HARVARD Kennedy School
JOHN F. KENNEDY SCHOOL OF GOVERNMENT

The Harvard Project on Climate Agreements

August 2013
Discussion Paper 13-59

Is There a Future for Intensity Targets in the Durban Platform Climate Negotiations?

Mariana Conte Grand

Universidad del CEMA
Buenos Aires, Argentina

Is There a Future for Intensity Targets in the Durban Platform Climate Negotiations?

Mariana Conte Grand

Universidad del CEMA

Buenos Aires, Argentina

Prepared for

The Harvard Project on Climate Agreements

THE HARVARD PROJECT ON CLIMATE AGREEMENTS

The goal of the Harvard Project on Climate Agreements is to help identify and advance scientifically sound, economically rational, and politically pragmatic public policy options for addressing global climate change. Drawing upon leading thinkers in Argentina, Australia, China, Europe, India, Japan, and the United States, the Project conducts research on policy architecture, key design elements, and institutional dimensions of domestic climate policy and a post-2012 international climate policy regime. The Project is directed by Robert N. Stavins, Albert Pratt Professor of Business and Government, Harvard Kennedy School. For more information, see the Project's website: http://belfercenter.hks.harvard.edu/climate

Acknowledgements

The Harvard Project on Climate Agreements would like to thank the Harvard University Center for the Environment for its generous support of the current series of publications.

The Harvard Project also receives support from Christopher P. Kaneb (Harvard AB 1990); the James M. and Cathleen D. Stone Foundation; ClimateWorks Foundation; and the Qatar National Food Security Programme. The Project is very grateful to the Doris Duke Charitable Foundation, which provided major funding during the period July 2007–December 2010. The Project receives ongoing support from the Belfer Center for Science and International Affairs at the Harvard Kennedy School.

The closely affiliated, University-wide Harvard Environmental Economics Program receives additional support from the Enel Endowment for Environmental Economics at Harvard University, the Enel Foundation, the Alfred P. Sloan Foundation, the Mossavar-Rahmani Center for Business and Government at the Harvard Kennedy School, Bank of America, Chevron Services Company, Duke Energy Corporation, and Shell.

Citation Information

Conte Grand, Mariana. "Is There a Future for Intensity Targets in the Durban Platform Climate Negotiations?" Discussion Paper 2013-59. Cambridge, Mass.: Harvard Project on Climate Agreements, August 2013.

The views expressed in the Harvard Project on Climate Agreements Discussion Paper Series are those of the author(s) and do not necessarily reflect those of the Harvard Kennedy School or of Harvard University. Discussion Papers have not undergone formal review and approval. Such papers are included in this series to elicit feedback and to encourage debate on important public policy challenges. Copyright belongs to the author(s). Papers may be downloaded for personal use only.

IS THERE A FUTURE FOR INTENSITY TARGETS IN THE DURBAN PLATFORM CLIMATE NEGOTIATIONS?

Mariana Conte Grand, Universidad del CEMA

EXECUTIVE SUMMARY

The international community has agreed that the average increase of global temperature should be limited to 2 degrees Celsius with respect to preindustrial levels in order to avoid massive damage due to climate change. To attain the atmospheric carbon concentration required for that goal, greenhouse-gas (GHG) emissions from all countries need to be reduced substantially. There is still no new commitment on which emission-reduction targets will be allocated to (and accepted by) various countries, but progress has been made.

In the international climate-change policy arena, Kyoto targets were designed as absolute caps with baselines in the past, as was the objective of the United Nations Framework Convention on Climate Change (UNFCCC). Copenhagen-Accord pledges are of four types: fixed reductions with respect to the past; absolute reductions with respect to the (future) business as usual (BAU) emissions; carbon neutrality objectives; and intensity caps with baselines in the past. Intensity caps, contrary to fixed caps, do not set a country´s allowable emissions level, but determine that level as a linear function of gross domestic product (GDP). Two countries submitted linearly indexed pledges to the Copenhagen Accord: China, to reduce its CO_2 emissions by 40–45 percent per unit of GDP by 2020, compared with 2005; and India, to reduce CO_2 emissions by 20–25 percent between 2005 and 2020.

