVID-19. Moreover, 2020 data are not available for all counties included in Table 1. The selection of 2010 is based on the fact that PBM, particularly carbon tax and ETS, are getting attention more recently. Hardly, any developing countries and only a few industrialized economies have adopted carbon pricing before 2010.

Canada	√	√	√		
Croatia		√	√	n.a.	n.a.
Cyprus		√	√		n.a.
Czech		√	√		n.a.
Denmark	√	√	√	√	
Estonia	√	√	√	√	√
Finland	√	√	√	√	√
France	√	√	√		
Germany	√	√	√		n.a.
Greece		√	√		
Hungary		√	√		
Ireland	√	√	√		
Italy		√	√		
Japan	√	√	√		
Latvia	√	√	√		
Liechtenstein	√		√		n.a.
Lithuania		√	√		
Luxembourg	√	√	√		n.a.
Malta		√	√		n.a.
New Zealand		√			√
Netherland	√	√	√		
Poland		√	√	n.a.	√
Portugal	√	√	√		
Republic of Korea		√			√
Slovakia		√	√		
Slovenia		√	√		
Spain	√	√	√		√
Sweden		√	√		
Switzerland	√		√		√
United Kingdom		√	√		√
United States		√	√		√

Countries with less than two PBMs are not included here to keep the table shorter. Other countries with carbon tax are Colombia, Iceland and Singapore. EU has an emission trading system but not included in the list of country as it is a region. Other countries with FiT are Albania, Andorra, Belarus, Bosnia and Herzegovina, Costa Rica, Ecuador, India, Israel, Jordan, North Macedonia, Maldives, Montenegro, Panama, Peru, Serbia, Tanzania, Turkey and Uruguay. Other countries that went through fossil fuel subsidy reduction are Bahrain, Bangladesh, Bolivia, Brunei Darussalam, El Salvador, Gabon, Ghana, Iraq, Kuwait, Qatar, Turkmenistan and United Arab Emirates.

The policies are implemented either at the national level or sub-national level. The empty cell under column “Carbon tax”, “ETS” and “FiT” and “Subsidy reduction” refers to that these policies are not introduced in the corresponding countries. Empty cell under column “Fossil fuel rise” refers to a drop in weighted average, tax inclusive fossil fuel prices. “n.a.” refers to data not available. A country is assumed to undergo fossil fuel subsidy reduction during 2010-2019 if its fossil fuel subsidy rate (fossil fuel subsidy per unit of energy supply) in each year between 2010 and 2019 is lower than that in 2010. A country is assumed to have increased fossil fuel prices if weighted average, tax inclusive fossil fuel prices are higher in 2019 compared to that in 2010. There might be more countries where subsidy removal and fuel price rise might have occurred but are absent here due to lack of data.

2.1 Carbon Tax

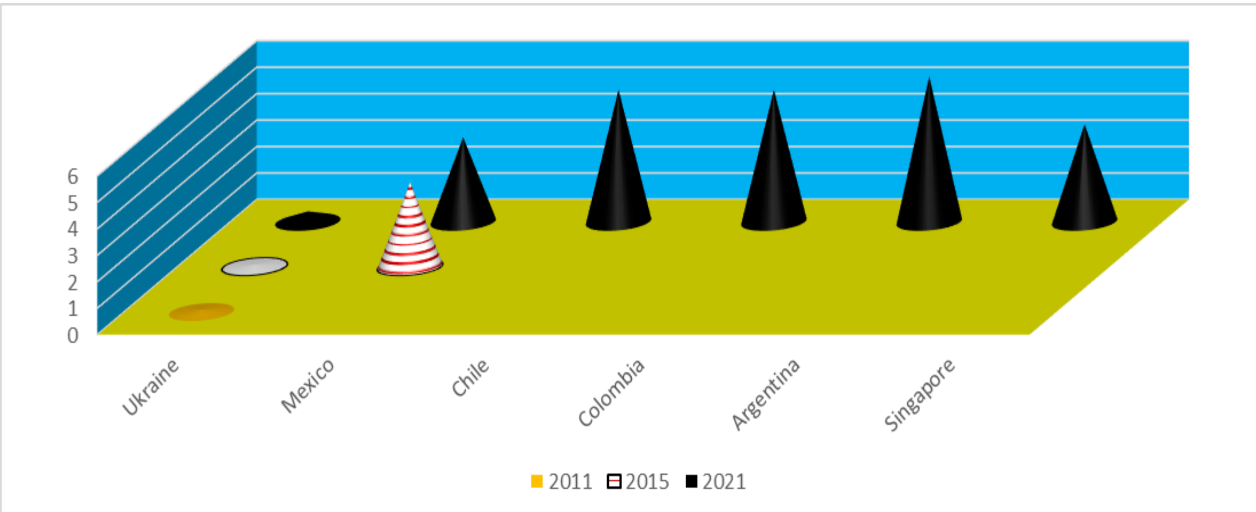
Figure 1a and 1b presents carbon taxes introduced at national and sub-national levels, respectively. Countries from the Nordic region (Denmark, Finland, Norway, and Sweden) and Poland have implemented carbon taxes in the early 1990s. Some Latin American countries (Chile, Colombia, and Argentina), Canada, Singapore, Luxembourg, and Netherlands have implemented carbon taxes in recent years, after Paris Agreement. In recent years, several countries have increased their carbon tax rates and adopted more ambitious trajectories showing their commitment to PBMs. For example, Latvia, Canada, and Ireland, have increased their carbon taxes dramatically in recent years. Between 2019 and 2021, carbon tax rate increased by three-folds in Latvia and doubled in Canada and Ireland (see Table 2a).

Despite the increasing interest on carbon taxes globally, only a few countries have carbon taxes higher than USD 50/tCO2e in 2021, a minimum price that is suggested to meet the goals of Paris Agreement. They are Sweden (USD 137.2/tCO2e), Liechtenstein (USD 101.5/tCO2e), Switzerland (USD 101.5/tCO2e), Finland (USD 72.8/tCO2e), Norway (USD 69.3/tCO2e) and France (USD 52.4/tCO2e). These six countries combined cover only 0.6% of the global GHG emissions. Likewise, at the subnational level, the Mexican state of Tamaulipas recently passed legislation enacting a carbon tax starting in 2021, an equivalent to USD 12.23/tCO2e to fixed sources and facilities that emit more than 25 tCO2e of emissions monthly.

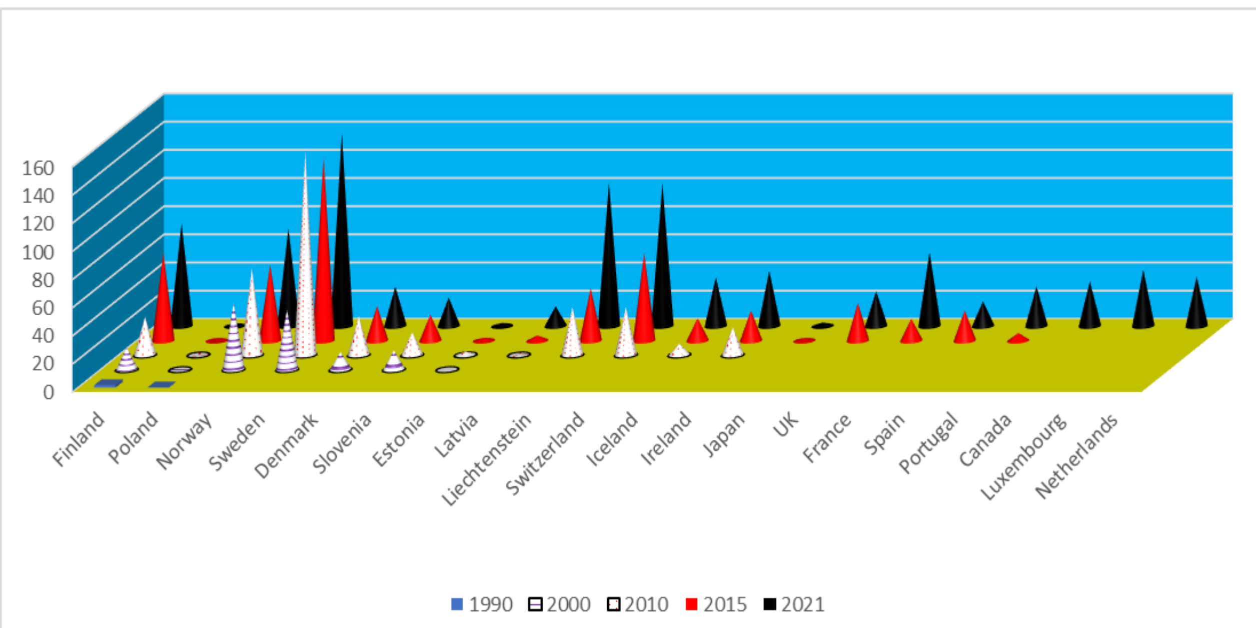
One attractive feature of carbon taxes is that they generate revenues that can be used for other GHG emissions mitigation or adaptation and lessen other social concerns such as softening distributional impacts and supporting poverty alleviation. In 2020, carbon taxes globally generated about half of the total revenue (USD 53 billion) generated by all carbon pricing instruments (World Bank, 2021). In 2020, the top six countries that have carbon taxes higher than USD 50/tCO2e have combined generated about two-thirds of the total carbon taxes revenue (USD 26 billion). Among these six countries, France alone generated about 40% (USD 9.6 billion) of the total national level revenues from carbon taxes in 2020.

Figure 1: Carbon taxes implemented at national and subnational levels (USD/tCO2e)

(a) Developing countries (including Non-OECD high income countries as relevant)



b) Developed countries (including all EU member states) -- National level



Source: World Bank (2021)

2.2 ETS

A wide range of countries and subnational governments continue to move toward carbon pricing, in particular adopting ETSs (Table 2). For example, in the EU, allowance prices have hit all-time highs, close to USD 50/tCO2e in 2021. Prices are also increasing in countries like Canada, Germany, New Zealand and Ireland. Despite reduced economic activity because of COVID-19 pandemic, there is a significant increase by 6 percentage points in global GHG emissions covered by CPIs from 2020 to 2021, largely due to the launch of China's national ETS. China's national ETS launched in February 2021, becoming the world's largest carbon market. In 2021, Germany's national fuel ETS also came into operation, covering all fuel emissions not regulated under the EU ETS — around 40% of national GHG emissions.

As a result of the increase in allowance prices of ETSs, particularly EU ETS, revenues generated also have increased. In 2020, ETSs generated USD 26 billion in revenues globally, which is about half of the total revenues generated by all carbon pricing instruments. In 2020, almost 87% of the total revenues generated by ETS came from the regional EU ETS schemes. At the subnational level, California's ETSs generated the most revenues and at the national level, South Korea generated the highest revenues from ETSs.

Table 2: Prices in implemented ETS at national, subnational, and regional levels (USD/tCO2e)

(a) Developing economies

	2013	2014	2015	2016	2017	2018	2019	2020	2021
Beijing		.5	.2	.0	.6	.4	0.4	3.4	.3
Guangdong		0.1	.5	.3	.9	.3	.9	.1	.7
Shanghai		.4	.7	.3	.7	.2	.1	.0	.3
Shenzhen	.6	3.0	.0	.6	.5	.7	.6	.5	.1
Tianjin*		.7	.2	.2	.3	.4	.1	.8	.8
Chongqing		.0	.9	.2	.2	.8	.6	.7	.7
Hubei		.4	.2	.1	.8	.3	.1	.7	.4
Fujian					.3	.2	.5	.8	.2

The ETS in all these cities were implemented as a pilot.

