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Closing the emission price gap

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A B S T R A C T

Even without internationally concerted action on climate change mitigation, there are important incentives for countries to put a price on their domestic emissions, including public finance considerations, internalizing the climate impacts of their own emissions, and co-benefits, such as clean air or energy security. Whereas these arguments have been mostly discussed in separate strands of literature, this article carries out a synthesis that exemplifies how policies to put a price on emissions can be conceptualized in a multi-objective framework. Despite considerable uncertainty, empirical evidence suggests that different countries may face quite different incentives for emission pricing. For instance, avoided climate damages and co-benefits of reduced air pollution appear to be the main motivation for emission pricing in China, while for the US generating public revenue dominates and for the EU all three motivations are of intermediate importance. We finally argue that such unilateral incentives could form the basis for incremental progress in international climate negotiations toward a realistic climate treaty based on national interest and differentiated emission pricing and describe how such an agreement could be put into practice.

1. Introduction and motivation

The Fifth Assessment Report of the Intergovernmental Panel on Climate Change reaffirms the serious consequences of unabated climate change (IPCC, 2013). In order to avoid the adverse effects of 'dangerous anthropogenic interference with the climate system' (UNFCCC, 1992) and to close the 'emission gap' between emission reductions from unilateral pledges under the Copenhagen Accord (UNFCCC, 2009) and a trajectory that limits the risk of global mean temperature increase of more than 2 °C, a list of actions specifying low-cost mitigation options in different sectors has been proposed (UNEP, 2014). These include, for example, encouraging no-tillage practices and improved nutrient and water management in agriculture, appliance standards, building codes, or vehicle performance standards.

However, from an economic perspective, the perhaps most important prerequisite for cost-efficient climate change mitigation lies in imposing a globally uniform price on GHG emissions that approximates their social costs (Stern, 2008; IPCC, 2014) instead of determining abatement requirements for each economic sector and technology option. By means of a price on emissions the global externality associated with climate impacts would be internalized into the decisions of all individuals and organizations and market prices will ideally guide individual incentives toward socially optimal abatement efforts (but additional policies will be required to provide low-carbon public goods and target additional market failures). Yet, collective action theory has provided a pessimistic outlook regarding the feasibility of an optimal global emission price. It is argued that free-rider incentives would undermine incentives to participate in an international arrangement for the provision of the global public good of emission reductions (Barrett, 1994; Carraro and Siniscalco, 1993). Nevertheless, despite the lack of an internationally binding climate agreement, several countries (including 18 of the world's 20 largest emitters) have implemented policies that explicitly aim to reduce their GHG emissions (Dubash et al., 2013 (Townshend et al., 2013; IPCC, 2014, Chapter 15).

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This article argues that even in the absence of a global climate agreement there are various unilateral, and in part short-term incentives for policy-makers to introduce mitigation measures, and in particular emission pricing. We exemplarily discuss incentives for unilateral climate policies, including (a) carbon pricing as an efficient source of public finance enhancing (at least in the short-term) economic growth, (b) opportunities to invest the revenues from carbon pricing in productive domestic uses (e.g. in public infrastructure), and (c) Pigouvian GHG pricing to value the domestic climate impacts of a country's own emissions as well as co-benefits. Whereas these arguments have been mostly discussed in separate strands of literature, this article carries out a synthesis that exemplifies how policies which put a price on emissions can be conceptualized in a multi-objective framework, illustrated in Fig. 1 and discussed in detail below. Even though the domestic incentives will likely be insufficient to achieve the globally optimal price for GHG emissions, each of them could contribute toward closing the 'emission price gap' between current GHG prices and a level that is globally desirable. Addressing several of these incentives simultaneously would be unlikely to result in an emission price equal to the sum of each incentive being addressed in isolation.

Early action by some countries, regions or industries could facilitate international negotiations to close (at least some part of) the current GHG price gap (Keohane and Victor, 2011; Ostrom, 2010; Urpelainen, 2013). This article discusses how unilateral emissions pricing could promote cooperation on the international level. Even though the literature in this respect is not very comprehensive, it has been shown that unilateral efforts can not only increase the overall level of climate change mitigation, but also promote collective action. Possible channels through which cooperation can be enhanced are via (a) technology spill-overs, (b) social learning with regards to uncertain costs and benefits as well as asymmetric information, (c) reciprocity and (d) changing the political economy and institution building. We propose that international negotiations should embrace approaches that provide flexibility to incorporate country-specific considerations, for example, by means of a climate regime focusing on coordinating domestic policy packages instead of specific emission reduction quantities. Top-down metrics such as a global temperature stabilization goal could be applied to evaluate the expected global aggregate outcomes of such packages to inform international negotiations with respect to the needs for enhancing the levels of climate policy ambition.

Recent years have witnessed the development of a vast literature related to proposals how to investigate international cooperation on climate change mitigation (Aldy and Stavins, 2007; IPCC, 2014) from a 'top-down' as well as a 'bottom-up' perspective

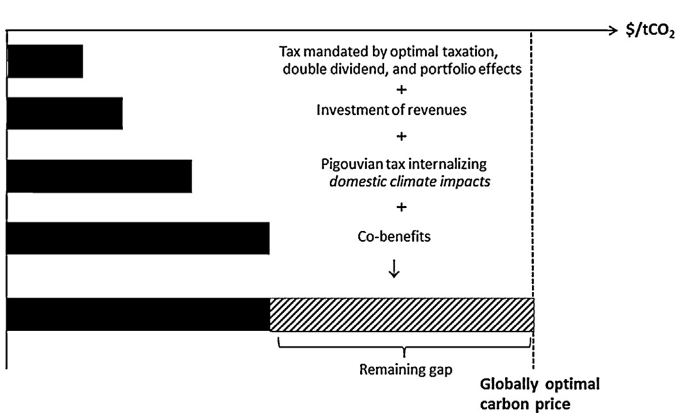

Fig. 1. Incentives to introduce unilateral emission prices and their relationship to international negotiations.

(Aldy et al., 2003). This is echoed in Chapter 13 of the recent Fifth Assessment Report of IPCC Working Group III on international cooperation (IPCC, 2014), which observes that "existing and proposed international climate agreements vary in the degree to which their authority is centralized", ranging from strong multilateral agreements to harmonized national policies and decentralized but coordinated national policies.

Top-down climate agreements start with a global temperature or concentration target. To define how this target should be achieved, it is broken down into actions by individual countries. A prominent example is the 'targets-and-timetables' approach under the Kyoto Protocol, which spells out binding national commitments to limit GHG emissions to a specific quantity for the period 2008–2012. Bosetti and Frankel (2011) and Den Elzen and Höhne (2010) are examples for analyses of alternative options for specifying a future targets-and-timetables regime. In a similar vein, the so-called 'budget approach' (WBGU, 2009), which aims at limiting cumulative global emissions for a certain time period (e.g. until 2050), is another top-down proposal for allocating emission quantities across countries. In contrast to quantitative limits, several authors have suggested to alternatively crafting a top-down regime by negotiating a globally harmonized carbon price (Nordhaus, 2007; Cooper, 2007; Weitzman, 2013).