The discussion of dynamic targets is not new. It began at the end of the 1990s as a means to foster developing countries´ participation in emissions reduction (Argentina designed a GDP-adjusted target in 1999). Intensity targets allegedly have the virtue, by indexing emissions with respect to GDP, of favoring green growth and avoiding "hot air" (allowances for emissions above expected levels) in uncertain contexts, such as those of many developing economies. General audiences tend to believe that intensity targets yield a sort of "double dividend": allowing growth and, at the same time, reducing emissions. What is certain is that these approaches deserve more attention.

This paper conducts a comparative analysis of fixed and intensity carbon targets and discusses their implications in simpler terms than has usually been the case. It focuses on four differences among those targets: how allowed emissions vary with GDP; how abatement levels depend on GDP; under which circumstances "hot air" can arise; and what are the critical factors that affect uncertainty about the level of emissions abatement. It then discusses intensity as an indicator of climate performance and deals with the need for homogeneity and reliability of GDP statistics in the design of intensity targets. In addition, several alternatives to pure intensity targets that attempt to overcome the difficulties associated with fixed caps and standard intensity targets are reviewed: growth-indexed emission limits; generalized intensity caps; dual targets; and "safety-valve" mechanisms.

Intensity targets add complexity, always involve lesser burdens than fixed targets at high GDP levels, and have the potential (in some cases) to lower abatement variability and decrease the likelihood of "hot air." There are countries and reduction levels for which intensity targets do not work. For those, alternative mechanisms should be given a chance. All alternatives have the potential to reduce the twin uncertainties of fixed targets (i.e., economic and environmental risk), so their adoption could be justified even if it implies increased effort. As stated by Goulder and Parry (2008, p.1), "selecting the 'best' instrument involves art as well as science." Uncertainty can alter the stringency of emissions targets so that the resulting abatement is

potentially different than what had been forecasted. But, it should be kept in mind that the ultimate objective of the new rounds of climate negotiations—intended to produce a new international agreement, under the Durban-/Platform process, by late 2015— is to engage all countries in actions that can alleviate climate change, through one type of target or another. Errors are possible, but the biggest error can be taking no action.

I. INTRODUCTION

The international community agrees that, in order to avoid massive damages due to climate change, the average increase of global temperature should be kept below 2 degree Celsius with respect to pre-industrial levels (Copenhagen Accord, Point 1[1]). Several research groups have analyzed the gap between the emissions levels needed to honor the Copenhagen Accord and the Parties´ climate policies (den Elzen and Höhne 2008, Macintsosh 2010, UNEP 2010, den Elzen et al. 2010, Levin and Bradley 2010, Rogelj et al. 2010). Analysis suggests the gap is substantial; closing it will require limiting emissions well below the level set by the Kyoto Protocol.

There is still no new commitment on which emission-reduction targets will be allocated to (and accepted by) various countries. Notwithstanding, progress has been made. The negotiations moved from the Thirteenth Conference of the Parties (COP-13) in Bali, where developed countries agreed to commit to quantifiable targets while developing countries would adopt "nationally appropriate mitigation actions" (NAMAs, Point 1.b.i., Bali Action Plan[2]), to the Seventeenth Conference of the Parties (COP-17) in Durban, where countries agree to "identify and to explore options for a range of actions that can close the ambition gap with a view to ensuring the highest possible mitigation efforts by all Parties" (Durban Platform of Enhanced Action, Point 7[3]).

All Parties are committed to combat climate change. But, the division between developing and developing countries remains. Developing countries argue that they have the right to increase emissions in order to meet their development needs, since they are not responsible for the GHG concentration levels that have resulted from developed countries´ economic growth. However, while growth in the developing world in recent years has surely lifted many of its inhabitants out of poverty, it has also has contributed to making less developed countries major CO_2 emitters.