(b) Developed economies

		2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021
National level ETS	New Zealand						2.4	5.4	.8	.7	.7	.9	3.0	3.5	5.2	7.5	2.5	5.8
	Switzerland							9.5	9.9	9.0	5.6	2.4	.2	.7	.9	.2	9.8	6.1
	Kazakhstan										.8	.0					.2	.2
	Rep. Korea											.1	5.1	8.1	0.5	3.5	8.8	5.9
	Canada																	1.8
	Germany																	9.4
State/Province level ETS	Alberta			3.0	4.6	1.9	4.9	5.6	5.1	4.8	3.6	1.9	5.4	4.0	3.3	2.5	2.6	1.8
	BC GGIRCA																	9.9
	Quebec										1.7	2.5	2.8	5.1	5.1	5.8	6.9	7.9
	Newfoundland & Labrador																	3.9
	Nova Scotia																	9.7

	Saskatchewan																	1.8
	New Brunswick																	1.8
	California								0.0	4.5	1.7	2.5	2.8	5.1	5.1	5.8	6.9	7.9
	Massachusetts																.3	.5
City level (*are pilots)	Tokyo								15.7	6.3	7.8	7.5	4.6	3.6	.7	.9	.7	.9
	Saitama							19.8	15.7	6.3	7.8	7.5	4.6	3.6	.7	.9	.7	.4
Regional	RGGI																0.3	.5
	EU ETS	9.0	2.2	.3	4.5	5.6	7.3	3.8	.3	.1	.8	.7	.9	.2	6.4	4.5	0.1	9.8

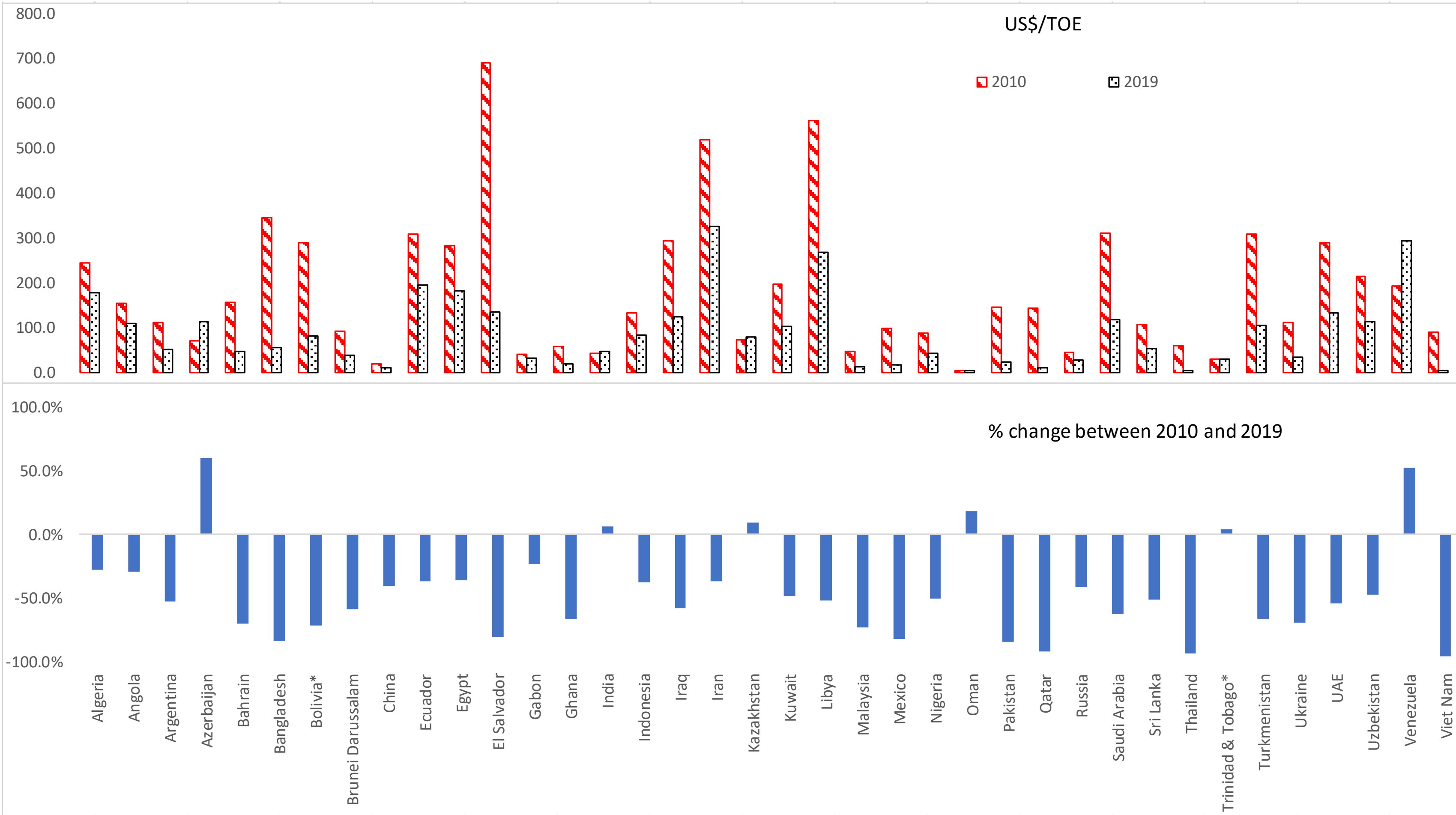
Source: World Bank (2021)

2.3 Reduction of fossil fuel subsidies and increased fossil fuel prices

The reduction or removal of fossil fuel subsidies has remained one of the key energy policy issues over the last two decades. Many countries have undergone reforms of fossil fuel subsidies. However, measuring the reduction of fossil fuels subsidies is complex. For a given period, if the absolute values of subsidies (US$) are decreasing and the amounts of fossil energy consumption are not decreasing, there would be a net reduction of fossil fuel subsidies. Even if absolute values of subsidies are increasing, they can still be decreasing if the growth of subsidies is smaller than the growth of fossil fuel consumptions. Therefore, the subsidy rate defined as subsidy values (US$) divided by fossil fuel consumption, which is measured in terms of energy unit (tons of oil equivalent or TOE) would be the right indicator to determine the reduction of fossil fuel subsidies over time. Figure 2 presents fossil fuel subsidy rates (US$/TOE) between 2010 and 2019 and also the percentage change in the subsidy rates between these two years. A country is assumed to reduce fossil fuel subsidy if its subsidy to fossil fuels per unit of energy supply decreases during the period.

Based on the data compiled by the IEA (IEA, 2022), in 2010, there were 13 countries with the highest level of fossil fuels subsidies per unit of fossil fuel consumption (> US$200/TOE): El Salvador, Libya, Iran, Bangladesh, Saudi Arabia, Turkmenistan, Ecuador, Iraq, Bolivia, UAE, Egypt, Algeria and Uzbekistan. The first three countries, El Salvador, Libya and Iran had fossil fuel subsidies exceeding US$500/TOE. By 2019, there were only three countries with fossil fuel subsidy rate exceeding US$200/TOE (Libya, Iran, Venezuela). Countries, which went through the highest reductions of fossil fuel subsidies during the 2010-2019 period are Viet Nam (95.5%), Thailand (93.6%), Qatar (92.4%), Pakistan (84.4%), Bangladesh (83.7%), Mexico (82.1%), El Salvador (80.3%), Malaysia (73.1%) and Bolivia (71.8%). Some countries, however, experienced an increase in their fossil fuel subsidy rates during the 2010-2019 period. These countries are Trinidad & Tobago, India, Kazakhstan, Oman, Venezuela, Azerbaijan, Republic of Korea and Colombia.

Figure 2. Fossil fuel subsidy rates in 2010 and 2019 (US$/TOE) and percentage change during the period (%)

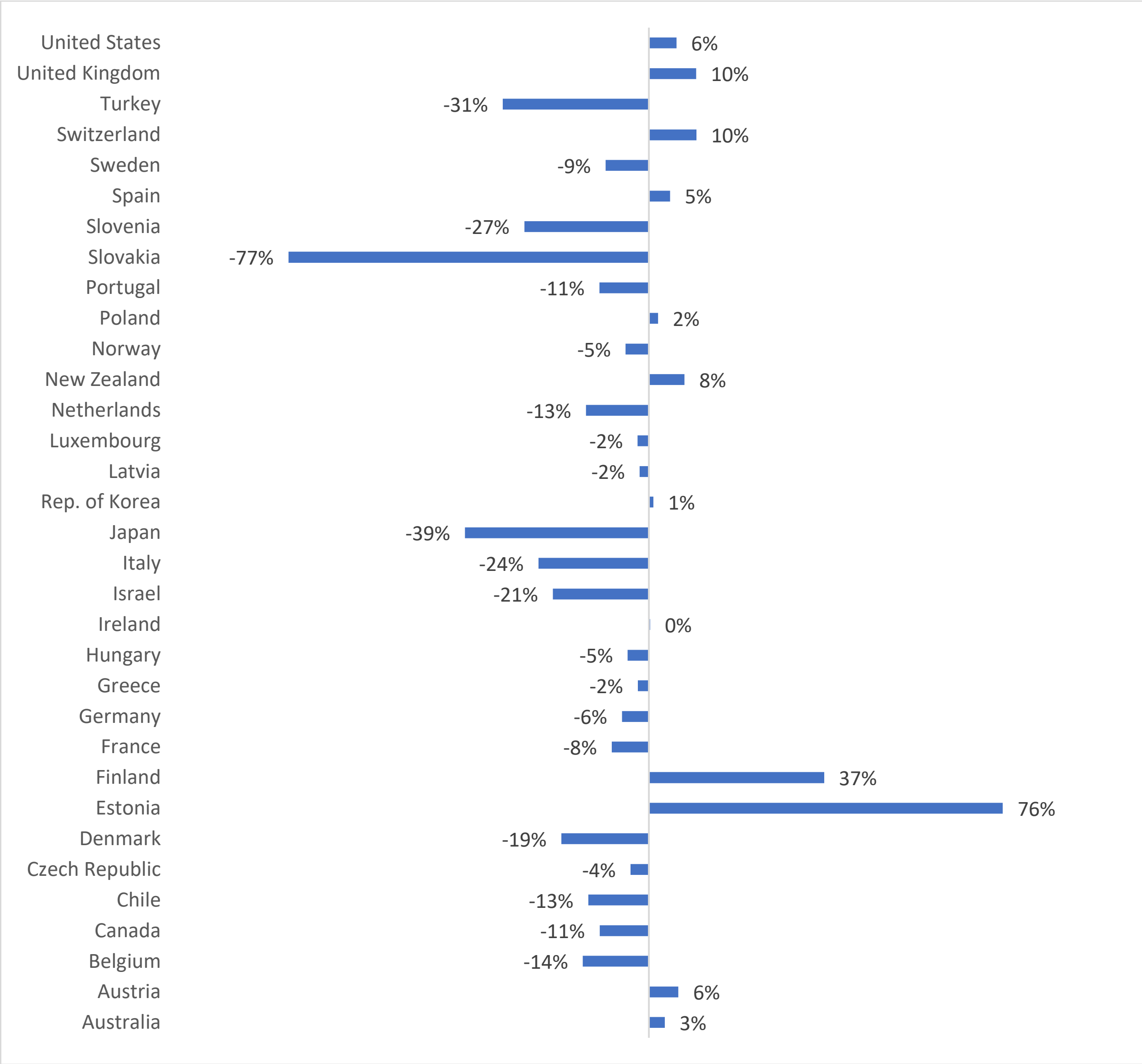


Source: Calculated based on IEA database (IEA, 2022a).

Any other taxes on fossil fuels can also be interpreted as PBM because they increase fossil fuels prices and cause their demand to drop, thereby reducing CO_2 emissions. However, since these taxes are introduced anyway for raising government revenues or for some particular purposes, such as the building of roads and bridges and their maintenance, one would argue that they do not cause additional CO_2 reduction as compared to the level they would occur anuway. Moreover, fuel prices in individual countries follow world energy prices, particularly oil prices, which are influenced by market factors (i.e., supply-demand) and non-market factors (political events, wars, and internal conflicts in energy-exporting countries). Since world oil price often takes a cyclic path, an increase in fuel tax in a year does not necessarily increase its price if its price is significantly lower than the previous year. Moreover, getting fuel taxes and price information for developing countries is challenging. While fossil fuel prices and taxes information is available from IEA for selected developed countries, no such information is available for most developing countries. Nevertheless, Figure 3 presents the change in weighted average fossil fuel prices during the 2010-2019 period in countries for which data are available.

If the weighted average prices of fossil fuels (including taxes) in 2019 are compared to those in 2010, mixed results are found. Some countries, such as Australia, Austria, Estonia, Finland, Republic of Korea, New Zealand, Poland, Spain, United Kingdom and United States experienced an increase in weighted average fossil fuel price. The rest of the countries experience a decline. Several factors might have influenced the trends. The mix of fossil fuels are different across countries. The weighted average price would be significantly different if the mix is different even if prices of individual fuels are the same or close. The number of fossil fuels taxes and their rates are different across the countries. The tax types and rates also vary across sectors in a given country. Moreover, the change presented here is between the year 2019 and 2010. The weighted average prices have cyclic trends during the period, meaning that the weighted average prices in the years between 2010 and 2019 could be higher or lower than those in these terminal years.