However, top-down approaches to regime design have frequently been criticized as being overly optimistic in their assumptions about the viability of international cooperation and hence unrealistic, as no country has sufficient incentives to provide the amount of the global public good of emission reductions that would be optimal from a social planner's perspective (Carraro and Siniscalco, 1993; Barrett, 1994, 2006). For this reason, bottom-up approaches start from policies that can be put into place from the perspective of national interest and then pose the question of how such individual national policies and measures can be combined to result in an international agreement. Prominent examples of such a bottom-up structure are technology cooperations aiming to harmonize standards and engage in joint R&D (De Coninck et al., 2008; Barrett, 2006; Pizer, 2007), or the linking of emission trading systems (Flachsland et al., 2009).

Our article is not the first to discuss how national carbon pricing schemes introduced from a bottom-up perspective could lay the foundation for a global climate agreement. Victor (2011) emphasizes that domestic measures that are coordinated on the international level have the highest chance to result in a self-enforcing climate agreement over time and discusses how reciprocity and coordination might promote collective action. In a similar vein, Morris et al. (2013) propose international 'Carbon Pricing Consultations' in order to coordinate pricing policies and share experiences regarding implementation issues.

However, these bottom-up proposals do not specify why countries should have an incentive to implement a carbon price that would result in an ambitious level of atmospheric stabilization in the first place. By combining the work on unilateral incentives for carbon pricing with the one on bottom-up climate agreements, our article's contribution to the literature is twofold. First, by providing an overview of potential incentives for domestic carbon pricing policies, we exemplify how self-enforcing bottom-up carbon pricing schemes could be a first step toward achieving ambitious climate targets even if countries only act in their national self-interest. Second, we apply arguments in favor of a step-wise approach to introduce (unilateral) climate measures to the case of carbon pricing to demonstrate how unilaterally implemented pricing schemes might be strengthened and extended over time by means of international coordination. By emphasizing domestic incentives, our article is similar to Stewart et al. (2013), who propose to put actions that are not primarily aimed at climate change mitigation, but nevertheless reduce emissions (such as clean air policies) as a complement to strengthen the current UNFCCC system. By contrast, our approach explains how a global climate regime could arise from bottom-up incentives for domestic carbon pricing. Hence, this article fills an important gap in the literature by combining the discussion of unilateral incentives for emission pricing in recent studies (Parry et al., 2014a) with top-down climate regime designs focusing on price-based policies.

2. Incentives for unilateral carbon pricing

2.1. Carbon pricing as an efficient source of public finance

In order to finance the provision of public goods – such as healthcare, education, or transport infrastructure – governments need to levy taxes. With the exception of Pigouvian taxes introduced to correct a negative externality (see below), mainstream economic theory suggests that taxes usually induce a distortion in the economy by inhibiting desirable activities, such as investment or participation in the labor market (IFS and Mirrlees, 2011). From this theoretical perspective, public goods should be provided to the extent that their marginal social benefit equals the marginal social costs induced by raising the required taxes. The theory of optimal taxation analyzes how to design tax systems in the least distortionary way (Mankiw et al., 2009). One central result of this kind of analysis is the Ramsey rule, stating that in order to raise a given amount of tax revenue economic factors should be taxed in inverse proportion to their demand elasticity (Ramsey, 1927). That is, as economic distortions from taxation are smaller for goods for which demand is less responsive to changes in prices (i.e. which are more inelastic), the latter should be taxed at a higher rate. From this perspective, it would be economically rational to impose a price on GHG emissions merely for the sake of generating revenues, that is, even if there were no related negative externalities (an alternative way to put a price on emissions consists in a tradable permit system with auctioned permits; we will treat these options as identical in outcome for the remainder of this article, see for example (Goulder and Parry, 2008) for a review of the discussion of price and quantity instruments for climate policy).

The efficiency impacts of pricing negative externalities such as GHG emissions have been examined in the 'double dividend' literature (Goulder, 1995; Parry, 1995). This literature argues that pricing externalities can be beneficial on two accounts: first, by internalizing the externality, private marginal benefits of an activity are equalized to their social benefits, such that the resulting market outcome will be economically efficient. Second, the associated tax revenues can be employed to lower existing distortionary taxes (e.g. on income), which will produce an additional benefit. Even though this beneficial effect is – at least partially – offset by interaction with other pre-existing economic distortions (e.g. with a minimum wage, increased energy prices result in lower labor demand and hence more unemployment), it is more efficient to include the associated revenues in the government budget compared to for example, lump-sum redistribution of revenues (as under the 'cap-and-dividend' approach), or free allocation of emission permits (as under the grandfathering approach). The latter would not lead to the macro-economic efficiency enhancements resulting from lowering pre-existing taxes (Goulder, 2013). Recent studies have further shown that, by broadening the tax base, a price on GHG emissions increases the overall efficiency of the tax system in economies with a large informal sector, which is affected by a GHG price but would otherwise not be subject to taxation (Markandya et al., 2013). The above effects could thus, at least in the short term, foster economic growth by means of more efficient use of economic resources.

The double-dividend literature focuses on tax cuts to lower the costs of public funds. But numerous other macroeconomic and fiscal effects of climate policy both on the revenue-raising and spending side exist (see Siegmeier et al., 2015 for a detailed overview). Two examples for effects that also lower the costs of public funds concern capital mobility and investment behavior (the revenue spending side is treated in the next section).

Existing studies on the double dividend mostly ignore international capital mobility. In the presence of tax competition – that is, to attract mobile capital – taxation of fossil fuel use can be more efficient than taxes on capital if the revenues are invested in productivity-enhancing infrastructure projects. International tax competition and resulting bottom-spiraling on capital taxation could thus be compensated for. The investments from revenues in turn could attract international capital and have therefore further potential to alleviate carbon leakage (Franks et al., 2014).

Furthermore, a mechanism through which emission pricing could improve macro-economic performance that has only received little attention in the literature concerns the composition of investors' portfolios in the presence of fixed factors of production. Investment in productive assets such as land, but also in fossil resource stocks does not increase their supply. At the same time, investment in *producible* capital as the alternative asset may be sub-optimally low relative to what would be mandated from an inter-generational perspective that takes into account the welfare of future generations. This misallocation of economic resources can be – at least partially – corrected by taxing rents of the fixed factors used in production – such as fossil fuels –, which directs investment toward producible capital (Edenhofer et al., 2013c; Feldstein, 1977; Siegmeier et al., 2014).