The discussion about which is the best type of target to achieve the 2 degrees goal lies within a broader discussion of which is the best instrument for environmental regulation. In economics, it is accepted that under certainty (i.e., when additional benefits and costs of emissions control are known), either price or quantity mechanisms are equivalent in terms of efficiency and that the key to choosing among regulations is whether costs or benefits change more rapidly when the level of emissions changes. A tax (cap) is preferred if additional costs change more (less) than additional benefits (Weitzman, 1974). For GHG emissions, additional benefits from their control are approximately constant, as each country contributes emissions during a period that does not greatly change the global emissions stock, which is the result of many years of emissions and is the cause of climate change. On the other hand, control costs depend on countries´ variables, particularly, on their economic situation. Hence, if a cap is adopted, costs may be far from the benefits achieved and so the level of control chosen would be inefficient *ex post*.

However, there is more to instrument choice than efficiency, as has been recognized by economists. Regulatory instruments have been analyzed in terms of equity and political feasibility (Keohane, et al. 1998 or

[1] Page 5 at http://unfccc.int/documentation/documents/advanced_search/items/6911.php?priref=600005735#beg

[2] Page 3 at http://unfccc.int/resource/docs/2007/cop13/eng/06a01.pdf

[3] Page 3 at http://unfccc.int/resource/docs/2011/cop17/eng/09a01.pdf

Goulder and Parry 2008, among others). Hence, even if taxes offer greater opportunities for efficiency in climate regulation, given public resistance to price instruments, policymakers end up choosing among various quantity regulations: simple emission reductions or more complex indicators as emission intensity alternatives (Pizer 2002; Newell and Pizer, 2008; Webster et al. 2010). Equity and political feasibility, more than efficiency, may explain the types of targets adopted in Kyoto, in the pledges submitted by Parties to comply with the Copenhagen Accord, and in future compromises.

In effect, the discussion of "intensity targets" began as a means to foster developing countries´ participation in emissions reduction (Baumert et al. 1999; Frankel 1999). At the end of the 1990s, the Clinton Administration had decided it would not submit the Kyoto Protocol for ratification to the U.S. Senate unless developing countries decided upon their "meaningful participation" in international climate policy. The advantage presented to the developing countries who adopted a target was access to all of the Kyoto instruments.[4] However, the difficulties of adopting fixed GHG targets soon came into view, and intensity caps appeared as a possible alternative for designing developing countries´ targets.

The advantages and disadvantages of fixed targets have been widely studied in the environmental economics literature. Lutter (2000) foresees two problems associated with fixed caps: 1) "economic risk" (if income increases more than expected, abatement would be higher than expected and so would be the corresponding costs of abatement), and 2) "environmental risk" (if a country suffers an unexpected low growth period, abatement can become negative and that country would sell emissions permits "without undertaking real reductions": emissions may be greater than in the absence of such commitments).[5] Governments tend to give higher priority to certainty in economic costs, as these have political costs. Avoiding the second likely impact of fixed targets ("hot air" or allowances for emissions above expected levels) is not a priority for individual negotiators, as the "extra" allowances have financial value, despite their adverse effect on the world environment.

Intensity targets allegedly have the virtue of favoring green growth and avoiding "hot air" in uncertain backgrounds, like those of many developing economies.[6] Intensity caps, contrary to fixed caps, do not set a country´s allowable emissions level, but determine it as a linear function of GDP. "Pure" or "linear" intensity targets imply determining emissions intensity, while fixed targets imply capping emissions. However, Ellerman and Sue Wing (2003) show, using a simulation model for the European Union and analyzing it for Germany, that if GDP is higher (lower) than expected, an absolute cap implies higher (lower) effort levels than an intensity cap, and thus higher (lower) costs. Hence, the superiority of one approach over the other depends on what the actual economic outcomes are, as compared to the expected ones. Intensity caps seemed less advantageous than they had been thought to be. Their apparent resolution of the "twin uncertainties" was questioned.

As a result, several alternatives to pure intensity targets were envisaged: growth-indexed emissions limits (Ellerman and Sue Wing 2003; Sue Wing et al. 2009); generalized intensity caps (Höhne and Harnish 2002; Jotzo and Pezzey 2007); dual targets (Philibert and Pershing 2001; Kim and Baumert 2002) and "safety valve" mechanisms (McKibbin and Wilcoxen 1997; Pizer 2002; Jacoby and Ellerman 2004). Each attempts to overcome

[4] The Kyoto Protocol introduced three market-based mechanisms. Joint Implementation (JI) and the Clean Development Mechanism (CDM) are project-based. While JI enables industrialized countries to carry out joint projects with other developed countries, the CDM involves developed countries´ investment in projects that reduce carbon emissions in developing countries. The Emissions Trading (ET) mechanism does not require a joint project to be undertaken with partners in another country. Through the Kyoto Protocol, the CDM is the only mechanism that can be used by developing countries, but that mechanism, since it is project-based, is less flexible than ET.