Figure 3. Changes in weighted average prices of fossil fuels between 2010 and 2019 (%)



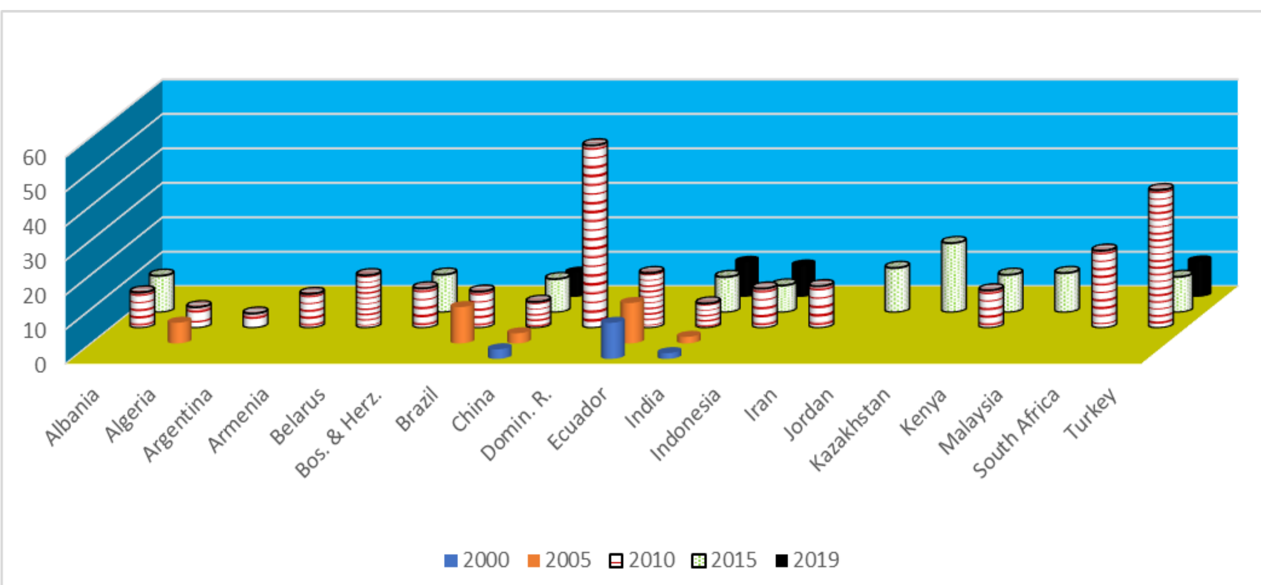
Source: Calculated based on IEA data (IEA, 2022b)

2.4 Renewable energy subsidies

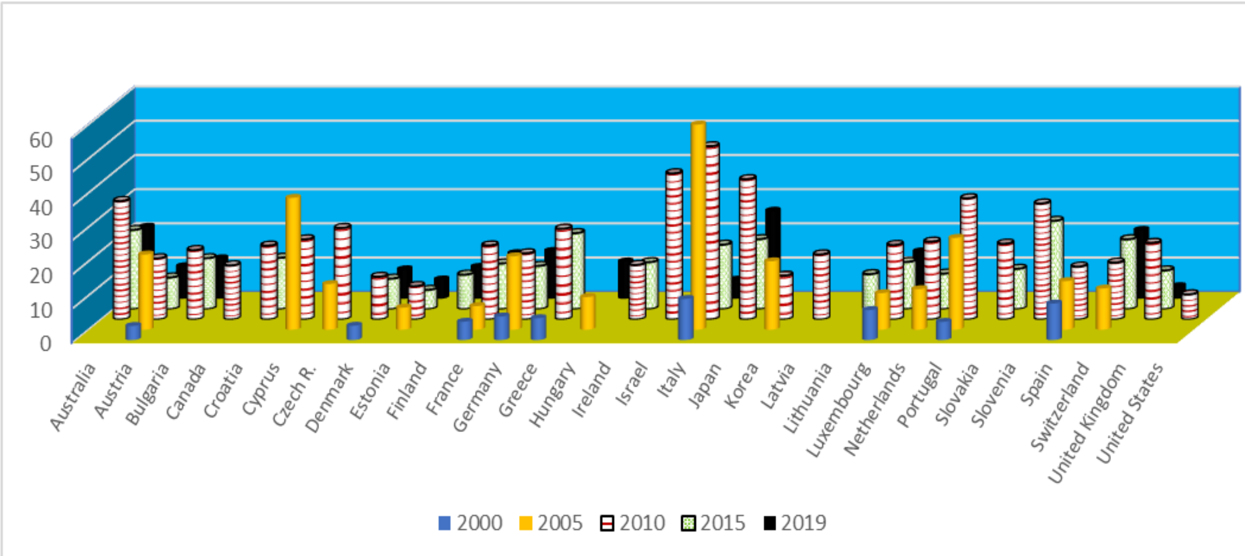
Feed-in-Tariff (FiT) is the main PBM to reduce GHG by substituting fossil fuels with renewable energy. Use of FiTs started in the late 1990s. Not only developed economies but also many developing economies have introduced FiT to promote renewable energy. More than 100 economies have introduced FiT to date (REN, 2021). The rates of FiT are different across (a) countries and (b) types of renewable energy technologies (e.g., solar PV, solar thermal, onshore wind, off-shore wind, small hydro, geothermal). Figure 4 presents average FiT rates (simple average across the renewable technologies) in different countries, for which data are available, in different years. The larger developing economies, such as Brazil, China and India introduced FiT before 2005. Others joined later. By 2010, most developing economies which have FiT today had already introduced FiT. The majority of the developing countries that have introduced FiT have rates below 15 US Cents per kWh throughout the period since they introduced it. In the case of developed economies, most of them introduced FiT by 2005. Their FiT rates are relatively higher as compared to that of developing economies, more than 20 US Cents per kWh. Since the costs of renewable energy technologies are declining and they are displaying more and more cost competitiveness with conventional sources of energy, FiT rates are declining in recent years.

Figure 4. Feed-in-Tariff for renewables in selected countries (US Cents/kWh)

(a) Average FiT for renewables in developing countries including high-income countries (US Cents/kWh)



b) Average feed-in-tariff for renewables in developed countries, including EU member states (US Cents/kWh)



Source: OECD (2022)

3. Empirical Evidence PBM Effectiveness on Reducing GHG Emissions

As discussed in the preceding section some forms of PBMs are in place in most of the countries around the world, and for many years in some countries. The question here is – have these PBMs actually reduced GHG emissions? This question is critical because PBMs in theory are expected to reduce emissions. However, the realities where the PBMs have been implemented are not necessarily the same as assumed in theory. The only way to answer this question is ex-post assessment of PBMs getting data from the field. In this section, we present results from empirical studies, that examine the contribution of PBMs in reducing GHG emissions in various economies or groups of economies, economic sectors and production firms. The evidence are presented by type of PBMs – carbon tax, ETS, FiT, subsidy removals and fuel taxation.

3.1 Effectiveness of carbon pricing

Several studies examine the effectiveness of a carbon pricing including carbon tax and cap-and-trade to reduce CO_2 emissions.

Best et al. (2020) estimate the effectiveness of carbon pricing at reducing national CO_2 emissions using panel data from 142 countries over a period of two decades. They find that the average annual growth rate of CO_2 emissions has been around 2 percentage points lower in countries with a carbon pricing system compared to countries without. They estimate that an additional euro per ton of CO_2 in carbon price is associated with a reduction in the subsequent annual emissions growth rate of approximately 0.3 percentage points, all else equal. Aydin and Ömer (2018) examine the relationship between environmental taxes and CO_2 emissions using data from 15 EU member states for the 1995–2013 period. They find that the carbon taxes in EU countries have reduced EU emissions by 2.2% during the study period (1995-2013).

Green (2021) presents a meta-review of empirical studies published since 1990 on the impacts carbon pricing on CO_2 emissions. It finds that the majority of studies show CO_2 emissions reductions in the range of 0% and 2% per year. Although he interprets these impacts to be disappointingly modest, in actuality the policies seem to be doing what they were designed to do. For example, the finding that the EU-ETS caused 0% to 1.5% CO_2 reduction per year is in line with annual cap reductions defined by the ETS, as well as limited coverage of sectors. Similarly, the levels of carbon taxes in practice have not been enough to cause a large or sudden reductions of CO_2 emissions. However, steady progress can accumulate over time.

3.2 Effectiveness of carbon tax on reducing CO_2 emissions

Several studies investigate the effectiveness of a carbon tax on emission reductions. Examples are presented in Table 3. The carbon tax in the Canadian province of British Colombia, perhaps, is most studied one. British Columbia introduced a carbon tax in 2008 with the rate of CN\$10/tCO_2. It increased by CN\$5/tCO_2 each year and reached CN30/tCO_2 by 2012 (Beck et al. 2015). By 2020, the rate of British Colombia carbon tax stands at CN\$40/tCO_2[7]. Murray and Rivers (2015) reviews many studies that investigate the impacts of British Colombia's carbon tax and reports that the carbon tax reduced provincial CO_2 emissions by 5–15% during the 2008-2012 period. Using a static, multi-sector, multi-region, multi-household CGE model of the Canadian economy, Beck et al. (2015) finds that the CN\$30/tCO_2 carbon tax reduced 9.22% when tax

[7] https://www.bennettjones.com/Blogs-Section/BC-Carbon-Tax-Increase-Delayed-Further-Due-to-COVID-19

revenues are not recycled. If the tax revenue is recycled to households; the percentage reduction drops slightly to 9.14% due to the rebound effect. Comparing with other provinces for the same period (2008-2012), Elgie and McClay (2013) observe that British Columbia reduced its CO_2 emissions through the carbon tax introduced in 2008. Contrary to these studies, Bumpus (2015) finds that firms in British Colombia experience difficulty in switching to low-carbon fuels and suggests complementary policies for climate change mitigation.

Employing a quasi-experiment technique in Sweden to investigate the impacts of a carbon tax on CO_2 emissions and study, Andersson (2019) find a significant causal effect of carbon taxes on emissions. For example, the carbon tax alone reduced transport sector CO_2 emissions by 11% percent relative to a synthetic control unit constructed from a comparable group of OECD countries. It also shows that the carbon tax elasticity of demand for gasoline is three times larger than the price elasticity. This finding is, however in sharp contrast with those in Lin and Li (2011), who analyze CO_2 intensity in Scandinavian countries where the carbon tax has been introduced since the early 1990s using a difference-in-difference (DID) study design. While the carbon tax is playing a significant role in reducing CO_2 emissions in Finland, the impacts of carbon taxes are not significant in the remaining three countries (Denmark, Norway and Sweden). Floros and Vlachou (2008) examine the response of manufacturing industries (two-digit level of international standards for industrial classification) to a carbon tax in Greece by employing the two-stage Translog cost function to time series data during the 1982–1998 period. They find that the carbon tax reduces CO_2 emissions in manufacturing industries in Greece, in part by reducing demand and in part by causing substitution of petroleum fuels with electricity and substitution of energy with capital. Martin et al. (2014) finds a strong negative impact of a carbon tax on energy intensity and electricity use in manufacturing firms in the UK. Aghion et el. (2016) investigate, using patent data from 3,412 automobile firms and individuals between 1965 and 2005 across 80 patent offices, the mechanism through which a carbon tax helps reduce CO_2 emissions in the long run. They find that clean innovation is stimulated by increases in fuel prices whereas dirty innovation is depressed. They also show strong path dependency, which locks economies into high levels of carbon emissions, even after the introduction of a mild carbon tax or R&D subsidies for clean technologies. Hájek et al. (2019) investigate the CO_2 mitigation effects of carbon tax pulling together data from Sweden, Finland, Denmark, Ireland and Slovenia. They find that if the carbon tax rate is raised by 1€/tCO_2, it reduces per capita GHG emissions by 11.58 kg.

Table 3. Examples of studies on the effectiveness of carbon tax in reducing CO_2 emissions

Study	Methodology	Key findings
Andersson (2019) Sweden's carbon tax introduced in 1991 on transport sector CO_2 emissions	Quasi-experimental techniques using DiD and synthetic control on 30 years (1960-1990) of pretreatment data and 16 years (1991-2005) of posttreatment data from 30 OECD countries	11 percent reduction of transport sector CO_2 emissions relative to a synthetic control unit constructed from a comparable group of OECD countries. The carbon tax elasticity of demand for gasoline is three times larger than the price elasticity
Hájek et al. (2019) Selected EU countries	Regression model applied on pooled data from Sweden, Finland, Denmark, Ireland and Slovenia.	An increase in carbon tax rate by 1€/tCO_2 reduces per capita GHG emissions by 11.58 kg.
Chakir et a. (2017) AFOLU emissions in France	Reduced-form, random-effect spatial error models to estimate emissions from nitrogen use, manure management, enteric fermentation during the 1990–2007 period, and land use, land-use change and forestry for the 1992–2003 period.	Significant impacts of prices on emission although the magnitudes vary across emission types; the effects are more significant when emissions are analyzed separately than aggregated; spatial dimension plays an important role on the emissions
Aghion et el. (2016)	Combination of production function and econometric models applied on patent data from 3,412 automobile firms and individuals between 1965 and 2005 across 80 patent offices	Higher fuel prices induce technical change away from dirty innovation; a firm's propensity to innovate in clean technologies is influenced by its own past history implying a path dependency on technical change; firm's direction of innovation is affected by local knowledge spillovers.
Murray and Rivers (2015) British Columbia's carbon tax introduced in 2008	Review of studies on the impacts of carbon tax on CO_2 emissions in BC, Canada	The carbon tax which was introduced at the rate of CN$10/t$CO_2$ in 2008 and increased to CN$30/t$CO_2$ in 2012 reduced emissions in the province by 5–15% from the hypothetical situation in the absence of the carbon tax
Beck et al. (2015) British Columbia's carbon tax introduced in 2008	Static, multi-sector, multi-region, multi-household CGE model of the Canadian economy	The CN$30/t$CO_2$ carbon tax reduced more the 9% of CO_2 reduction from the hypothetical situation in the absence of the carbon tax
Martin et al. (2014) Effects of climate change levy (CCL) and voluntary climate change agreement (CCA) introduced in 2001 on CO_2 emissions from manufacturing industries in UK	Different econometric techniques (39 separate regressions) applied on panel data from Annual Respondents Database (ARD) maintained by the Office for National Statistics (ONS) for 1993-2004 period	Robust evidence that the pricing instruments under CCL scheme cause a larger reduction in energy intensity and electricity use than the energy efficiency or consumption targets agreed under the CCA.