2.2. Spending revenues from carbon pricing

Due to its potential to raise revenues at low (or potentially even without) macro-economic distortions, carbon pricing constitutes an attractive source of public finance. This not only increases macro-economic efficiency by lowering the costs to raise the current amount of revenues as discussed in the previous section. Rather, lower marginal costs of public funds will result in a new equilibrium with higher revenues and higher public spending. Hence, revenues from emission pricing could for example be used for productive uses such as public debt reduction, or to increase public investment.

If the reduction of public debt is an objective of government policy, revenues from carbon pricing may be used for this purpose (Carbone et al., 2013; Rausch, 2013). For this reason, carbon pricing has been recommended by some as an appropriate measure to balance government budgets suffering from the impacts of the current financial crisis (Vivid Economics, 2012).

Alternatively, the provision of public goods or infrastructure investments, such as health, education, transport, or telecommunication, could be increased (Jakob and Edenhofer, 2014). Higher levels of public infrastructure have been shown to be related to economic growth, reduced inequality (Calderon and Serven, 2014) and improvements in human well-being (Drèze and Sen, 2013). And it has been shown that in many cases the stock of public infrastructure is below its optimal level (Estache and Fay, 2007). This argument is in accordance with investment needs related to public infrastructure to achieve human development goals, such as the currently discussed 'Sustainable Development Goals' (Griggs et al., 2013). For instance, in order to achieve universal energy access by 2030, Riahi et al. (2012) estimate that additional investments of US$ 36–41 bln per year in the global energy system, compared to the business-as-usual projection, are required. Likewise, Jamison et al. (2013) suggest that a 'great convergence' of global health standards can be achieved by investing about US$ 40 bln per year until 2035.

A tax on fixed factor rents (such as from fossil fuels) can directly finance otherwise underinvested capital stocks (Mattauch et al., 2013). This ensures that the social return to all factors of production (e.g. natural, physical, and human capital) is equalized. Thus, GHG pricing could help to cover these investments without introducing new (or increasing already existing) distortionary taxes. To give an impression of the amount of revenues from a carbon price that theoretically could be available, Fig. 2 shows the range of tax revenues in different regions for scenarios assuming carbon prices of US$10, 30, and 50/ton of CO_2, as calculated with the integrated assessment model ReMIND-R. Depending on the magnitude of the global emission tax, total global revenues (in 2005 US$) range from USD 400 bln (in 2020 for a tax rate of USD 10) to USD 2100 bln (in 2030 for a tax rate of USD 50). For scenarios in which global actions is delayed or particular mitigation technologies are unavailable and thus higher GHG prices are required to achieve ambitious climate objectives, annual revenues may be higher (see Krey, 2014 for a detailed discussion).

Revenues from GHG pricing could of course also be invested in public infrastructure that is directly related to climate change. Recent estimates suggest that an ambitious global mitigation target would require global investments in the power sector for transmission, distribution, and storage of between USD 267–597 bln per year (McCollum et al., 2015). As pointed out by Bowen et al. (2013), and in line with the order of magnitude of revenues shown in Fig. 2, revenues from carbon pricing would provide more than sufficient funds to fully cover these investments. Even though a large share of investments for climate change mitigation will likely come from the private sector incentivized for example, by a GHG price signal, public finance will arguably have a role to play. In the power sector, the largest utilities in industrialized countries as well as in India and China are often publicly owned, with at least partial public ownership in almost all cases, thus raising the issue of publicly financed decarbonization in case of these climate-relevant state owned enterprises (Koske et al., 2015). In the transport sector, cost-effective mitigation requires that private decisions are complemented by coordinated infrastructure investments. For example, to induce a shift toward cleaner modes of transport in cities, investments in public transport infrastructure or bicycle lanes are required (Bongardt et al., 2013).

Further investment needs arise for adaptation to the unavoidable impacts of climate change (Malik and Smith, 2012), with costs to adapt to the likely impacts of climate change believed to amount to between US$ 25 bln per year to well over US$100 bln per year by 2015–2030 (Fankhauser, 2010). Finally, addressing technology R&D market failures which are not appropriately tackled by a price on GHG emissions (Jaffe et al., 2005; Kalkuhl et al., 2012) would also require additional public support. However, these should be expected to be rather modest compared to energy system investments. According to the IEA (2014), in 2012 global spending on energy R&D from public as well as private sources amounted to about US$ 18.5 bln (out of which roughly US$ 2.5 bln were dedicated to fossil technologies, US$4 bln to renewables, US$3 bln to energy efficiency and a bit less than US$5 bln to nuclear). An efficient up-scaling of these funds would require incremental increases to enable R&D systems to absorb them in a productive manner.

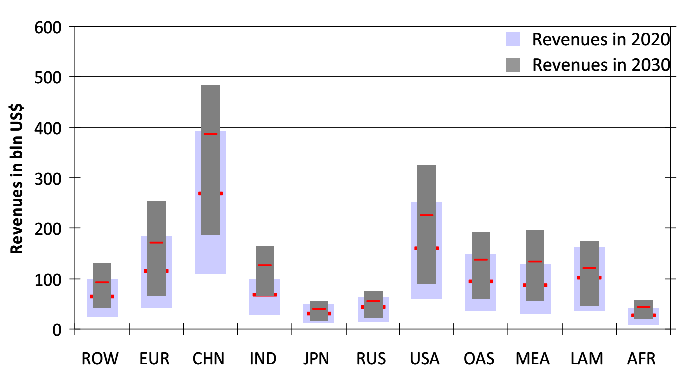

Fig. 2. Amount of annual revenues in bln US$ for different regions for different tax levels in 2020 (light gray) and 2030 (dark gray). Tax levels are set to $10 (lower bound of bars), $30 (red line) and $50 (upper bound of bars) per ton of CO_2, respectively in 2020, increasing by 5% per year. All mitigation technologies are assumed to be available. Scenarios are calculated using the ReMIND model (Leimbach et al., 2010) as described in (Luderer et al., 2013). See SI for details. (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)

2.3. Internalizing domestic climate change impacts and co-benefits of emission reductions

The failure of collective action has frequently been mentioned as a reason why individual countries so far have not introduced prices on emissions. Yet, even without taking into account the negative external effects inflicted on other countries, there should be an incentive to put a price on emissions that internalizes the climate impact that a country exerts on itself (Barrett, 1994; Carraro and Siniscalco, 1993).[1] For instance, a game-theoretic analysis based on the numeric model MICA (Lessmann et al., 2009) calibrated on different damage functions[2] employed in the literature reveals that in a Nash equilibrium in which countries strategically choose emission prices in a purely self-interested manner, India and China would – as identified by the largest estimates – implement carbon prices amounting to up to almost 40% and 25% of the optimal price respectively, while for the US and the EU the maximum values are up to 10% and slightly below 30%, respectively (see Fig. 3). The large spread in estimates between regions can be explained by differences in regional abatement costs and regional climate impacts, as well as possibilities to alleviate them through adaptation.[3] However, it should be also noted that there are large variations between estimates for any single regions. These are due to considerable model uncertainties related to (i) physical climatic changes, (ii) socio-economic impacts, and (iii) their monetary valuation (e.g. with regard to health). This large variation is not a particular to our study, but is a general feature of the literature assessing the 'social cost of carbon' (Tol, 2009).