[5] Kim and Baumert (2002, p. 109) refer to those two problems as "twin uncertainties".

[6] Lutter (2000), analyzing the U.S. Energy Information Administration's past projections of U.S. emissions, calculates that 87 percent of the forecasts turn out to be too low. That lack of precision in both GDP and emissions forecasts has been highlighted by several authors: Jotzo (2006) for 22 countries, Newell and Pizer (2008) for 19 high-emitting countries, and Marchsinski and Edenhofer (2010) for China, India, and Russia. In unstable economies, such as those of many developing countries, reliable forecasting of GHG emissions is especially difficult.

the difficulties associated with standard intensity targets. But, in doing so, each adds complexity to both the design and the evaluation of the regulation.

This paper specifically discusses alternative economy-wide types of targets, not emphasizing their legal character.[7] It seeks to contribute to more informed discussions about the metrics of caps in the new rounds of international climate negotiations. In other words, the main objective is to review intensity targets' performance in a simpler way than that which is usually found in the literature and, on that basis, discuss the strengths and weaknesses of intensity targets. This should help improve policymakers' and negotiators' understanding of the advantages and disadvantages of adopting intensity targets and thus be a guide for future discussions of climate targets.

This paper is organized as follows. The following section reviews briefly the types of quantified economy-wide emissions caps in climate fora since the UNFCCC's signing. Section III describes emissions and emissions-intensity metrics—their strengths and weaknesses—and illustrates how the shape of the relationship between emissions and GDP affects the relative performance of different types of targets. Section IV summarizes alternatives to fixed and intensity targets. Section V concludes.

II. QUANTIFIED ECONOMY-WIDE EMISSIONS CAPS IN CLIMATE FORA

This section discusses different caps´ metrics adopted or proposed in international climate-change negotiations.[8] The first cap on emissions related to climate change was the UNFCCC voluntary target for Annex I Parties (i.e., developed countries and economies in transition) that established the desirability of returning individually or jointly to the 1990 levels of GHG emissions by 2000 (art 4.2. a. and b[9]). After that, under the Kyoto Protocol, Annex B Parties (mostly the same countries as those in Annex I, except for the United States) commit themselves to "quantified emission limitation and reduction commitments" for GHG (art. 3.1 [10]) to have been attained in 2008–2012. The limitations varied among Parties, but accounted for an average of a 5.2 percent reduction with respect to 1990 levels. Most Parties were required to reduce emissions below the base year level (from minus 5 to minus 8 percent), some had limitations set at the base year level (Russian Federation, New Zealand, and Ukraine), while others had limits above that base year level (plus 10 percent for Iceland, plus 8 percent for Australia, and plus 1 percent for Norway).[11]

Developing countries never adopted specific quantified targets either under the UNFCCC or under the Kyoto Protocol. Nevertheless, there are two exceptions to that rule: Kazakhstan and Argentina. These nations enacted at some point in time different policies than the other developing economies. Kazakhstan requested to be admitted to Annex I for the purpose of the Kyoto Protocol, while Argentina, in 1999, developed a target and asked for a "new option" of entry into the Protocol (Argentine Republic, 1999). Argentina´s target represented

[7] Herzog et al. (2006) structure the discussion of targets around four issues: *target metrics* (how the target is measured); *stringency* (emissions reduction required); *scope* (type of gases and sectors it encompasses); and *legal character* (voluntary or compulsory). Up until now, emissions caps were mandatory while intensity caps were all voluntary, and intensity targets may be better for some sectors than others or not. But, the discussion here is limited to the form of the target. References to stringency are made only to the extent that it impacts the performance of target metrics.