Lin and Li (2011) Effects of carbon tax on CO_2 intensities in Scandinavian countries	Difference-in-difference technique with sample panel data from 17 EU countries and Norway for 1981- 2008 period.	Carbon tax is significantly reducing CO_2 emissions in Finland, however its impacts are not significant in Denmark, Norway and Sweden
Floros and Vlachou (2008) Manufacturing sector, Greece	Two-stage translog cost function, that estimates the relationship of economic output with capital, labor and energy using time series data from 22 two-digit manufacturing sectors over the period 1982–1998	A tax of $50 per ton of carbon could reduce CO_2 emissions at the range between 11.4% and 26.5% from 1998 level with highest level of reduction in textiles, non-metallic minerals, basic metal industries and pulp and paper industries

The impacts of pricing policies on emission reductions are also conducted on emissions from sources other than fossil fuel combustion. Chakir et al. (2017) investigates the effects of input and output prices on GHG emissions from agriculture, land-use and forestry (AFOLU) sector in France. They apply structured econometric models that allow to control for both individual heterogeneity and spatial correlation (i.e., random effects model for individual heterogeneity and a spatial error model for spatial correlation) on N_2O emissions from the use of synthetic fertilizers, CH_4 emissions from enteric fermentation, N_2O and CH_4 emissions from manure management and CO_2 emissions from land-use change and forestry during the 1990-2007 period. They find that prices affect both the level and spatial distribution of emissions. The effects are more significant for individual emission categories than for aggregated emissions from AFOLU, with a stronger price effect on N_2O emissions from synthetic fertilizer use than on emissions from other agricultural sources.

3.3 Effectiveness of ETS in reducing GHG emissions

Another important type of carbon pricing is, of course, a cap-and-trade system. The best-studied cap-and-trade system is the EU Emissions Trading System, which covers a total of 31 countries (the EU plus Norway, Iceland and Liechtenstein), some 14,000 power stations and industrial installations, and about 40% of the total greenhouse gas emissions in the EU (Table 4).

Bayer and Aklin (2020) examines the CO_2 mitigation impact of EU ETS between 2008 and 2016 and finds that the program has reduced EU emissions by 3.8% between 2008 and 2016 despite the fact that carbon price rate during the period was relatively low. Based on existing empirical studies (e.g., Herold, 2007; Ellerman et al. 2010; Anderson and DiMaria, 2011) and using different level of measurements (e.g., aggregate level, sectoral level), Marin et al. (2016) reports that EU ETS has caused 2.4% to 4.7% during the first phase (2005-2007). During the second phase (2008-2009), Egenhofer et al. (2011) estimates that EU ETS reduced the overall emission intensity by 3.35%, on average. Using a panel data with all German manufacturing plants having more than 20 employees, Petrick and Wagner (2014) finds that German firms participating in EU ETS reduced their emissions by 26% compared to nonparticipating firms. Wagner et al. (2013) finds 16% reduction in CO_2 emission in French manufacturing firms participating in EU ETS program. On the other hand, Jaraitė and Di Maria (2016) show, using a panel dataset of about 5,000 Lithuanian firms between 2003 and 2010, that the change in CO_2 emissions from the firms controlled by the EUETS are not significantly different from those not controlled by EUETS.

In Japan, the Tokyo metropolitan government introduced an ETS in 2010 to provide a flexibility in achieving its 25% emission reduction in office buildings in 2020 from the 2000 level. A few studies investigate its effectiveness to reduce CO_2 emissions (Roppongi et al. 2015; Arimura and Abe, 2021). Applying three separate econometric techniques on 1200 office building samples, Arimura and Abe (2021) find that more than half (6.9%) of total CO_2 reduction (13.3%) in Tokyo's office buildings during 2010-2013 is caused by the ETS. The other half (6.4%) of reduction is caused by electricity price increase due to Fukushima nuclear disaster in 2011.

The Regional Greenhouse Gas Initiative (RGGI) introduced in 2009 in the northeastern United States is one of main ETS introduced in the U.S. to reduce power sector CO_2 emissions in the region. Some existing studies investigate the effectiveness of this scheme to reduce CO_2 emissions. Using an econometric technique on panel data, Murray and Maniloff (2015) quantify the role of a range of policy, market, and environmental factors contributing to the emissions reduction in the RGGI region. Among the several factors examined, the ETS is found to be the largest contributor to power sector emission reduction in the RGGI region. It reduced power sector CO_2 emissions by 19%, which amounted to half of the region's total CO_2 reductions from the power sector during the 2009-2012 period. The remaining reduction of 21% was found to be caused by economic recession, drop in natural gas prices and renewable portfolio standards.

Table 4. Examples of studies on the effectiveness of ETS in reducing CO_2 emissions

Study	Methodology	Key findings

Arimura and Abe (2021) Tokyo emission trading scheme introduced in 2010	Three econometric techniques on facility level data collected from 1200 office building samples in Tokyo	An ETS with implicit carbon price of US$50/t$CO_2$ reduces 6.9% CO_2 emissions during 2010-2013 period. An 13% increase in electricity price due to the 2011 Fukushima nuclear disaster caused 6.4% of CO_2 reduction.
Bayer and Aklin (2020) EU ETS for 2008-2016 period	Synthetic control econometric technique	EU ETS reduced EU emissions by 3.8% between 2008 and 2016 at a relatively low carbon (permit) price
Marin et al. (2016) EU ETS	Literature review	EU ETS has caused 2.4% to 4.7% during the first phase (2005-2007).
Jaraitė and Di Maria (2016) EUETS on Lithuania	Econometric techniques on panel data from 5000 firms between 2003 and 2010	No significant change in CO_2 emissions in firms controlled by the EUETS as compared to those not controlled by EUETS
Murray and Maniloff (2015) RGGI in Northeastern United States	Econometric techniques on panel data from 48 US states including the participants of the RGGI program	ETS reduced 19% power sector CO2 emissions during 2009-2012 period which was almost half of the total CO_2 reduction caused by various factors in the RGGI region (ETS, economic recession, drop in natural gas prices and renewable portfolio standards).

3.4 Effectiveness of FiT in reducing GHG emissions

Existing studies do not necessarily examine the direct impacts of FiT on CO_2 reduction, instead, they examine if the FiT help promote renewables. However, even if renewables are promoted, it does not guarantee that power sector emissions decrease. The reduction of CO_2 emissions depends on the size of renewables promoted and the power supply mix of a country. In a power system with pre-dominant non-fossil fuel-based generation (e.g., hydro, nuclear), increased renewables may not reduce CO_2 emissions. Existing literature does not settle if FiT promotes renewables. While earlier studies (e.g., Jenner et al., 2013) did not find a role of FiT on the development of renewables, recent studies find a strong role (Hitaj and Löschel, 2019; Dijkgraaf et al., 2018). Based on the observations from the fields one could argue that FiT might have worked earlier when renewables were expensive as FiT incentivized and attracted the investors. However, as the cost of renewables started to significantly drop and even became cheaper on levelized costs of electricity generation (Timilsina, 2022), countries started to reduce FiT if not completely eliminated it.

Table 5 presents a few examples of studies examining the climate change mitigation impacts of FiT. Jenner et al. (2013) investigates the effectiveness of FiT to promote solar PV and onshore wind in 26 EU member states during the 1992–2008 period. They develop an indicator capturing level of FiT, variability in tariff size, contract duration, digression rate and electricity price and production cost, and regress this indicator on added renewable capacity using a fixed effects specification. They do not find a robust influence of FiT on wind power development, instead they show that the interaction of policy design, electricity price and electricity production cost influences more on the development of renewables than the FiT policy design alone.

Hitaj and Löschel (2019) investigates the impacts of FiT on the expansion of wind power in Germany over time and across the space using an econometric technique on panel data for 1996–2010 period. They find a significantly positive effect of FiT on wind power development in the country. They find that one cent Euro increase in the initial FIT rate would cause an addition of 765 MW wind power capacity, on average, annually during 1996–2010 and 1055 MW during 2000–2010. They also find that the reduction of CO_2 and local air pollutants due to wind power specific FIT would be 4% greater than the equivalent uniform FiT for all renewables.

Dijkgraaf et al. (2018) analyzes the impact of FIT policies in developing solar PV in OECD countries during the 1990–2011 period. Using panel data from 30 OECD countries, it finds a relationship stronger than reported in the earlier literature, between the FiT and expansion of solar PV capacity. It finds that a FIT can increase, on average, 5.5 Wp per capita installed capacity of solar PV. The maximum effect, which is 7 times higher than the average effect, occur when FiT rate is high and contract duration is long. Consistency is especially important when tariffs are low. If the FiT policy is overlapped with other pricing policies, such as ETS, the effects of FiT decrease. The study also reports that the FiT policies do not have significant impacts on CO_2 emissions. This is not surprising though because the share of solar in OECD is still too small to make any significant substitution of fossil fuel-based electricity generation.

Table 5. Examples of studies on the effectiveness of FiT in reducing CO_2 emissions

Study	Methodology	Key findings
Du and Takeuchi (2020)	Spatial regression discontinuity design on panel data from 71 counties of Inner Mongolia, Shanxi, and	Regional differentiation of FiT mitigates the uneven regional distribution of wind power and

Differential impacts of FiT spatial allocation of renewable production	Shaanxi for 2009 - 2016 period	solar power generation, and also reduce the overproduction in resource rich provinces
Hitaj and Löschel (2019) Impacts on wind power in Germany	Regression analysis on the relationship between the FiT level and wind-power capacity addition using panel data for the 1996–2010 period	One cent Euro increase in FIT causes 765 – 1055 MW wind power capacity addition; Wind power specific FIT would cause higher reduction of CO_2 than the equivalent uniform FiT for all renewables
Dijkgraaf et al. (2018) Impacts on the development of solar PV in OECD countries	Panel data estimations are employed for 30 OECD member countries in the period 1990–2011.	A positive effect, stronger than reported in the literature, on per capita solar PV capacity addition. No significant effect on CO_2 emissions.
Jenner et al. (2013) Impacts on renewables in 26 EU member states	Fixed effect regression on panel data for the 1992–2008 period	No robust evidence that FiT promotes renewables

Du and Takeuchi (2020) analyze the effectiveness of regionally differentiated FiT for the development of renewable energy in China. Using spatial regression discontinuity design on panel data from 71 counties of Inner Mongolia, Shanxi, and Shaanxi for 2009 - 2016 period, they regress regionally differentiated FITs and indicators of wind and solar power generation, such as utilization rate, installed capacity, power generation, and hours of operation. They find that the regional differentiation of FiT mitigates the uneven regional distribution of both the wind power and solar power industries in China. It also reduces the overproduction in wind-rich yet remote regions, by improving the utilization rate of wind turbines in resource-poor regions.

3.5 Fossil fuel subsidy removals, fossil fuel price changes and GHG reduction

Removal of a fossil fuel subsidy is equivalent to adding a new tax or increasing an existing tax on it. Like any other taxes due on fuels, removal of subsidies on fossil fuels increases the price of fuels. Depending on the price elasticity, fuel demand decreases, and associated emissions drop. There are several modeling studies estimating the size of emission reduction due to removal of fossil fuel subsidies under different scenarios. However, we are not looking for ex-ante economic modeling results which might be influenced by model assumptions and parameter values. Instead, we are looking for evidence reported by ex-post empirical studies based on observed data. Unfortunately, empirical studies that examine the relationship between removal of fossil fuel subsidies and reduction of GHG emissions are rare.

Since there is a direct relationship between fossil fuel combustion and CO_2 emissions, reduction in fossil fuel demands caused by any tax, such as fuel tax or gasoline tax also reduces CO_2 emissions. However, since these taxes are introduced for other purposes, particularly to generate government revenues and they are implemented anyway, they may not be interpreted as carbon taxes. Yet, one could argue that some countries impose higher taxes on fuels than others, which cause lower their GHG emissions. The CO_2 emission effect of fuel taxes depend on their price elasticities. Figure 2 in the next section present price elasticities of gasoline and diesel in several countries. As can be seen in these figures, countries such as Republic of Korea, Austria, Oman, Bahrain, Guatemala, Canada have price elasticity of gasoline, in absolute value[8], higher than 0.5. Gasoline is more price elastic in these countries. Whereas the absolute values of price elasticities of gasoline are lower than 0.1in Bangladesh, Cote d'Ivoire, Iraq, Kuwait, Libya, Saudi Arabia, Qatar, Argentina and Colombia. In these countries, gasoline is less price elastic. A gasoline tax reduces higher level of CO_2 emissions in countries where gasoline demand is more price elastic than in countries where gasoline demand is less price elastic. The same interpretation is applicable to other fuels.

3.6 Insights from other approaches

The results from the empirical studies have helped us understand the role of PBMs in reducing GHG emissions. The findings are critical because most existing studies have employed modeling techniques to estimate the GHG mitigation impacts of PBMs, and findings from these modeling studies are sensitive to elasticity parameters which are rather assumed than rigorously estimated. There were some doubts about whether PBMs cause GHG reductions in the real world. The findings of the empirical studies presented here reveal that in general, they do. However, the level or rate of GHG mitigation of PBMs significantly varies across countries depending on the energy supply mix that allows cheaper substitution of fossil fuels with renewables. It also depends on the economics and technical flexibilities of substituting fossil fuel-driven technologies with electricity in the demand side. Some sectors, such as power sector, offer better substitution possibilities between fossil and non-fossil fuel technologies. Even within fossil fuel-based power generation, better substitution possibilities occur between more carbon-intensive technologies

[8] Note that price elasticities of fuels are negative.

(e.g., coal-based generation) and less carbon-intensive technologies (e.g., natural gas-fired technologies). On the other hand, the transportation sector does not offer much room for fuel substitution in the short-run and therefore role of PBM is limited to reducing GHG emissions.