The transformation of the global energy system toward low-carbon technologies and energy efficiency enhancements triggered by carbon pricing could have economic benefits that exceed those of avoided climate change. More efficient resource use, technological innovation, and additional employment opportunities are hoped to increase economic performance by means of 'Green Growth' (UNEP, 2011) and lay the foundation for a 'Green Industrial Revolution' (Stern, 2009). These arguments imply that an energy transition would be desirable even without taking climate change into account. However, recent studies have pointed

[1] Suppose there are three countries, A, B, and C, with marginal damages of 20,10 and 5 $/t$CO_2$, respectively. According to the Samuelson rule, the socially optimal policy would then be a carbon price of 35$ in each country, internalizing all damages. Yet, without cooperation countries would not impose this price. However, if they act rationally, they would impose an emission price equal to their own marginal damages, i.e. they unilaterally would impose (differentiated) prices of 20,10, and 5$, respectively.

[2] Damage functions are usually generated by fitting a cost function of a particular functional form (e.g. quadratic) to estimates from case studies for individual regions and economic sectors.

[3] The high estimate of the carbon price for India is explained by high damages as well as high abatement costs. By contrast, Sub-Saharan Africa, which also exhibits high vulnerability to climate impacts, would implement a lower domestic carbon price due to lower marginal abatement costs.

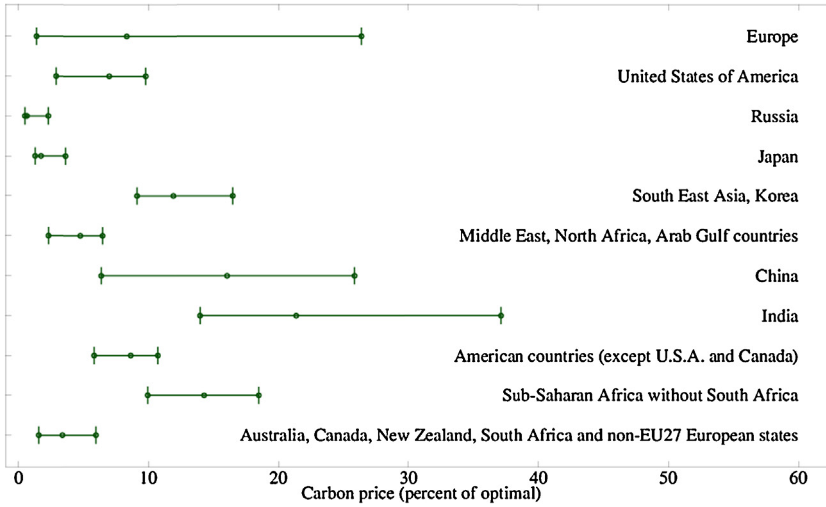

Fig. 3. Unilateral carbon prices calculated with the MICA model based on different damages functions as used in the RICE (Nordhaus and Boyer, 1999) and STACO (Dellink et al., 2004) models, expressed in terms of percentage of the optimal global carbon price calculated by MICA. For details, see SI.

out that the alleged benefits in terms of energy efficiency improvements and employment are likely to be smaller than expected by optimistic assessments (Allcott and Greenstone, 2012; Borenstein, 2012) and that a switch to low-carbon energy technologies does not entail the deep restructuring of economic activity and society witnessed during the industrial revolution (Demailly and Verley, 2013). Nevertheless, even though emission reductions are probably not a 'no-regret' option by themselves, they very likely entail synergetic benefits by either triggering the use of negative cost energy efficiency options that would otherwise remain untapped due to behavioral or market barriers (Staub-Kaminski et al., 2014), or increased technology spill-overs to other economic sectors (Dechezlepretre et al., 2013).

Besides the impacts of climate change, there are other externalities that are positively correlated with GHG emissions, at least in a second-best setting in which not all associated policy objectives are optimally addressed by specific policy instruments (Lipsey and Lancaster, 1956). For instance, according to McCollum et al. (2013) stringent GHG emission reductions would also improve air quality as a consequence of cleaner energy production, such that in 2030 the loss of 2–32 million disability adjusted life years would be prevented. A major uncertainty for policy design is that not only the material extent of these co-benefits, but also their economic valuation, is fraught with large uncertainties. Carrying out a review of the economic benefits of improved air quality from climate change mitigation in multiple countries, Nemet et al. (2010) find a range of US$ 2–196 per tCO_2 with a mean of US$49 per tCO_2 (with the highest co-benefits in developing countries). So, at least at the higher end of this range, these (domestic) co-benefits would be similar to – or even higher than – the (global) benefits of avoided climate impacts. Other co-benefits of climate change mitigation include reduced congestion, which would – as a consequence of reduced travel time – result in considerable economic benefits (Duranton and Turner, 2011). For example, for the city of Beijing, Creutzig and He (2009) estimate that the social costs of congestion as well as those of air pollution both amounted to more than 3% of regional GDP in 2005. Other urban transport benefits include public health effects from increased physical activity and noise ambience (Creutzig et al., 2012; Woodcock et al., 2009). In addition, low-carbon energy technologies have been identified as promising options to provide energy access to the poorest members of society, especially for regions without connection to the electricity grid (Casillas and Kammen, 2010). Henceforth, these policy objectives might be more important domestic motives for emission reductions than climate considerations, leading to a situation where multiple objectives are best addressed by multiple interacting policy instruments (Edenhofer et al., 2013d). This is confirmed by case study evidence suggesting that for India, energy security considerations dominate the climate policy discourse (Dubash, 2013), while for Vietnam increased resource efficiency appears to be the main objective of recently implemented Green Growth policies (Zimmer et al., 2015). Importantly, these types of benefits would unfold over much shorter timespans than those of climate change, and thus tend to align better with the priorities of policymakers.

2.4. Synthesis of unilateral incentives

We now provide in Fig. 4 a tentative comparison of quantifiable incentives for domestic action, revenue generation, avoided climate damages, and co-benefit. While the main purpose of this article is to provide an overview of the principal motivations to implement an emission price rather than speculating about its precise value, this tentative comparison demonstrates the relevance of this framework by pointing to plausible quantitative magnitudes of non-climate incentives. Revenues from emission pricing (x-axis) are calculated as described in Fig. 2 for an emission price of $30 in the year 2020, and avoided climate damages (y-axis) are median estimates from Fig. 3. Regional co-benefits of reduced ozone and PM2.5 pollution (area of circles) are taken from West et al. (2013) who employ a global chemical transport model. As a conservative value, we use their results obtained for their lower bound estimate for the 'statistical value for the loss of life'.