[8] Domestic policies can vary considerably from international ones. For example, the United States has enacted a fixed target in international fora, but has set an intensity target domestically (in February 2002,the White House (2002)- announced a domestic target to reduce emissions intensity by 18 percent over the decade 2002–2012). Here, the discussion is on countries´ international climate policies only.

[9] Page 12 at: http://unfccc.int/files/essential_background/background_publications_htmlpdf/application/pdf/conveng.pdf

[10] Page 3 at: http://unfccc.int/resource/docs/convkp/kpeng.pdf.

[11] Generally, the base year is 1990 but some countries (Bulgaria, Poland, Romania, and Slovenia) have another base year, while Hungary´s base is an average of three years.

minus 10 percent with respect to the BAU scenario in 2008–2012 and determined allowed emissions with respect to the square root of GDP. Argentina´s incentives to adopt such an intensity cap were its political alignment with the United States at that time and its interest in participating in all the Kyoto flexibility mechanisms. However, Argentina finally removed its proposal from the agenda because its administration changed, and the new government, which had been elected just before the announcement of the target at COP 4 (Buenos Aires, 1998), did not support the idea of adopting a GHG target of any form (Barros and Conte Grand 2002; Bouille and Girardin 2002).

Finally, another set of quantified targets in climate negotiations (though voluntary) are those proposed under the Copenhagen Accord (CA).[12] Developed countries have submitted emissions reduction pledges that go from minus 5 percent to minus 40 percent. Caps are designed to be attained by 2020, and the base years differ among the proposals. For example, Australia uses 2000 as the reference year, the U.S. and Canadian targets are anchored to 2005, while the rest of the pledges refer to emissions in 1990 (Levin and Bradley 2010). On the other hand, some developing countries have submitted proposals that include NAMAs, but also economy-wide emissions caps. Developing countries´ proposed caps are of four types (Levin and Finnegan, 2011). Some of those targets are set as percentage reductions of emissions with respect to a given base year (the same metric as developed countries´ reduction pledges). In many cases, commitments are absolute emissions reductions from the (future) BAU levels in 2020. Other countries set reductions in emissions intensity in comparison to a base year. For example, China made a pledge to cut CO_2 emissions per unit of GDP by 40–45 percent below its 2005 level by 2020, and India proposed a 20–25 percent emissions intensity reduction over the same period.[13] And, finally, there are countries (e.g, Costa Rica) whose aim is to achieve carbon neutrality by 2020 (i.e., zero net emissions: emissions do not exceed sequestration). Table 1 shows the different types of caps.

Table 1. Different types of targets in international climate negotiations

	Country	Base	Target	Metric	Stringency (θ)
Kyoto Protocol*	Australia	1990	2008-2012	CO2eqEmissions	+8%
	Bulgaria	1988	2008-2012	CO2eqEmissions	-8%
	Canada	1990	2008-2012	CO2eqEmissions	-6%
	Croatia	1990	2008-2012	CO2eqEmissions	-5%
	Czech Republic	1990	2008-2012	CO2eqEmissions	-8%
	Estonia	1990	2008-2012	CO2eqEmissions	-8%
	EU-15**	1990	2008-2012	CO2eqEmissions	-8%
	Hungary	1985-1987	2008-2012	CO2eqEmissions	-6%
	Iceland	1990	2008-2012	CO2eqEmissions	+10%
	Japan	1990	2008-2012	CO2eqEmissions	-6%
	Latvia	1990	2008-2012	CO2eqEmissions	-8%
	Liechtenstein	1990	2008-2012	CO2eqEmissions	-8%
	Lithuania	1990	2008-2012	CO2eqEmissions	-8%
	Monaco	1990	2008-2012	CO2eqEmissions	-8%
	New Zealand	1990	2008-2012	CO2eqEmissions	0
	Norway	1990	2008-2012	CO2eqEmissions	+1%
	Poland	1988	2008-2012	CO2eqEmissions	-6%
	Romania	1989	2008-2012	CO2eqEmissions	-8%
	Russian Federation	1990	2008-2012	CO2eqEmissions	0
	Slovakia	1990	2008-2012	CO2eqEmissions	-8%
	Slovenia	1986	2008-2012	CO2eqEmissions	-8%
	Switzerland	1990	2008-2012	CO2eqEmissions	-8%
	Ukraine	1990	2008-2012	CO2eqEmissions	0

[12] CA, Point 4: "Annex I Parties commit to implement individually or jointly the quantified economy wide emissions targets for 2020, … Annex I Parties that are Party to the Kyoto Protocol will thereby further strengthen the emissions reductions initiated by the Kyoto Protocol" (page 6 at: http://unfccc.int/resource/docs/2009/cop15/eng/11a01.pdf). Developing countries, on the other side, have to present concrete action toward climate change, but not specific caps (CA, Point 5).