The mixed evidence offered by the empirical studies on the impacts of pricing policies on GHG reduction contradicts with theoretical and numerical studies and results from macroeconomic simulation models, such as CGE models. The latter demonstrates that PBMs are most efficient instruments for reducing GHG emissions.[9] There are many reasons for the disagreement between theoretical/numerical/modeling studies and empirical evidence. Some of them are as follows:

- Theoretical, numerical and modeling studies make several assumptions to simplify the real complex situations, such as perfectly efficient markets. The real situation is much different as the market is distorted. While the predictions of theoretical/numerical/simulation models are indicatively correct or at least correct in terms of the direction of effects, they are not necessarily precise in the magnitude of the impact.
- The numerical and simulation models use many parameters, such as price elasticity of demand, the elasticity of substitution, and total factor productivity. The values of these parameters are rather taken from 'literature' instead of estimating them from the fields (countries, sectors, fuels) where the studies are intended. The results from the models are sensitive to the values of the parameters. The discussion presented in Section 4.3 also highlights this fact.
- The PBMs so far introduced in countries are not pure as guided by a theory; instead, they are highly distorted. For example, economic theory suggests that a carbon tax should be universally homogenous for its effective performance. In practice, a carbon tax is highly distorted because many sectors and fuels are exempted from it for political or social reasons. Existing empirical studies use the data from these distorted practices. Their results might have been influenced by the distortions.
- The estimation techniques, data, or methods used in the empirical studies are not necessarily the robust ones as these techniques are evolving and improving. The results of

[9] Please see Timilsina (2022) or Timilsina (2018) for a synthesis of theretical, numerical and modeling studies on the impacts of carbon tax on CO_2 emissions.

the studies might have been influenced by the limitations of the methodologies employed in the empirical studies. More empirical studies are needed with quality data and improved methodologies.

4. Challenges and Barriers to PBMs

PBMs face several barriers to their introduction and successful implementation. These barriers include political, social, institutional and technical barriers. In this section, we briefly discuss key barriers and also indicate, where appropriate, how the RBCF help address these barriers. The next section presents more details on the potential role of RBCF to implement PBMs.

4.1 Public perceptions about PBMs

The general public perceives pricing-instruments as a driver to increase fuel prices. Moreover, they argue that carbon prices are not effective to curtail GHG emissions citing the examples of price inelasticity of gasoline or other fossil fuels. Some studies investigate why people are reluctant to accept pricing instruments for climate change mitigation (see e.g., Murray and Rivers, 2015; Gevrek and Uyduranoglu, 2015; Bumpus, 2015 and Lo et al. 2013). Using polling data, Murray and Rivers (2015) show that the majority of the public was opposed when the carbon tax was introduced in British Columbia, Canada for the first time in 2008, but that three years post-implementation, the public generally supported the carbon tax. Gevrek and Uyduranoglu (2015) conduct a choice experiment in Turkey to assess public preference to carbon tax and show that Turkish people prefer a carbon tax if it is designed with a progressive cost distribution instead of regressive cost distribution.

Baranzini and Carattini (2017) assess public acceptability of carbon taxes in Geneva, Switzerland using survey data and find that individuals are more concerned by the environmental effectiveness of the tax than its economic costs. They find that people are interested in receiving more local environmental benefits from a carbon tax. They do not worry about the competitiveness issues but express concerns on its distributional effects. The study concludes that effective communications, particularly explaining to the people of the primary and ancillary benefits of carbon taxes are essential for improving their acceptability. Although the findings look intuitive, they cannot be generalized because the level of environmental awareness of the Swiss population is much higher than that in many developing countries.

4.2 Political economy

Politicians are often reluctant to PBMs for climate change mitigation for several reasons. First, political parties in the incumbent governments are sensitive to voters' sentiments. Voters do not like fuel price hike for the obvious reason. Second, a unilateral carbon pricing could compromise competitiveness of emission-intensive trade exposed (EITE) goods. Industries producing EITE goods, therefore, do not favor price-based instruments for climate change mitigation unless there exist a mechanism to compensate them.

Political violence erupted in many countries due to fuel price rise (Table 6). The price rise was caused due to removal of existing subsidy or increased world oil price or increased existing fuel tax for any other reason. The latest violence was noted in Kazakhstan where an increase in CNG (compressed natural gas) price, one of the main fuels used in vehicles, ignited demonstration in the country's largest city Almaty on January 2, 2022. The protesters burned the city hall, stormed and briefly seized the airport, and sporadic gunfire was reported in the city streets. The demonstration spread throughout the country and took a political color. It resulted deaths of 164 people. A state of emergency was declared and military help was requested from Russia to curb the demonstration. It was the worst unrest in the country since it became independent 30 years ago. To address the unrest, the president dissolved the cabinet and removed the head of the National Security Council, Nursultan Nazarbayev, who served as the president of Kazakhstan for 30 years. The government set a 180-day price cap on vehicle fuels and a moratorium on utility rate increases.[10]

In October 2019, the Ecuadorian government removed gasoline and diesel subsidies to satisfy a condition set for the International Monetary Fund loan to address its worsening financial situation. The removal of subsidy caused the diesel price to almost double and gasoline price to increase by 25%. It triggered violent demonstrations for 12 days. Protesters shut down streets and set fire in buildings. The president declared a state of emergency and moved out the government of the capital. Seven people were reported dead. To contain the protest, the government retracted the removal of fuel subsidies.[11]

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[10] AP News dated January 10, 2022. https://apnews.com/article/kazakhstan-europe-national-security-terrorism-2c026ecb00584aba668f320d4482d0f1

[11] Reuters October 14, 2019. https://www.reuters.com/article/us-ecuador-protests/ecuadors-moreno-scraps-fuel-subsidy-cuts-in-big-win-for-indigenous-groups-idUSKBN1WT265

Table 6. Examples of Major Recent Demonstrations and Political Unrests caused by Fuel Price Increase

Country	Cause	Incidence	Result
Kazakhstan, 2022	Increased prices of vehicle fuels	Huge demonstrations all over the country which got stretched to worst political unrest in the country since its independence	Government collapsed, more than 160 people died, fuel prices were capped for 180 days
Ecuador, 2019	Removal of fuel subsidies	Violent demonstrations for 12 days. Protesters shut down streets and set fire in buildings.	The government withdrew removal of fuel subsidies
France, 2018	Increased price of oil and petroleum products	The Yellow-vest movement started in France and spread many places in Europe; it attracted world-wide attention	The new proposal on carbon tax was withdrawn
Haiti, 2018	Removal of fuel subsidies on petroleum	Violent demonstration erupted in July when the government increased prices of petrol by 38%, diesel by 47% and kerosene by 51 %	The price hike was withdrawn within 24 hours of the announcement to increase
Mexico, 2017	Removal of subsidies on petroleum	Violent protests as the government reduce fuel subsidies that cause increase of petroleum prices	Government did not back down, instead managed to explain the removal of fuel subsidies.

In July 2018, violent demonstration erupted in Haiti when the government announced to increase the prices of petrol by 38%, diesel by 47% and kerosene by 51%. The price hike was a part of an agreement with the International Monetary Fund to get $96 million financial support for economic recovery of the country. Protestors erected flaming roadblocks, attacked hotels and businesses. The demonstration led to deaths of at least three people. The U.S. Embassy in Haiti advised U.S. nationals in the country to shelter in place and the U.S. airlines cancelled flights to the capital Port-au-Prince. As a result, the Prime Minister, Mr. Jack Guy Lafontant resigned, the government backed down the price increase.[12]

The Yellow-vest movement started in France in 2018, appears as an icon to use the protest fuel price rise as a symbolic protest for, according to the protesters, broader social injustice. The movement started in mid-November 2018 to protest rising crude oil and other petroleum products prices and turned into a mass movement participated in by millions and spread over Europe. They use yellow vests because they are more visible, even in the dark, and mandated by the French law for all drivers to wear during emergency situations. The vest is also considered as a symbol of

[12] Associate Press, July 7, 2018. https://www.voanews.com/a/protests-violent-haiti-gas-price-hike/4471810.html

working-class population. The protests involved demonstrations by blocking of roads and fuel depots and in some cases developed into major riots. One of the reasons for an increased petroleum price was a carbon tax on gasoline proposed in France. Due to the persistent protests and escalated violence, the carbon tax policy was backtracked, which was a big setback for carbon pricing (Mehleb et al. 2021).

On the New Year's Day of 2017, violent protests broke throughout Mexico with the supports of political parties, labor unions and other groups against government's decision to reduce fuel subsidies that resulted increase fuel prices. The protestors mounted sit-ins, roadblocks and hindered the state oil company Pemex's ability to distribute fuel to some parts of Mexico. Looters seized the opportunity to strike in hundreds of stores. Security forces were mobilized resulting in four deaths and hundreds of arrests. However, the government did not back down, instead explained why it was necessary to reduce the fuel subsidy.[13]

The above-mentioned incidents are only examples. There are many more in different parts of the world (e.g., India, Indonesia, Nigeria and the UK). The incidents or demonstrations that occurred in many countries indicate that fuel price increase serves as a flash point to ignite demonstrations. The general public participates in such demonstrations not only due to the fear of burden caused by the fuel price hikes but also to express their grievances and dissatisfaction to the incumbent government. Naturally, opposition political parties or groups often use these incidents as opportunities for their political benefits. It is interesting to note that sometimes demonstrators are those who are not directly impacted by the fuel price hikes. For example, gasoline is not used by students or low-income households, however, these groups of people also come to protest when gasoline price is increased.

The concern of losing competitiveness of EITE industries arises when the carbon pricing is unilateral meaning that a single or group of economies implement carbon pricing, whereas others producing competing goods do not. Several studies have highlighted this issue or provided analytical evidence (see e.g., Timilsina, 2021; Aldy and Pizer 2015; Coxhead et al. 2014). Several approaches have been suggested in the literature to address this issue. The most common is the 'border carbon adjustment' or 'BCA', which suggest applying domestic carbon prices to imports

[13] Insider, January 5, 2017. https://www.businessinsider.com/enrique-pena-nieto-response-mexico-gas-price-protests-gasolinazo-2017-1

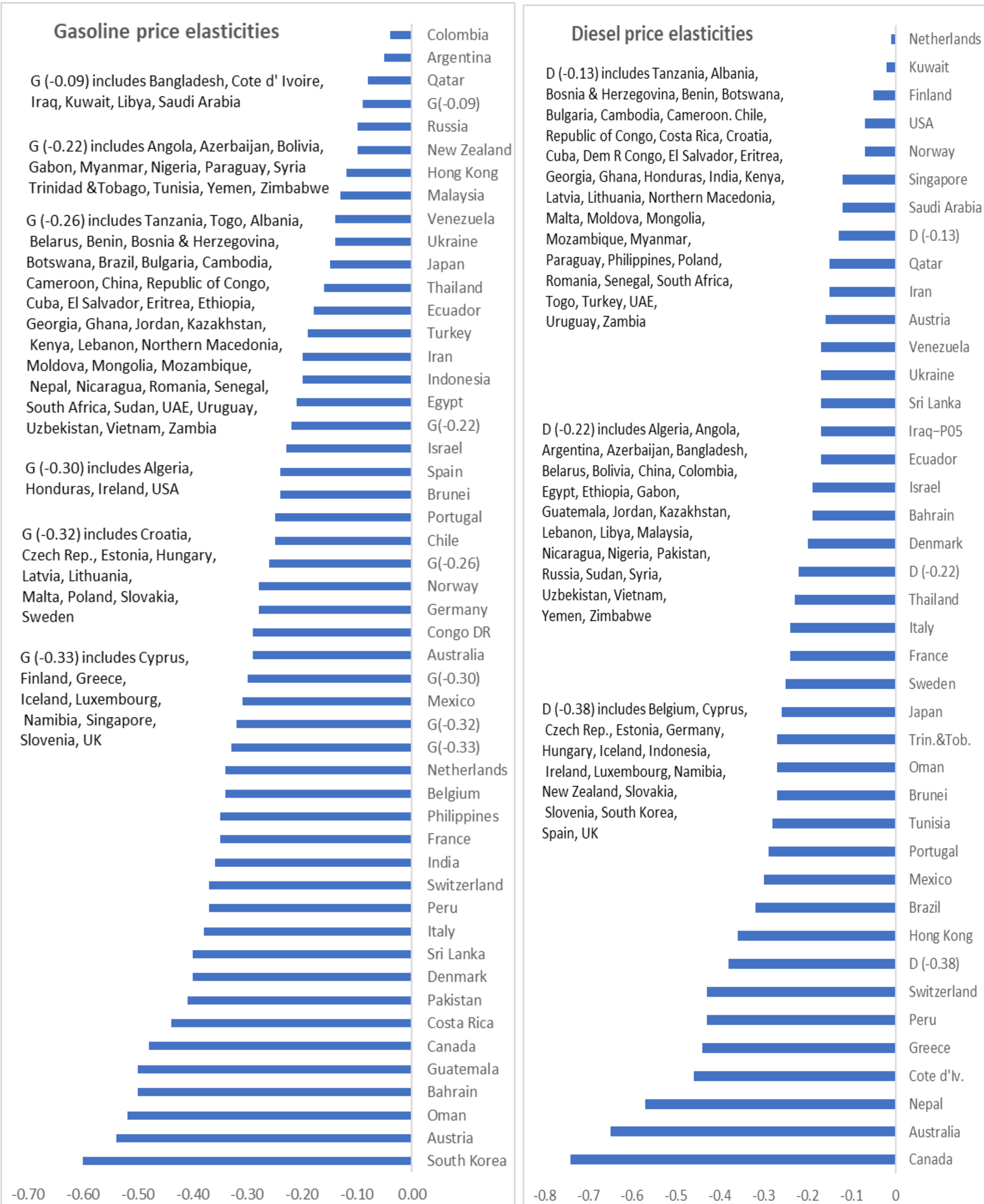
from countries without carbon pricing based on carbon intensity of the imported goods (Cosbey et al. 2019). Now, the EU has formally announced to introduce the BTA. The other approach is to subsidize EITE goods through various mechanisms, such as general cuts in their payroll, corporate income taxes, and output-based rebating (Bohringer et al. 2017; Metcalf, 2014).