The results should be read as indicative, as substantial uncertainties, especially in avoided climate damages and to lesser degree in co-benefits, underlie the data. In addition, to comprehend the interplay between these motivations, they need to be assessed in a second-best framework à la Lipsey and Lancaster (1956), in which an economic distortion associated with one of the aspects simultaneously influences the emission price appropriate to target all others. That is, there are interaction effects between the different motivations, which – similar to the tax interaction effect identified in the double-dividend literature (see e.g. Goulder, 2013) – may have a downward influence relative to the thought experiment case in which heterogenous tax rationales are merely added up. The hypothesis adopted in this article is that – at least for a realistic set-up – each motivation

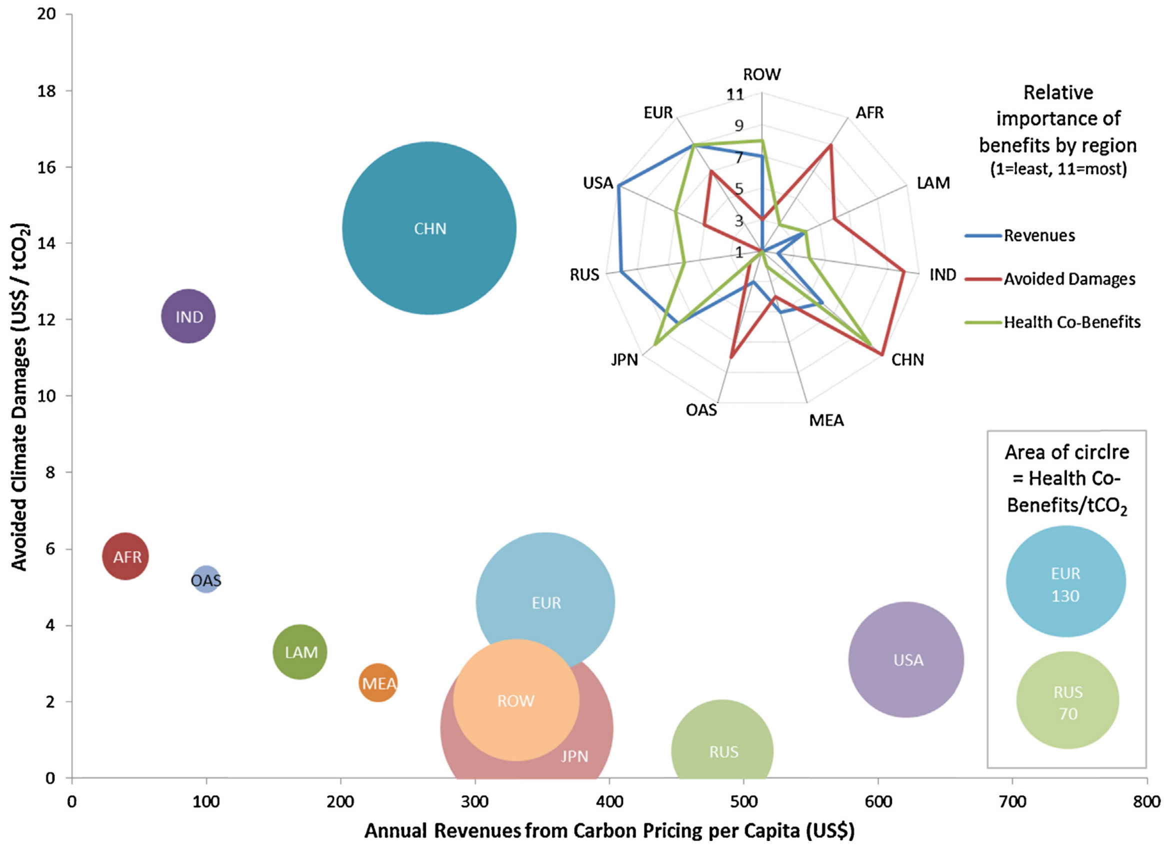

Fig. 4. Summary of incentives for unilateral carbon pricing by region: annual per capita revenues from a carbon price of USD 30/tCO_2 (*x*-axis), avoided climate damages per avoided tCO_2 (*y*-axis) as well as health co-benefits (area of circles). The upper right inlay ranks regions according to the size of benefits in these three dimensions. Data for revenues and avoided climate damages and were obtained from the calculations used for Figs. 2 and 3, respectively. See SI for details.
Source: Data for health co-benefits are from West et al. (2013).

included in the analysis results in an emission price above the one that would obtain if it were excluded, that is, that its positive influence on the emission price is not over-compensated by a negative interaction effect (for an example of optimal internalization of co-benefits in an Pigouvian urban transport setting see Creutzig and He, 2009). A more rigorous theoretical treatment and a quantification of the total into individual effects as well as their interaction require further analysis. In addition, most countries already apply an implicit emission price by means of for example, fuel and energy taxes. For the OECD, these emission prices range from below zero (subsidies) to above 800 €/ton CO_2, with an average of approximately US$ 27 per ton of CO_2 (OECD, 2013). These implicit prices might already capture or even exceed what is mandated by the motivations discussed in this article. A comprehensive assessment would require the formalization, quantification, analysis of interaction as well as evaluation of the multiple rationales underpinning each of these policies. Our analysis should hence best be regarded as formalizing a framework that helps to correct inefficient choice of taxes and other public policies.

Nonetheless, a few tentative conclusions on world-region-specific policy agendas emerge from this synthesis. Most importantly, China would have an incentive to act on climate change from all three quantified dimensions, but most importantly in terms of co-effects in reduced air pollution and avoided climate damages. The equally populous India, in turn, would profit mostly from avoided climate damages, but less so from co-benefits and revenues. The incentive structure is different for OECD countries and Russia. The US and to lesser degree Russia and then the EU and Japan would mainly benefit from obtained revenues of domestic climate pricing.

Overall these results suggest that world regions could start with differentiated pricing reflecting their idiosyncratic incentives. In turn, as incentives are different even for approximately equal pricing levels, domestic instruments could be designed but also communicated in a way that incorporates these specific incentive structures. For example, the US could highlight the revenue effects, or the compensating reduction in other taxes (White House, 2014). In turn, China could focus its mitigation efforts where these also reduce air pollution, for example, by first mothballing old coal power plants close to metropolitan regions and tackling urban transport.