[13] China´s target has received a high level of attention in the empirical literature in part because it is based on an intensity indicator, but also because China represents a very large share of total global emissions. It has grown at an exceptionally high rate over recent years, and so have its emissions, but its emissions intensity has declined. China´s target has raised the issue of whether or not it just represents the BAU trend. There are no unanimous conclusions in that regard. Some authors consider China´s commitment to be on the BAU emissions trajectory and that emissions intensity in China was decreasing anyway (Qiu, 2009). Some articles refer to a target slightly more ambitious than BAU (Steckel et al., 2011). Others believe that China´s target, while feasible, is rather ambitious (for example, Stern and Jotzo, 2010 estimate that a BAU scenario is a reduction in emissions intensity of 24 percent, not 40 percent or 45 percent).

Copenhagen pledges	Australia	2000	2020	GHGEmissions	-5/-25%
Annex I	Belarus	1990	2020	GHGEmissions	-5/-10%
	Canada	2005	2020	GHGEmissions	-17%
	Croatia	1990	2020	GHGEmissions	-5%
	EU and its Member States	1990	2020	GHGEmissions	-20/-30%
	Iceland	1990	2020	GHGEmissions	-15/-30%
	Japan	1990	2020	GHGEmissions	-25%
	Kazakhstan	1992	2020	GHGEmissions	-15%
	Liechtenstein	1990	2020	GHGEmissions	-20/-30%
	Monaco	1990	2020	GHGEmissions	-30%
	New Zealand	1990	2020	GHGEmissions	-10/-20%
	Norway	1990	2020	GHGEmissions	-30/-40%
	Russian Federation	1990	2020	GHGEmissions	-15/-25%
	Switzerland	1990	2020	GHGEmissions	-20/-30%
	Ukraine	1990	2020	GHGEmissions	-20%
	USA	2005	2020	GHGEmissions	-17%
Non-Annex I***	Antigua and Barbuda	1990	2020	GHGEmissions	-25%
	Marshall Islands	2009	2020	CO2 emissions	-40%
	Republic of Moldova	1990	2020	GHGEmissions	No less than 25%
	Brazil	BAU	2020	Emissions	-36.1/-38.9%
	Chile	BAU	2020	Emissions	-20%
	Indonesia	BAU	2020	Emissions	-26%/-41%
	Israel	BAU	2020	GHGEmissions	-20%
	Mexico	BAU	2020	GHGEmissions	UP TO -30%
	Republic of Korea	BAU	2020	GHGEmissions	-30%
	Singapore	BAU	2020	GHGEmissions	-16%
	South Africa	BAU	2020	Emissions	-34%
		BAU	2025	Emissions	-42%
	China	2005	2020	Carbon dioxide emissions per unit of GDP	- 40/-45%
				Share of non-fossil fuels in primary energy consumption	Reach 15%
				Forest coverage and forest stock volume	+ 40 mill.has./+ 1.3 bill.m^3
	India	2005	2020	Emissions intensity of its GDP (grams of CO2eq excluding agriculture, per Rs. of GDP)	-20/-25%
	Bhutan		2020	Emissions do not exceed its sequestration capacity	
	Costa Rica		2021	Carbon neutrality	
	Maldives		2020	Carbon neutrality	
	Papua New Guinea		2030	GHG emissions	-50%
			2050	Carbon neutrality	

Source: http://unfccc.int/kyoto_protocol/items/3145.php. Kyoto Protocol to the UNFCCC, United Nations 1998 (Article 3, Annex A, Annex B). Appendix I Quantified economy-wide emissions targets for 2020 http://unfccc.int/meetings/copenhagen_dec_2009/items/5264.php. Appendix II Nationally appropriate mitigation actions of developing country Parties http://unfccc.int/meetings/cop_15/copenhagen_accord/items/5265.php.