4.3 Less optimistic efficacies of pricing-based instruments

Price-based instruments reduce GHG through the demand responsiveness of a fuel to its price increase. Most PBMs are aimed to increase prices of fossil fuels relative to zero-carbon fuels. High carbon content fuels, such as coal and petroleum products, face higher increase in their prices compared to lower carbon content fuels, such as natural gas. The price of electricity also increases depending upon the share of fossil fuel-based generation in the total electricity generation. Therefore, the strength or efficacy of a price-based instrument, except in the case of FiT, depends on the degree of responsiveness of fossil fuel demands to their price change or their price elasticities. A wide range of estimates are available for fossil fuel price elasticities. Dahl (2012) presents price and income elasticities of gasoline and diesel demand for 124 countries (Figure 5). The study finds that price elasticities of gasoline and diesel are low, especially in the short run. Almost 95% of the countries considered have price elasticities of gasoline lower than -0.4. Almost 70% of the countries have price elasticities of gasoline lower than -0.3. Similarly, almost 80% of the countries have diesel price elasticity is lower than -0.3.

Many ex-ante or modeling studies use price elasticities of fuel from the literature to estimate CO_2 emission impacts of a PBMs. The robustness of their estimations depends on the value of elasticities they use and the sensitivity analysis they conducted. The low value of elasticities discussed above cast doubts on the efficacies of price-based mechanisms, particularly carbon tax, to reduce CO_2 emissions, particularly in the transport sector, one of the main sources of CO_2 emissions, where substitution of fossil fuels with zero-carbon fuels is limited. In the case of ETS, the cap is already set, therefore, emission reduction is expected to be achieved as long as the emission baseline is properly set and emission reduction is credibly verified.

Figure 5. Price elasticities of gasoline and diesel

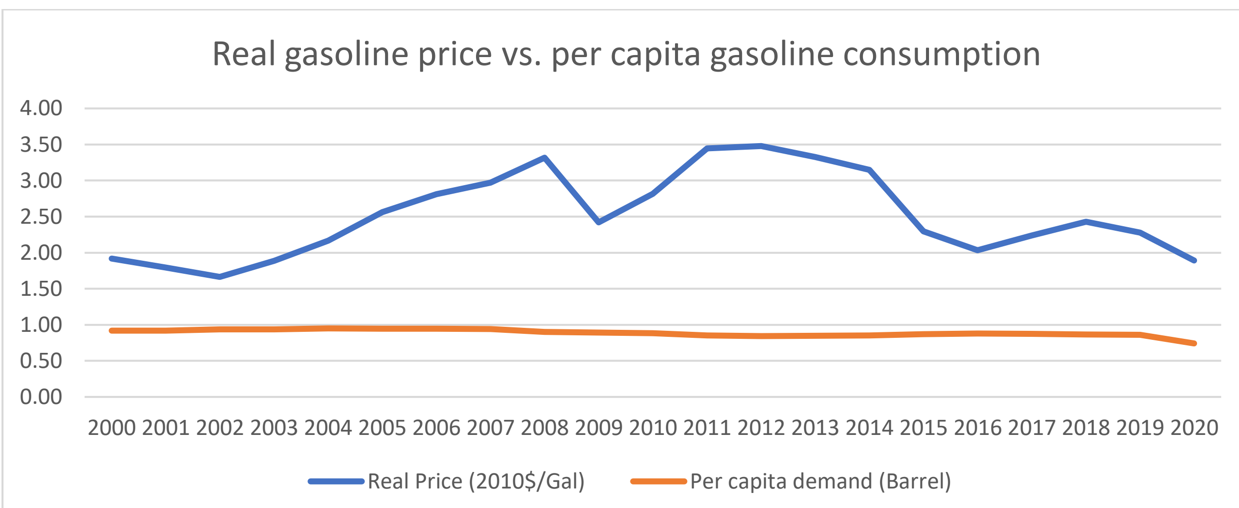


Source: Dahl (2012)

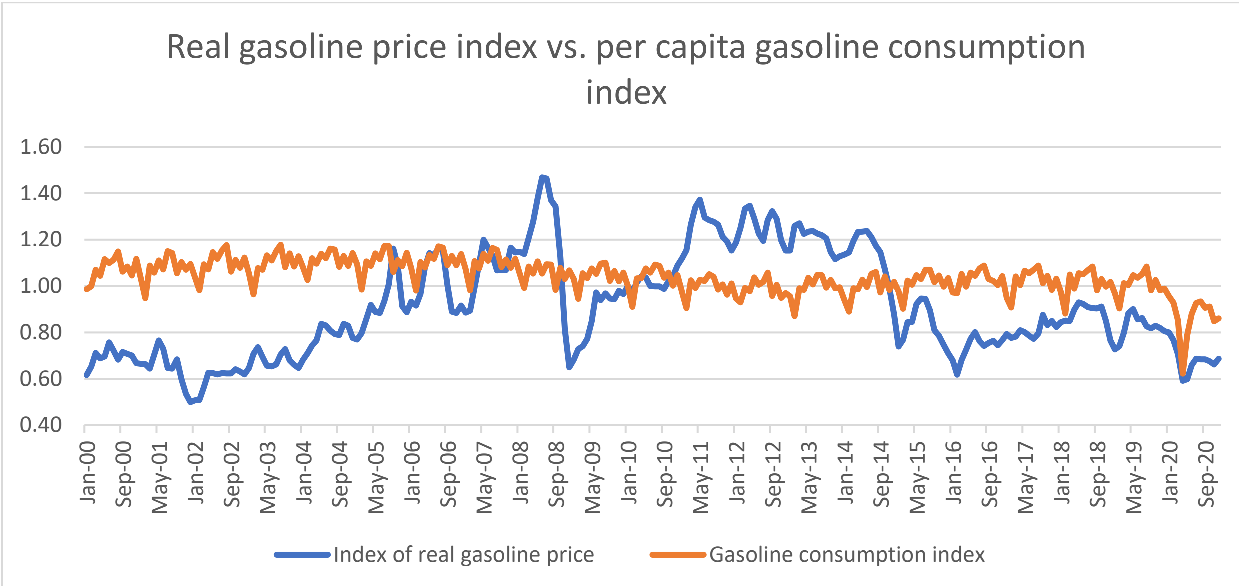
Although the price elasticities measure the responsiveness of fuel demand with respect to price change and fossil fuel demand as well as associated emissions, actual data on price change does not show noticeable impacts on fuel consumption. Figure 3 shows the historical trends of real (inflation adjusted) prices of gasoline and per capita gasoline consumption in the United States. The message delivered by Figure 6 is revealing and often ignored by policymakers and researchers. These figures indicate the decoupling of gasoline price change and per capita gasoline consumption in the United States. While gasoline prices adopted a cyclic trend, per capita gasoline consumption remained basically flat. In fact, it is slightly declining overtime despite the increase in per capita income. The slightly declining trend might be caused by increased fuel efficiency of vehicles which could be results of regulatory policies, such as vehicle mileage standards or autonomous technological improvements.

Figure 6: Historical trends of gasoline prices and consumption in the United States

Annual average gasoline prices vs. annual per capita gasoline consumption in the United States



(b) Indices of monthly average gasoline prices and monthly per capita gasoline consumption in the United States



4.4 Technical Barriers

The measurement of emission reductions from a pricing instrument is difficult in practice because it is hard to distinguish the emission reductions achieved from a pricing instrument from other instruments when multiple policies for GHG mitigation are mixed. While it would be easier to measure GHG mitigation from a project (e.g., solar energy project) or a program (e.g., energy efficiency program)[14], it would not be straightforward to measure GHG mitigation from a policy, such as carbon tax. It is complex to determine whether the resulted mitigation is due to a carbon tax or other factors because it involves several uncertain parameters, such as price elasticities of fossil fuels. The same problem exists for a program to reduce or remove fossil fuel subsidies. One could estimate price elasticities of fossil fuels based on historical data and use those elasticities to calculate the mitigation. However, calculation of such elasticities is not feasible in many countries where historical fuel prices are determined by the government (or independent regulator) instead of a market.

[14] There are hundreds of methodologies developed during the Clean Development Mechanism (CDM) or Joint Implementation (JI) periods, which are useful to estimate the GHG mitigation due to a project or program.

Another issue is setting the baseline which represents the hypothetical situation in the absence of the carbon pricing policy. CO_2 mitigation due to the policy is measured against this baseline. Setting a baseline for project activities, like in the case of Kyoto Mechanisms (JI and CDM), is simpler, and hundreds of methodologies were developed for that purpose. However, there is a fundamental difference between Kyoto Mechanisms and PBMs. Whereas Kyoto Mechanisms normally needed activity-level or program-level baselines, whereas PBMs need national or sectoral baselines; projects or program-level baselines are not useful here. National or sectoral baselines involve much higher level of uncertainties than project and program-level uncertainties. Improper baselines causes over or underestimation of emission reduction.

One common challenge to pricing instruments is monitoring of emissions and verification of emission reduction. At the project level, like in the case of CDM and JI projects, third party verifications were prescribed. Measurement of emissions from a particular project activity and its verification from a third party is straightforward as long as the methodologies are in place. However, at the national level emission reduction, such a monitoring and verification is complex as a sovereign nation may not except verification of its emissions from a third party. The system, therefore, will rely on the national reporting of emissions and emission reductions under the UNFCCC. This is something like reporting national emission registry to the UNFCCC under various provisions including the Paris Accord.

5. Role of RBCF to Facilitate PBMs

RBCF could help facilitate introduction and implementation of PBMs in many ways. These are discussed in this section. For example, it helps develop enabling activities for PBM that are a pre-requisite for the introduction of a PBM. It can be also used to reform the energy market if the existing market structure inhibits introduction of PBMs. Moreover, RBCF can directly incentivize introduction of PBMs. For example, payment can be made if the recipient country introduces a PBM or facilitates measurable conditions for the introduction as well as efficient implementation of PBMs. Below, we discuss how RBCF facilitates the introduction and successful implementation of PBMs in various ways. Moreover, RBCF could also be used to alleviate any adverse effects of PBMs; note, however, that the size of adverse impacts (e.g., GDP loss due to a carbon tax) could be high depending upon the size of the carbon tax and type of scheme to recycle carbon tax revenues (Timilsina, 2022), so enough RBCF may not be available offset the economic costs of

PBMs. While it would be helpful to share the experiences of result-based financing from other sectors (e.g., health sectors, energy sectors, education sectors) and infer how these experiences could be useful in the context of utilizing RBCF for promoting PBMs, this would be a natural extension of the current study.

5.1 Development of institutional setup to implement PBM

A country cannot introduce a PBM unless a required institutional setup is established. For example, if a country plans to introduce an ETS, an institutional setup is needed for (i) a government entity to register trading participants and to record transactions of emission credits/allowances, (ii) an independent regulatory institution that sets all rules and regulations for ETS and their enforcement and (iii) third party entities that verify (or certify) emission reductions. Many of our client countries do not have capacities to undertake these activities. Lack of capacity to set up the institutional arrangements would be a barrier to introduce a PBM. Countries need sizable financial supports to set up the institutional arrangements. RBCF can serve as a financial source. Payments can be made against achievement of agreed milestones, for example, set up a unit within the Ministry of Environment to supervise ETS operation. RBCF can also finance setting up a unit under the Ministry of Finance to supervise a carbon tax scheme.

5.2 Incentivizing the implementation PBMs

In most of the cases, RBF are used as a direct incentive for policy introduction and implementation. For example, the World Bank has used RBF to support educational system enhancement policies in Cambodia from 2016-2021. Several result milestones, such as improving student learning outcomes, improving school-based management, improving equitable access to quality learning environments. Cash payments were made after satisfactory meeting the indicators to measure these milestones.[15] Similar projects have been implemented in many countries in health, clean energy and agriculture sectors. Experiences from past World Bank initiatives on the use RBF for sectoral reforms could be useful while exploring the role of RBCF for promoting PBMs.

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[15] https://imagebank2.worldbank.org/search/33359205

Different milestones towards the implementation of PBMs are set first. These include, for example, preparatory or background work for the introduction of PBMs, establishment of regulatory or administrative body to facilitate, operate and regulate the PBM systems, development of laws and regulations to govern or enforce the PBMs and actual implementation of PBMs. RBCF will be disbursed after the achievement each of these milestones. The direct incentives would be the most powerful instruments to implement PBMs because the results (i.e., implementation of PBMs) will be achieved before the payments are made.