A few specific observations complicate the picture. First, the co-benefits from air pollution are surprisingly large with values of up to $200/$tCO_2$ reported, higher than many estimates of the social costs of carbon. This could lead to the conclusion that climate change is only a secondary concern. Such a conclusion, however, is unwarranted for two reasons. First, the co-benefits correspond to direct physical benefits; they were not analyzed and calculated in systematic counterfactual analysis and hence do not reveal the opportunity costs of, for example, choosing climate mitigation action instead of direct tackling of air pollution measures (IPCC, 2014, Chapter 3). In short, the numbers were not obtained on equal par and cannot be compared as such. Second, the climate damages could be understood as being conservative in so far as climate change involves many unknowns of which, obviously, the costs are not known, if they can be calculated at all (e.g. climate-change contributions to deteriorating health, civil wars and mass migrations). Nevertheless, this analysis reveals two crucial observations: first, as effects other than climate change mitigation need to be included in the calculation, the resulting emission price will in general differ from (and might even exceed) the avoided climate damages. Second, as already noted by Hourcade and Gilotte (2000), different country-specific incentives, due to, for example, different levels of pollution and different preferences, result in different emission prices for different regions.

A patchwork of differentiated pricing of GHG emissions could reflect local incentives but could also be globally inefficient. In fact, climate change economics has for long argued in favor of a globally uniform price on carbon in order to avoid leakages. This concern suggests a way forward to the interplay between domestic action and international negotiations. While domestically differentiated pricing schemes can, first of all, lead to rapid action, international negotiations can then focus on harmonizing and distribution issues, increasing effectiveness, efficiency and equity of the differentiated pricing scheme.

One often voiced concern against differentiated emission pricing is emission leakage. That is, the emission reductions achieved in one area could be at least partially offset by increases in other areas with lower prices by means of relocation of polluting industries (Copeland and Taylor, 2004) or declining prices – and hence increased consumption elsewhere – of fossil fuels (Sinn, 2008). Yet, recent studies suggest that this effect is likely too small to seriously undermine the effectiveness of unilateral climate measures. For instance, in a comparison of 12 computable general equilibrium models, Böhringer et al. (2012) find leakage rates (i.e. the fraction of emission reductions offset by an increase of emissions elsewhere) between 5% and 19%, with a mean value of 12%. Some have pointed out that leakage could even become negative (i.e. there could be inter-regional emission reduction effects from first movers) either due to technology spillovers (Bosetti et al., 2009), crowding out of 'dirty' capital stock (Carbone, 2013; Baylis et al., 2013), induced inter-fuel substitution in other countries (Arroyo-Currás et al., 2013), or technology spill-overs that reduce other countries' abatement costs (Di Maria and van der Werf, 2008). Finally, emission leakage can to a certain extent be alleviated by specific policy instruments, including free allocation of emission permits to energy-intensive, trade-exposed sectors (Fischer and Fox, 2012) and trade measures (Jakob et al., 2014). For the latter, border tax adjustments and carbon tariffs, both of which impose a price on imports proportional to the amount of emissions generated in their production (Jakob et al., 2013), as well as trade sanctions that pose an incentive to adopt cleaner technologies (Urpelainen, 2013; Lessmann et al., 2009) are the most prominent instances.

Further, not only a price on emissions, but also the development of new technologies and learning effects that reduce the costs of existing technologies are crucial for the composition of technology portfolios and mitigation costs (Luderer et al., 2011). As argued above, a price on GHG emissions is essential to internalize the environmental externality. However, as there are additional market failures related to the development and diffusion of technologies, an emission price is not sufficient for cost-efficient climate change mitigation (Jaffe et al., 2005), especially when learning-by doing can result in a lock-in of carbon-intensive technologies (Acemoglu et al., 2012; Kalkuhl et al., 2012). For these reasons, emissions pricing needs to be complemented by technology policies, such as R&D subsidies, feed-in-tariffs, or renewable energy quotas, to address the corresponding market failures (Fischer and Newell, 2008). Emissions pricing can constitute one potential source to provide the financial resources for these policies.

Finally, like any economic policy, emissions pricing creates winners and losers. Some studies have indicated that emissions pricing would be regressive, as poorer households spend larger shares of their incomes on energy (the 'income uses' effect; Grainger and Kolstad, 2010). However, a more comprehensive analysis taking into account general equilibrium effects on factor rewards (such as interest on capital) finds a countervailing progressive effect (the 'income sources' effect Rausch et al., 2011), which may cancel out the income uses effect. In any case, an emission tax or similar instrument can be adjusted to have a progressive distributional effect if either existing taxes are lowered in a manner benefitting low-income households or public goods are provided in a way that more than proportionally benefits poorer people (Rausch et al., 2010). A further consideration for the political feasibility of emission pricing concerns the potential resistance of powerful interest groups, such as industry lobbies. While tax exemptions – which remove the incentive conveyed by the price signal – are economically inefficient to compensate losers, free allocation of emission permits has been discussed as a viable alternative (Pizer, 2002). As pointed out by Goulder (2013), if the US were to implement the emission reduction proposed under the Waxman-Markey bill, giving away about 13% of emission permits to energy-intensive industries would be sufficient to fully retain their profits. Under a tax system, a symmetric approach could be pursued by charging a tax not on actual emission, but on the difference to a defined threshold only, implying an infra-marginal tax exemption (Pezzey and Jotzo, 2013).

3. International negotiations

The previous sections have identified incentives for the unilateral adoption of a price on GHG emission that often operate on short-term time scales; they have argued that even without a global agreement to reduce GHG emissions several reasons exist for a government to impose an emission price above zero. While for most countries the motivations for unilateral action are unlikely to be sufficient to result in a domestic carbon price that is as high as the global socially optimal price, they might close a part of the gap between current emission prices in many world regions (see Fig. 1) and open opportunities for incremental progress toward an effective global climate regime. Hence, this section first evaluates how unilateral action could promote international cooperation and identifies gaps in existing research. It then outlines possible structures for an international climate agreement based on unilateral carbon pricing policies.

3.1. Changing the incentive structure

It is an open question whether an international climate regime can resolve the pervasive free-riding dilemma in protecting the atmospheric commons and adopt a globally (at least roughly) uniform optimal GHG price (Edenhofer et al., 2013a). But the benefits arising on the domestic level increase incentives for domestic carbon pricing. As optimal policy choices are interdependent (Hovi et al., 2014) – implications for one country's carbon pricing influences the optimal carbon pricing scheme in other countries. It remains nonetheless unclear whether – and under which circumstances – this interdependence can also promote international cooperation (Finus and Rübbelke, 2013). For instance, Hoel (1991) notes that in a game-theoretic setting, unilateral emission reductions could even increase global emissions, depending on the other players' reaction functions, and Konrad and Thum (2014) argue that – as it lowers the stakes of failing to agree for the other parties involved in the negotiation – early action can negatively affect the chance of reaching an agreement in a bargaining process. The question of interdependent reaction functions has only relatively recently been addressed by

Table 1
Channels through which unilateral action could promote collective action and main effects identified in the literature.