*Notes: Rs. = Rupees. * Targets of Kyoto Protocol in carbon dioxide equivalent.** EU-15=15 States who were EU members in 1997 when the Kyoto Protocol was adopted.**** Includes non–Annex I countries who submitted a pledge with their NAMAS. Guyana and Thailand are not included: they submitted pledges, but not NAMAs.

III. EMISSIONS AND EMISSIONS INTENSITY METRICS

This section synthesizes the advantages and disadvantages of fixed emissions and emissions intensity targets.[14]

III.1. STRENGTHS AND WEAKNESSES OF FIXED AND INTENSITY TARGETS

Fixed targets imply the determination of emissions to be attained in the future as reductions with respect to some baseline. Intensity targets set allowed emissions as a function of GDP, or, which is the same, determine a reduction in emissions intensity (i.e., amount of GHG emissions per unit of GDP) with respect to some point in time. This can be expressed as:

Allowed emissions for fixed targets:

$$E_T^p = (1-\lambda)\cdot E_B \tag{1}$$

Allowed emissions for intensity targets:

$$E_T^p = (1-\lambda)\cdot I_B \cdot GDP_T, \qquad I_B = \frac{E_B}{GDP_B} \rightarrow I_T = (1-\lambda)\cdot I_B \tag{2}$$

Where E_T^p is the level of allowed emissions in the target commitment year or period (T), E_B is the level of emissions in the base year (as shown in Section II, the base year can be in the past or can correspond to

[14] Appendix A shows the derivation of the results in this section using basic arithmetic, calculus, and statistics.

forecasted emissions in some future year), I_B refers to emissions intensity, GDP_T is the country's gross domestic product, and λ is a fraction that reflects the percentage reduction intended by the target (in general $0 < \lambda < 1$, but as shown in Table 1 there are a few countries for which $\lambda \leq 0$ for Kyoto fixed caps). The stringency parameter can be adjusted to make expected allowed emissions under an intensity target equivalent to allowed emissions under a fixed target.[15]

The first difference in the design of those two targets is that the level of allowed emissions is known from the beginning in the first case, while it varies with the (future) GDP in the second case. For absolute targets, the level of allowed emissions is independent of GDP changes. In the case of intensity targets, given that $(1-\lambda)$ and emissions intensity in the baseline (E_B) are positive, there is a positive relationship between allowed emissions and GDP: when GDP increases, target emissions increase. That relationship is seen as one of the main advantages of intensity targets: they accommodate the need for emissions growth, while fixed targets do not. However, others see that characteristic as a drawback, as allowed emissions are uncertain at the moment the intensity target is designed, while they are known with certainty under a fixed target. Dudek and Golub (2003) go further and state that intensity targets are a way to "wrap up a weak environmental policy and make it look better." Nevertheless, it is not correct to say that intensity targets are *per se* less environmentally stringent than absolute targets. If economic growth is as expected, both types of targets are equivalent in terms of emissions.

Second, the adoption of a target implies reducing (abating) emissions with respect to what they would have been without the target:

$$A_T = E_T^{BAU} - E_T^p \tag{3}$$

where A_T is the reduction in the level of emissions (or abatement), E_T^{BAU} is the level of emissions under the BAU scenario, and E_T^p is the level of emissions that fulfill the commitment. In the case of fixed targets, if GDP is higher, the country's abatement effort has to increase because the level of BAU emissions increases, while the level of allowed emissions remains constant. The relationship between abatement and GDP is positive. For intensity targets, if the level of emissions does not follow GDP growth closely, and the stringency of the target is low (high), the effort imposed by an intensity target decreases (increases) when the economy improves. This happens because the level of emissions increases slightly (greatly) due to economic activity but the level of allowed emissions increases to a greater (lower) extent. In other words, the level of effort or abatement decreases (increases) when the economy evolves, depending on how the emissions level changes when the GDP changes in comparison to the stringency of the target. The relationship between abatement and GDP can be positive (or negative) and depend on the GDP level. What always holds is that abatement is lower (higher) under intensity targets than under fixed targets if GDP is higher (lower) than expected, because in the former the level of emissions is adjusted to economic circumstances, while for the latter there is no such adjustment.