5.3 Sectoral reform to facilitate introduction of PBMs

The energy sector, where a PBM activates emission reduction, is highly distorted in many countries. In most countries, fossil fuels are subsidized. An introduction of a carbon tax in a country where fossil fuel subsidy exists is not easy to justify. RBCF can be utilized to support fossil fuel subsidy removal programs. If a country plans removal of fossil fuel subsidy and introduction of carbon tax and needs help from development partners, RBCF could be a good financial instrument to support. For example, if a government wants to remove fossil fuel subsidies, in so doing, however, the government expect strong and perhaps violent resistance, government can use RBCF to finance communication, awareness and other activities that minimize the risks of resistance. Fuel subsidy removal/reform programs implemented after well preparation through proper communication and awareness became successful. In Ghana, for example, the government undertook a media campaign to explain the need for fuel subsidy removals and its benefits. It immediately (before the fuel subsidy is removed) started elimination of tuition fees at government-run primary and junior secondary schools and also improved public transport. The public accepted government’s explanation and were satisfied with measures that the government undertook, in advance, for the reallocation of subsidy savings (Laan et al. 2010). RBCF can be used to finance this type of preparatory measures for the implementation of fuel subsidy removals or carbon pricing.

Energy prices are fixed or regulated in many countries. PBM, particularly carbon tax and ETS would not as effective as they should be where energy prices are fixed. This is because a fixed price system does not allow carbon pricing to fully passthrough consumers (households, industries, vehicles) and does not cause reductions in fossil fuel consumption and emission reductions. Reform of such energy markets are necessary before introduction of carbon pricing. Even though national emission trading scheme is introduced focusing on the power sector in China, the system does not represent a true ETS. It is inflexible and does not allow substitutions between power generations from different sources (e.g., coal, gas). In fact, it is a trading of emission standards (efficiency) within the same type of generation (e.g., coal-fired generation) (Goulder et al. 2017). Moreover, the Chinese electricity dispatching system does not follow market-based or merit order dispatching system. In the absence of such a system, a carbon pricing instrument does not work effectively (Timilsina et al. 2021). RBCF could be used to reform energy markets to facilitate effective implementation of a PBM. Normally, large-scale World Bank projects are being implemented to reform energy and electricity markets (e.g., Pakistan, Nepal) and RBCF can supplement these programs.

5.4 Providing safeguards against the burden of PBMs on the poor

PBMs that increase energy prices could pose a burden to poor households, since household expenditure shares on energy are often higher in low-income households than that in high-income households (Fullerton et al. 2012; Marron and Toder, 2014). RBCF funds could be utilized for designing safeguard provisions in case the burden of PBMs (e.g., carbon pricing, removal of fossil fuel subsidies) disproportionately falls on the poor. For example, if the subsidy removal increases the prices of electricity, RBCF can be used to support a lifeline electricity tariff – the minimum tariff designed for poor households that consume electricity below a specified threshold. Similar provision can be made if a carbon tax increases the energy expenditure of the poor. Alternatively, savings from subsidy removals or revenues from carbon taxes could be used to protect the poor from the undesired burden of the PBMs. However, using RBCF would be an additional incentive to accelerate the implementations of PBMs. Despite the fact that governments know the reallocations of saved subsidies or carbon tax revenues could be used to protect the vulnerable, they have not shown much interest to implement the PBMs. It implies that additional incentives are needed and RBCF could provide it.

5.5 Alleviating private sector anxiety over PBMs

PBMs could be a new instrument for the private sector. They envision a risk in participating PBMs (e.g., ETS and investing on renewables in response to FiT). RBCF could be used as a guarantee facility for the private sector to implement renewable energy projects promoted under the FiT scheme. If a private firm is running carbon-intensive business (e.g., coal-fired power plants) and a PBM (e.g., carbon tax) causes a threat to its existence thereby causing stranded assets and structured unemployment (e.g., an engineer in coal-fired power plant cannot immediately switch to solar power plants), RBCF could be used to provide relief during the transition time. RBCF could help the firms running coal-fired power plants to switch their businesses to solar or wind power generation. However, such programs should be implemented through a systematic approach rather than an ad hoc manner. For example, governments could create a fund with additional supports from RBCF. The fund can be used to help carbon-intensive business to switch over to renewable energy business. Such a provision could be instrumental to help small and medium size fossil fuel-based entrepreneurs to move to the renewable energy business.

5.6 Enhancing awareness about PBM to relax public reluctance

As usual, people are reluctant to accept any policy that directly causes a burden on them by increasing the prices of fuels. Increased fuel prices cause costs of passenger and freight transportation to increase. They also increase the prices of goods and services, particularly those produced from energy-intensive industries (e.g., construction materials, fertilizers, chemicals). However, those burdens can be lowered through a careful (efficient as well as equitable) design of PBMs. If people are communicated well before the introduction of PBMs, how these instruments would reduce global and local pollution, they might understand the importance of these instruments and may not oppose them. For example, most benefits of fuel subsidies go to high-income people. If the fuel subsidy is replaced with a cash transfer, low- and middle-income households would benefit. The same is true in the case of a carbon tax – recycling carbon tax revenues to households could provide relief to low-income households.

PBMs do not only help reduce GHG emissions, they can also create fiscal co-benefits and environmental co-benefits. Timilsina et al. (2021) finds that a carbon tax could be beneficial to a low-income economy in Sub-Saharan Africa. In a case study of Cote d'Ivoire, they found that a carbon tax significantly helps reduce tax (VAT) evasion and reduce economic informality, the major public finance challenges faced by the country. However, policymakers and officials in the Ministry of Finance are not aware of these co-benefits. Increasing the awareness of the co-benefits of PBMs would significantly help their introduction. RBCF could be utilized in the awareness programs.

5.7 Complementing other programs to promote PBMs

There exist a large number of projects or activities financed by the World Bank and other development partners to enable the introduction and implementation of PBMs. These activities are currently funded through various windows of technical assistance provided by the World Bank, other multilateral development banks, and bilateral donors. In many cases, however, enough financial resources are not available for those projects and activities. RBCF could complement those activities. Again, the RBCF complementarity payment is subject to the achievement of the results of the project activities. The World Bank Group has a long experience of using result-based finance to complement other programs. For example, the Health Results Innovation Trust Fund (HRITF), a RBF approach for the health sector, complemented IDA-supported policies and projects for the achievement of health-related Millennium Development Goals (MDGs) and to fulfill the Sustainable Development Goal (SDG 3)[16].

6. Conclusions

PBMs are the key instruments for climate change mitigation. They have been implemented in many countries since 1990, when international negotiations on climate change began. At present, more than 120 nations and sub-nations have introduced carbon pricing instruments (ETS and carbon tax). The feed-in-tariff, another PBM, has been instrumental to promote renewable energy that replaces fossil-fuels and reduce GHG emissions. Hundreds of countries around the world have implemented FiT, for decades in some countries. The removal of fossil fuel subsidies has also contributed to climate change mitigation by increasing the effective price of fossil fuels and thereby reducing their demand. The Paris Climate Accord has enhanced the importance of PBMs in meeting the ambitious target for climate change mitigation. Almost all parties to the Paris Accord have included some form of PBMs in the package of policy instruments to meet their NDCs.

A series of empirical studies have been carried out to understand the effectiveness of PBMs in reducing GHG emissions. While most of the studies demonstrate that PBMs do mitigate GHG emissions, the question is how much. The results from the ex-post empirical studies reveal that the

[16] https://www.rbfhealth.org/projects

levels of reductions are not as large as predicted by ex-ante modeling studies. There are many reasons for the disagreements between the evidence offered by the empirical studies and conclusions drawn by ex-ante simulations of PBMs or theoretical and numerical studies. The disagreements are caused by limitations of the models and quality of data used in the ex-post empirical studies as well as ex-ante numerical simulations. More empirical studies with better quality data and improved methodologies are needed to address these concerns.

Although in practice in many years in several economies and having increasing attention to policymakers from the developing world, PBMs face many barriers. Political sensitivity is one of the biggest barriers because politicians do not want to irritate their voters by increasing energy prices introducing PBMs, in particular carbon pricing and subsidy removal. In the past, fuel price increase due to removal of subsidy or introduction of a new tax, such as the carbon tax, has incited massive violent protests that led to loss of properties, lives and downfall of incumbent governments. Therefore, politicians do not want to take risk of introducing PBMs even if they agree with economists that these mechanisms are efficient in reducing GHG emissions and are necessary to achieve their NDCs. There are certain limitations on efficacy of PBMs, particularly carbon tax; they may not be as effective in practice as stated in theory. For example, a carbon tax may not achieve many reductions of emissions from transport sector, one of main sources of CO_2 emissions in any economy, unless alternative low-carbon transportation modes are available. An economically feasible low-carbon transportation system does not exist with scale in any of the countries around the world. Besides, there are several institutional/financial/technical barriers causing the implementation of PBMs challenging. These include lack of institutional capacity to implement PBMs, difficulty in setting up credible baseline due to uncertainties, expensive monitoring and verification system and misalignment between the PBM design and incentives needed by the actors (source of emissions).

Result-based climate finance, a specifically designed output- or result-based financing scheme, could play a role in lowering barriers to PBMs. RBCF has been used to finance hundreds of climate change mitigation projects, but it has not been used yet to facilitate implementation of PBMs. There are many ways that RBCF can facilitate PBMs. The first one is the financing enabling activities to implement PBMs, including building institutional capacities and setting up regulatory/enforcement mechanisms. RBCF can also be used to relax political sensitivities and public resistance, one of the main barriers to PBMs, including establishment of safety measures to those vulnerable to PBMs, such as low-income households where burden of PBMs could fall disproportionately. It could be also used to protect small and medium size industries that would be severely impacted by PBMs and facilitate them to transform. It can also support education and awareness activities in favor of PBMs. Existing energy markets are not conductive to PBMs because of various market distortions, so RBCF could provide supplemental funding for energy market reforms that facilitate implementation of PBMs. It can be also used to augment the private sector's participation in PBMs by offering guarantees and reducing risks. RBCF could also be used to create and exchange knowledge, particularly to learn from countries where PBMs have been already implemented successfully.

A quantitative measurement of efficacy of RBCF to implement PBMs is not possible as it has not yet used for that purpose. One way to increase understanding in this direction would be to investigate the experiences of other result-based financing schemes applied in other sectors (e.g., health sector, energy sector, education sector). The results will infer the potential success of RBCF in promoting PBMs. Such investigations will be natural extensions of the current study.

References

Aghion, Philippe, Antoine Dechezlepretre, David Hemous, Ralf Martin and John Van Reenen (2016). Carbon Taxes, Path Dependency, and Directed Technical Change: Evidence from the Auto Industry. Journal of Political Economy, 124 (1), 1-51.

Alberini, Anna, and Marco Horvath (2020), "All Car Taxes are Not Created Equal: Evidence from Germany," USAEE working paper 20-474, October, available at https://papers.ssrn.com/sol3/papers.cfm?abstract_id=3707822#

Alberini, Anna, and Markus Bareit (2019), "The Effect of Registration Taxes on New Car Sales and Emissions: Evidence from Switzerland," Resource and Energy Economics, 56, 96-112.

Aldy, Joseph E., Alan J. Krupnick, Richard G., Newell, Ian W. H Parry, and William A. Pizer (2010). Designing Climate Mitigation Policy. Journal of Economic Literature, Vol. 48 (4), pp. 903-34.

Aldy, Joseph E., Marc Hafstead, Gilbert E. Metcalf, Brian C. Murray, William A. Pizer, Christina Reichert and Roberton C. Williams III (2017). Resolving the Inherent Uncertainty of Carbon Taxes. Harvard Environmental Law Review Forum. Vol. 41, pp. 1-13.

Aldy, Joseph E. and William A. Pizer (2015). The Competitiveness Impacts of Climate Change Mitigation Policies. Journal of the Association of Environmental and Resource Economists, Vol. 2 (4), 565-595.

Andersson, Julius J. (2019). Carbon Taxes and CO2 Emissions: Sweden as a Case Study. American Economic Journal: Economic Policy, Vol. 11(4), pp. 1–30.

Arimura, Toshi H. and Tatsuya Abe (2021). The impact of the Tokyo emissions trading scheme on office buildings: what factor contributed to the emission reduction? Environmental Economics & Policy Studies, Vol. 23, No. 3, pp.518-533.

Aydin, Celil and Ömer Esen (2018). Reducing CO_2 emissions in the EU member states: Do environmental taxes work? Journal of Environmental Planning and Management, Vol. 61, No. 13.

Baumol, W. (1972). On Taxation and the Control of Externalities. American Economic Review, Vol. 62, No. 3, pp. 307-322.

Baylis, Kathy, Don Fullerton and Daniel H. Karney (2013). Leakage, Welfare, and Cost-Effectiveness of Carbon Policy. The American Economic Review, Vol. 103 (3), pp. 332-337.

Beck, Marisa, Nicholas Rivers, Randall Wigle and Hidemichi Yonezowa (2015). Carbon Tax and Revenue Recycling: Impacts on Households in British Columbia. Resource and Energy Economics, Vol.41, pp. 40-69.

Best, Rohan, Paul J. Burke, Frank Jotzo (2020). Carbon Pricing Efficacy: Cross-Country Evidence. Environmental and Resource Economics. Vol. 77, pp. 69–94.