Channel	Effects
Technology spill-overs	Reducing abatement costs in other countries (Heal, 1999; Heal and Tarui, 2010), transform climate change mitigation in a coordination game in case of a 'breakthrough technology' (Barrett, 2006)
Social learning and signaling	Reduce uncertainty over benefits and/or abatement costs (Brandt, 2004; Kolstad, 2007), signal high willingness to provide side-payments in future agreement (Caparrós et al., 2004; Jakob and Lessmann, 2012)
Reciprocity	Preference for equitable burden sharing (Lange and Vogt, 2003; Lange et al., 2007), preference for cooperative behavior (Andreoni and Samuelson, 2006)
Political economy and institutions	Easing political opposition (Putnam, 1988), creating constituencies (Urpelainen, 2013), building institution (Keohane, 1984; Ostrom, 2010)

an emerging literature on the issue of leadership, which identifies conditions under which unilateral action can promote action in other regions (Schwerhoff, 2015). Some key insights from this literature are summarized below (see Table 1).

First, early action by some countries has the potential to enhance mitigation incentives for other countries and facilitate the implementation of a more ambitious international climate regime (compared to the case where countries do not implement domestically motivated carbon prices) when mitigation costs decrease via technology spill-overs (Heal and Tarui, 2010). If such spill-overs can reduce the costs of low-carbon technologies below those of traditional energy technologies, climate change mitigation is transformed from a prisoners' dilemma into a coordination game (with a carbon-intensive and a low-carbon equilibrium) (Heal, 1999). This is particularly relevant for the case in which R&D costs decrease with the amount of R&D undertaken. Then, a green 'breakthrough' technology is more likely to be adopted and to increase the size of the coalition of countries contributing to the provision of the public good (Barrett, 2006). However, there are also strategic incentives to delay investment in clean technologies in order to achieve a more favorable bargaining position in a future global agreement (Beccherle and Tirole, 2011).

Second, in a setting with asymmetric information, early action can be perceived as a signal of high willingness to cooperate in the future (Jakob and Lessmann, 2012). If it credibly conveys the information that the early movers have a high willingness-to-pay for climate change mitigation but also face high abatement costs, other countries will expect to receive side-payments in the future, establishing an incentive to also introduce their own carbon pricing schemes. Hence, removing uncertainty with regards to the benefits of early movers can also help transform the underlying game from a prisoners' dilemma into a coordination game (Caparrós et al., 2004). It has further been demonstrated that, if abatement costs are correlated across countries and only known with uncertainty, early action by one can act as a credible signal for low overall abatement costs, giving rise to additional abatement by other countries (Brandt, 2004). In a similar vein, reduced uncertainty with respect to costs and benefits of climate change mitigation has been shown to increase participation in and contributions to an international climate agreement (Kolstad, 2007). From this perspective, early action can be regarded as contributing to social learning that entails knowledge transfer – similar to technology spill-overs – to other countries (Chatterji et al., 2013). Likewise, it has been pointed out that building a regime to facilitate future cooperation can be an important motivation for unilateral action and is identified by some authors as one of the main drivers of EU climate policy (Gupta and Ringius, 2001).

Third, national policies are arguably not exclusively determined by cost–benefit considerations, but also influenced by notions of justice and fairness (Gardiner, 2004). For instance, laboratory experiments indicate that individuals have a strong tendency to reciprocate cooperative behavior and reward others for the provision of a public good (Rand et al., 2009). Even though it is not straightforward to draw the analogy from individual behavior to national policies, it seems plausible that such normative preferences also play a role for international relations theory (Keohane, 1984). As a consequence, one can conjecture that with a preference for equitable burden sharing, unilateral action by some countries could foster participation by other countries in an international climate agreement (Lange and Vogt, 2003). For instance, even though developing nations might have considerable interest in climate change mitigation, their willingness to reduce their emissions likely depends to at least some degree on whether industrialized countries are perceived to contribute their 'fair share' to climate stabilization (Lange et al., 2007). Hence, appropriately taking into account people's preference for cooperation in institutional design and gradually increasing commitments to create trust can promote collective action (Andreoni and Samuelson, 2006).

Fourth, unilateral emission pricing policies possibly starting at moderate levels of ambition (and moderate economic and political risk) might facilitate incremental progress toward an ambitious international regime by creating constituencies and changing the landscape of the political economy. As the introduction of emission pricing in some countries could alleviate leakage and competitiveness concerns and hence ease the resistance of energy-intensive industries in other countries (especially those perceiving each other as direct economic competitors), unilateral action has the potential to trigger further participation in an international climate treaty.[4] Furthermore, an institutional framework that identifies areas where international climate finance would be particularly useful for a country given its specific circumstances (co-benefits) could serve as a basis for policies that might be modified contingent upon the reception of international climate finance (e.g. increasing domestic carbon prices, or increasing stringency of technology policies, perhaps including modified compensation measures for targeted societal groups financed by international climate finance) (Urpelainen, 2013).

Therefore, unilateral policies could be regarded as a key building block of a 'polycentric climate regime' that takes into account the benefits of climate change mitigation arising in different dimensions and at different levels of governance in decentralized and partially coordinated policies (Ostrom, 2010). This is exemplified by the mutual reinforcement of interests of member states, the European Commission, and the European Parliament that resulted in the formulation of EU climate policies (Schreurs and Tiberghien, 2007). Furthermore, policy coordination opens avenues to extend carbon pricing through 'issue linkage', for instance by negotiating environmental provisions jointly with

[4] A similar mechanism that conceives international agreements as 'two-level games' (Putnam, 1988), in which actions in one country influence the domestic political economy in other countries, has been demonstrated for the 'domino-theory' of trade liberalization (Baldwin, 1993).

technology cooperation (Lessmann and Edenhofer, 2011) or trade agreements (Baghdadi et al., 2013). Likewise, trade sanctions could be introduced as a punishment mechanism to deter free-riders (Lessmann et al., 2009).

3.2. Possible shapes of a hybrid international climate agreement

Several recent contributions have assessed hybrid regimes in which bottom-up incentives are coordinated in an international framework. Rietig (2014) argues that climate negotiations should, instead of focusing on legally binding quantitative reduction commitments, be organized as open to exchange bottom-up pledges and share experiences with regard to policy design and effectiveness. Edenhofer et al. (2013b) propose a hybrid and dynamic architecture for an international climate regime emerging from The Durban Platform for Enhanced Action. Such a regime might emerge from a bottom-up approach based on decentralized country policy pledges, in particular with regard to domestic carbon prices. Centralized top-down coordination functions, such as monitoring of emissions, peer-review of commitments, or regulation of carbon markets could then be undertaken within existing or newly created UNFCCC mechanisms (Dubash and Rajamani, 2010). Interstate institutions could be complemented by more decentralized transnational policy coordination allowing sub-state actors and civil society to advance the climate policy debate and circumvent lack of ambition on the national level (Abbott, 2012). Such coordination mechanisms could also serve as platforms to coordinate domestic policies, for example, for the linking of regional or national emission trading systems (as currently pursued by California and Quebec (Ranson and Stavins, 2014) or joint R&D efforts (De Coninck et al., 2008).