Bohringer, Christoph, Brita Bye, Taran Faehn and Knut Einar Rosendahl (2017). Output-Based Rebating of Carbon Taxes in a Neighbour's Backyard: Competitiveness, Leakage and Welfare. Canadian Journal of Economics, Vol. 50 (2), pp. 426-55.

Bumpus, Adam G. (2015). Firm Responses to a Carbon Price: Corporate Decision Making under British Columbia's Carbon Tax. Climate Policy, 2015, Vol. 15 (4), pp. 475-93.

Chakir, Raja, Stéphane De Cara, Bruno Vermont (2017). Price-Induced Changes in Greenhouse Gas Emissions from Agriculture, Forestry, and Other Land Use A Spatial Panel Econometric Analysis. Revue économique. Vol. 68 (3), pp. 471-490.

Cosbey, A., S. Droege, C. Fischer, and C. Munnings. 2019. Developing guidance for implementing border carbon adjustments: Lessons, cautions, and research needs from the literature. Review of Environmental Economics and Policy 13 (1) (Winter): 3–22.

Coxhead, Ian; Anan Wattanakuljarus and Chan V. Nguyen (2014). Are Carbon Taxes Good for the Poor? A General Equilibrium Analysis for Vietnam. World Development, Vol. 51, pp. 119-31.

Dahl, Carol (2012). Measuring global gasoline and diesel price and income elasticities. Energy Policy, Vol. 41, pp. 2-13.

Dechezlepretre, Antoine, Caterina Gennaioli, Ralf Martin, Mirebelle Muuls and Thomas Stoerk (2021), "Searching for Carbon Leaks in Multinational Companies," Centre for Climate Change Economics and Policy Working paper 187, Leeds and London, February.

Dechezlepretre, Antoine, D. Nachtigall, and F. Venmans (2020), "The Joint Impact of the European Union Emissions Trading System on Carbon Emissions and Economic Performance," OECD Economics Department Working Papers 1515, Paris, France.

Dijkgraaf, Elbert, Tom P. van Dorp and Emiel Maasland (2018). On the Effectiveness of Feed-in Tariffs in the Development of Solar Photovoltaics. The Energy Journal, Vol. 39 (1), pp. 81-99.

Du, Yimeng and Kenji Takeuchi (2020). Does a Small Difference Make a Difference? Impact of Feed-In Tariff on Renewable Power Generation in China. Energy Economics, Vol. 87, pp.

Egenhofer, C., M. Alessi, N. Fujiwara, and A. Georgiev. 2011. The EU Emissions Trading System and climate policy towards 2050: Real incentives to reduce emissions and drive innovation? CEPS Special Report, Centre for European Policy Studies.

Elgie, Stewart and Jessica McClay (2013). BC's Carbon Tax Shift Is Working Well after Four Years. Canadian Public Policy. Vol. 39, Supplement 2, pp. S1-S10.

Ellerman AD, BK Buchner (2008). Over-allocation or abatement? A preliminary analysis of the EU ETS based on the 2005–06 emissions data. Environment and Resource Economics, Vol. 41(2), pp. 267–287.

Elliott, Joshua; Ian Foster, Samuel Kortum, Todd Munson, Fernando Perez Cervantes and David Weisbach (2010). Trade and Carbon Taxes. American Economic Review, Vol. 100 (2), pp. 465-69.

Federal Ministry for the Environment, Nature Conservation, Germany (FMENCG) (2017). Carbon Pricing: Using Market-based Mechanisms to Mitigate Climate Change. FMENCG, Berlin.

Fischer, Carolyn and Alan K. Fox (2012). Climate Policy and Fiscal Constraints: Do Tax Interactions Outweigh Carbon Leakage? Energy Economics, Supplement 2 December 2012, Vol. 34, pp. S218-27.

Floros, Nikolaos and Andriana Vlachou (2005). Energy Demand and Energy-Related CO2 Emissions in Greek Manufacturing: Assessing the Impact of a Carbon Tax. Energy Economics, Vol. 27 (3), pp. 387-413.

Fullerton, Don; Garth Heutel and Gilbert E. Metcalf (2012). Does the Indexing of Government Transfers Make Carbon Pricing Progressive? American Journal of Agricultural Economics, Vol. 94 (2) pp. 347-53.

Goulder, Lawrence H., Richard D. Morgenstern, Clayton Munnings and Jeremy Schreifels (2017). China's National Carbon Dioxide Emission Trading System: An Introduction. Economics of Energy & Environmental Policy, Vol. 6, No. 2. DOI: 10.5547/2160-5890.6.2.lgou

Green, Jessica F. (2021). Does carbon pricing reduce emissions? A review of ex-post analyses. Environmental Research Letters, Vol. 16, No. 4. 043004.

Hájek, Miroslav, Jarmila Zimmermannová, Karel Helman and Ladislav Rozenský (2019). Analysis of carbon tax efficiency in energy industries of selected EU countries. Energy Policy, Vol. 134, 110955.

Herold, A. 2007. Comparison of verified CO_2 emissions under the EU Emission Trading Scheme with national greenhouse gas inventories for the year 2005. ETC/ACC Technical Paper no. 2007/3, European Topic Center on Air and Climate Change, Bilthoven.

Hitaj, Claudia and Andreas Löschel (2019). The impact of a feed-in tariff on wind power development in Germany. Resource and Energy Economics, Vol. 57, pp. 18-35.

International Energy Agency (IEA) (2020). World Energy Balances 2019. IEA, Paris.

International Energy Agency (IEA) (2022a). Fossil Fuel Subsidies Database. IEA, Paris. https://www.iea.org/data-and-statistics/data-product/fossil-fuel-subsidies-database. Downloaded (February 1, 2022).

International Energy Agency (IEA) (2022b). Online data on fossil fuel prices and taxes.
https://www.iea.org/data-and-statistics/data-product/energy-prices#energy-prices. Downloaded (March 3, 2022).

Jaraitė, Jūratė and Corrado Di Maria (2016). Did the EU ETS Make a Difference? An Empirical Assessment Using Lithuanian Firm-Level Data. The Energy Journal, Vol. 37, No. 1 pp. 1-23.

Jenner, Steffen, Felix Groba and Joe Indvik (2013). Assessing the strength and effectiveness of renewable electricity feed-in tariffs in European Union countries. Energy Policy, Vol. 52, pp. 385-401.

Kachi, Aki and Thomas Day (2020). Result-based Finance in the Paris Era: Consideration to Maximize Impacts. New Climate Institute. https://newclimate.org/2020/12/16/results-based-finance-in-the-paris-era/

Kuehl, Jonas, Andrea M. Bassi, Philip Gass and Georg Pallaske (2021). Cutting Emissions Through Fossil Fuel Subsidy Reform and Taxation. International Institute for Sustainable Development, Manitoba, Canada.

Klier, Thomas and Joshua Linn (2015). Using Taxes to Reduce Carbon Dioxide Emissions Rates of New Passenger Vehicles: Evidence from France, Germany, and Sweden. American Economic Journal: Economic Policy, Vol. 7(1), pp. 212–242.

Laan, T., C. Beaton and B. Presta, (2010). Strategies for Reforming Fossil-Fuel Subsidies: practical lessons from Ghana, France and Senegal', Global Subsidies Initiative (GSI), International Institute for Sustainable Development (IISD), Geneva, Switzerland http://www.globalsubsidies.org/files/assets/strategies_ffs.pdf

Lawley, Chad and Vincent Thivierge (2018). Refining the Evidence: British Columbia's Carbon Tax and Household Gasoline Consumption. The Energy Journal, Vol. 39, No. 2. pp. 142-171.

Lockwood, Ben and John Whalley (2010). Carbon-Motivated Border Tax Adjustments: Old Wine in Green Bottles? World Economy, Vol. 33 (6), pp. 810-19.

Marron, Donald B. and Eric J. Toder (2014). Tax Policy Issues in Designing a Carbon Tax. The American Economic Review, Vol. 104, No. 5, pp. 563-568.

Martin, Ralf, Laure B. de Preux and Ulrich J. Wagner (2014a). The impact of a carbon tax on manufacturing: Evidence from microdata. Journal of Public Economics, Vol. 117, pp. 1–14.

Martin, Ralf, Mirabelle Muûls, and Ulrich J. Wagner (2016). The Impact of the European Union Emissions Trading Scheme on Regulated Firms: What Is the Evidence after Ten Years? Review of Environmental Economics and Policy, Vol. 10(1), pp.129–148.

Martin, Ralf, Mirabelle Muuls, Laure B. De Preux, and Ulrich J. Wagner (2014b), "Industry Compensation Under Relocation Risk: A Firm-Level Analysis of the EU Emissions Trading Scheme," American Economic Review, 104(8), 2482-2508.

Martin, Ralf, Mirabelle Muuls, Laure B. de Preux, Ulrich J. Wagner (2014c), "On the Empirical Content of Carbo Leakage Criteria in the EU Emissions Trading Scheme," Ecological Economics, 105, 78-88.

Mehleb, Rimel, Giorgos Kallis and Christos Zografos (2021). A discourse analysis of yellow-vest resistance against carbon taxes. Environmental Innovation and Societal Transitions, Vol. 40, pp. 382-39.

Metcalf, Gilbert E. (2014). Using the Tax System to Address Competition Issues with a Carbon Tax. National Tax Journal, Vol. 67 (4), 779-806.

Montgomery David W. (1972). Markets in licenses and efficient pollution control programs. Journal of Economic Theory, Vol. 5, pp.395-418.

Murray Brian and Peter T. Maniloff (2015). Why have greenhouse emissions in RGGI states declined? An econometric attribution to economic, energy market, and policy factors. Energy Economics, Vol. 51, pp.581–589.

Murray, Brian C. and Nicholas Rivers (2015). British Columbia's Revenue-Neutral Carbon Tax: A Review of the Latest 'Grand Experiment' in Environmental Policy. Energy Policy, Vol. 86, pp. 674-83.

Murray, Brian C. and Peter T. Maniloff (2015). Why have greenhouse emissions in RGGI States declined? An econometric attribution to economic, energy market, and policy factors. Energy Economics, Vol. 51, pp. 581–589.

Narassimhan, E., K.S. Gallagher, S. Koester, and J. R. Alejo (2017). Carbon Pricing in Practice: A Review of the Evidence. Center for International Environment and Resource Policy, The Fletcher School, Tufts University.

Nordhaus, William D. (1977). Economic growth and climate: The carbon dioxide problem. The American Economic Review, Vol. 67(1):341-346.

Organization of Economic Cooperation and Development (OECD) (2022). Online Statistics. https://stats.oecd.org/Index.aspx?DataSetCode=RE_FIT (Downloaded on February 10, 2022)

Petrick, S., and U. J. Wagner. 2014. The impact of carbon trading on industry: Evidence from German manufacturing firms. Kiel Working Paper No. 1912, Kiel, Germany.

Pigou, A.C. (1920). The Economics of Welfare, London.

Poterba, J. (1991). Tax policy to combat global warming: On designing a carbon tax. Dornbusch, R.; Poterba, J.M. (eds.); Global warming: Economic policy responses. pp. 71-108; MIT Press; Cambridge, MA.

Renewable Energy Network for 21st Century (REN21) (2021). Renewables 2020 - Global Status Report. https://www.ren21.net/reports/global-status-report/

Roppongi H, A. Suwa, A. Jose and P. De Oliveira (2017) Innovating in sub-national climate policy: the mandatory emissions reduction scheme in Tokyo. Climate Policy, Vol. 17, No. 4, pp. 516–532.

Tietenberg, Tom H. (2013). Reflections--Carbon Pricing in Practice. Review of Environmental Economics and Policy, Vol. 7 (2), pp. 313-29.

Timilsina, Govinda (2018a). Carbon Pricing for Climate Change Mitigation. CAB Reviews, Vol.13, No. 8, pp. 1-13.

Timilsina, Govinda (2018b). Where is the carbon tax after thirty years of research? Policy Research Working Paper 8493, World Bank, Washington, DC.

Timilsina, Govinda (2021). Are renewable energy technologies cost competitive for electricity generation? Renewable Energy, Vol. 180, pp. 658 – 672.

Timilsina, Govinda (2022). Carbon Taxes, Journal of Economic Literature. Forthcoming.

Timilsina, Govinda, L. Kurdgelashvili and P. A. Narbel (2012). Solar energy: Markets, economics and policies, Renewable and Sustainable Energy Reviews, Vol. 16, No. 1, pp.449-465.

Timilsina, Govinda, Jun Pang and Xi Yang (2021). Macroeconomic Impacts of Power Sector Reforms in China. Energy Policy. Vo. 157, 112509.

Timilsina, Govinda and Sunil Malla (2022). Have Price-based Mechanism Reduced GHG Emissions? Draft Report.

Timilsina, Govinda, Yazid Dissou, Mike Toman and Dirk Heine (2021). Carbon Tax in an Economy with Informality: A Computable General Equilibrium Analysis for Côte d'Ivoire. World Bank Policy Research Working Paper, WPS 9710. World Bank Washington, DC.

World Bank (2017). Result-Based Climate Finance in Practice: developing Climate Finance for Low-Carbon Development, World bank, Washington, DC.

World Bank (2020). State and Trends of Carbon Pricing 2020. World Bank, Washington, DC.

World Bank (2021a). State and Trends of Carbon Pricing 2021. World Bank, Washington, DC.

World Bank (2021b). Commodity Markets Outlook, March 2021. World Bank, Washington, DC.