To enable flexibility in accommodating diverging policy preferences, it seems reasonable and in fact unavoidable to allow countries committing to a broad range of policy packages, such as carbon pricing, emission reduction targets, intensity targets, support for renewable energy technologies and R&D, or energy efficiency programs, instead of focusing rigorously on negotiating country-level long-term ‘targets and timetables’ or ‘emission budgets’, which have been the focus of UNFCCC negotiations over the last decades (Victor, 2011).

One focus of negotiations could be on increasingly harmonizing domestic GHG prices across countries (Cooper, 2007; Nordhaus, 2007; Weitzman, 2013; Morris et al., 2013). This would ensure efficiency of the global mitigation effort by harmonizing the level of ambition across countries, and would address concerns over competitiveness and carbon leakage arising in a world of strongly asymmetric GHG prices (see below). Countries that have adopted cap-and-trade systems which regulate the quantity of emissions rather than their price might consider the implementation of minimum and maximum prices (so-called price collars; Fell et al., 2012). This approach has been adopted in the ETS recently established in California and Quebec as well as in the Regional Greenhouse Gas Initiative (RGGI) scheme and does not only offer more stable investment environments for private firms and enhanced certainty over public finance revenues from permit auctioning, but would also enable the coordination of minimum GHG prices across world regions. Such international coordination might involve precisely defined conditionality of domestic carbon pricing schedules contingent of other regions’ implementation of certain carbon price levels (and potentially other policy reforms, such as the phase-out of fossil fuel subsidies). To address differences in the willingness or ability to impose carbon prices in line with a global target price range, transfer payments (Chichilnisky and Heal, 1994) channeled through, for example, the Green Climate Fund (http://www.gcfund.org/) might be conceived.

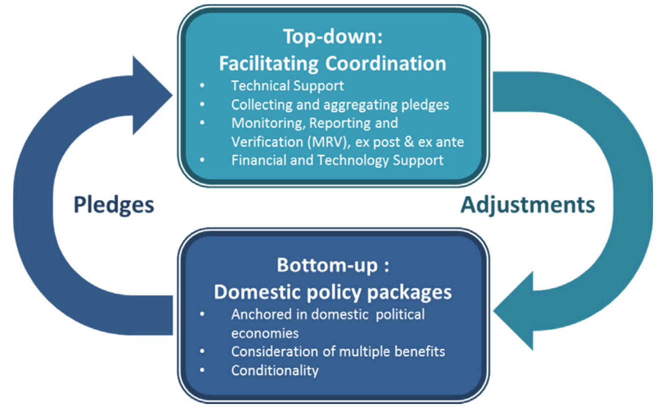

Fig. 5. Structure of a dynamic hybrid climate regime.
Source: Based on Edenhofer et al. (2013b).

Centralized functions of the formal climate regime might include technical support in devising domestic policy packages, collecting and aggregating pledges in terms of their combined outcomes in order to inform negotiations over enhancing the collective level of ambition, providing transparent monitoring, reporting and verification (MRV) of policy packages to assure countries they do not become victims to free-riding (Aldy and Pizer, 2014), and financial as well as technological country support (see Fig. 5). Such a regime could be rendered dynamic by enabling adjustments to domestic policy packages as well as international coordination functions over time, with countries increasing their efforts conditional on increased ambition by other countries (Victor, 2011).

4. Conclusions

This article demonstrates that even in the absence of a global agreement on climate change mitigation, every country has a plausible reason to impose an emission price above zero. First, emission pricing would be mandated to generate revenues for the government budget that enables decreasing other distortionary taxes, as well-established in the double-dividend literature. Second, an emissions price may improve macroeconomic efficiency by reducing tax competition and correcting investment behavior, and additional revenues from emission pricing could help to promote human well-being by financing the provision of public infrastructure and contribute to meeting financing needs for mitigation and adaptation. Third, even if countries do not internalize the negative effects of their emission on others, they would still put a price on their emissions equal to the marginal damage they exert on themselves. Furthermore, important co-benefits in the form of for example, reduced air pollution, less congestion, increased energy access and energy security as well as improved resource efficiency could be at least as important as the benefits of climate change mitigation. We also show that the above incentives can differ rather widely across countries: while for China avoided climate damages and co-benefits of reduced air pollution appear to be the main motivation for emission pricing, for the US generating public revenue is perhaps of highest importance, and for the EU all three incentives are of intermediate importance.

These unilateral motivations are unlikely to be sufficient to achieve the globally optimal emission price. However, they could – by closing part of the ‘emission price gap’ – pave the way toward a global climate agreement and – by avoiding lock-in of carbon-intensive technologies and infrastructures – keep the option of achieving ambitious climate change mitigation in the future open. Importantly, many of these positive effects operate on much shorter timescales than climate change, thus providing incentives for their adoption by policymakers operating under short-term political constraints.

We have proposed that unilateral emission prices in different countries could form the building blocks of a 'polycentric climate regime'. These domestic policies could be coordinated on the international level by a 'hybrid agreement' allowing coordination of a variety of policy packages instead of focusing on a rigid targets and timetables approach to emission reductions.[5] Such an agreement could be gradually scaled up over time by countries pledging to increase their effort conditional on policy support or more ambitious targets in other countries. Regardless of the underlying motivation for adopting domestic GHG emission reduction policies, the agreement structure outlined above would provide the required flexibility to coordinate national policies into an international framework. In particular, as the motivations appeal to different interest groups on short-term time horizons they offer an opportunity for policy makers to assemble suitable societal coalitions to garner political support for GHG emission pricing. In this context, emissions pricing can increase the political feasibility of emission reduction policies: even though non-market regulatory policies (such as efficiency standards) may appear politically attractive by not making mitigation costs explicit, the cost efficiency of price based policies could potentially provide a more important political rationale. For instance, Parry et al. (2014b) estimate that for the US energy efficiency standards "when viewed as substitutes, these standards forgo 60 percent or more of the potential welfare gains from corresponding pricing policies" (p. 104). Finally, besides reducing current emissions, emission pricing could also have important long-term consequences by lowering future mitigation costs and hence making a policy reversal by successor governments less likely (Urpelainen, 2011).

Appendix A. Supplementary data

Supplementary data associated with this article can be found, in the online version, at doi:10.1016/j.gloenvcha.2015.01.003.

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[5] However, quantitative assessments of emission limits required to achieve a certain reduction target, such as carbon budgets, may provide useful focal points for negotiations.

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