A third difference among targets, related to the sign of the relationship between abatement and GDP, concerns the likelihood of "hot air" (in the words of Baumert et al. 1999: "allowances for emissions above expected levels", simply $A_T < 0$):

"Hot air" for fixed targets:

$$E_T^{BAU} < (1-\lambda) \cdot E_B \tag{4}$$

[15] Appendix B details the calibration of λ to yield emissions equivalence between fixed and intensity targets with baselines in the past and in the future.

"Hot air" for intensity targets: $$E_T^{BAU} < (1-\lambda) \cdot I_B \cdot GDP_T$$
(5)

In the case of fixed targets, "hot air" can only occur at low levels of GDP because there is a lower level of emissions in *T* under the BAU scenario than in the levels assigned by the target. Since *A* depends positively on GDP, "hot air" occurs for low GDP levels. But, "hot air" can also occur with intensity targets. For example, for high levels of economic activity when abatement depends negatively on GDP (which is possible for low emission-to-GDP elasticity levels and low levels of the target), it can happen that the level of emissions is high because of economic development, but the level of allowed emissions is even greater.

Finally, another characteristic that differs among targets is their uncertainty regarding costs. That uncertainty can be measured by the variability of abatement required by each. For fixed targets, the variance of abatement is determined by the variance of the level of BAU emissions, as the level of allowed emissions in the base year is given, and thus there is no uncertainty surrounding them. The variance of abatement with intensity targets is more complex, as it depends on uncertainty surrounding GDP and the level of emissions as well as on the stringency of the target. The intensity metric may be a means of reducing abatement (and cost) uncertainty by compensating for fluctuations in emissions levels due to economic activity. However, intensity targets do not always reduce abatement uncertainty, as they can under- or over-compensate for GDP changes. If uncertainty about future GDP is much higher than uncertainty about future emissions levels, then a coupling of the target to the GDP introduces more uncertainty instead of less. Similarly, if the correlation between emissions levels and GDP is low, there is not much advantage to coupling allowed emissions levels to GDP. This is the reason why, as it is broadly recognized in the literature, intensity targets do not work in economies or parts of economies where emissions levels are independent of GDP (i.e., non-CO_2 GHG emissions and emissions from land use change). Countries with a strong correlation between economic output and emissions levels and relatively low output variance are the ones that should favor intensity targets.[16]

III. 2. An Illustration

As shown in Section III.1. (and Appendix A), the characteristics of indexed intensity targets strongly depend on the relationship between emissions levels and GDP and on the target stringency. Hence, the linkage between emissions levels and GDP is the basis for designing intensity targets. The relationship between those two variables has been studied in the literature. For example, Höhne and Harnisch (2002) with International Energy Agency (IEA) data from 1971–1999 looked at GDP and emissions levels over time for four countries (India, the former Soviet Union, the United States, and the United Kingdom). They find significant GHG emissions-to-GDP elasticities (except for the United Kingdom) between 0.45 and 1.48, depending on the period and the country. Kim and Baumert (2002) found an elasticity of 0.95 for the Republic of Korea based on U.S. Energy Information Administration data for 1981–1998, Barros and Conte Grand (2002) estimate a 0.5 elasticity for Argentina with local data for 1990 –2005. In most of these cases, the relationship between emissions and GDP is assumed to have a specific log-log functional form. That shape results from taking logarithms of both sides of the following equation:

$$E_t = b \cdot {GDP_t}^a \qquad (6)$$

[16] Jotzo and Pezzey (2007, p. 266): "...standard intensity targets are expected to reduce uncertainty unless the degree of GDP-emissions linkage is very small compared to the target stringency". Newell and Pizer (2008, p. 223): "Those countries with a strong correlation between output and emissions and relatively low output variance tend to favor indexed quantities".

where E_t denotes emissions, GDP_t is the gross domestic product, and a is the elasticity of emissions with respect to GDP. In general, every country tends to have a fraction of its emissions somehow dependent on economic activity (generally those derived from energy, transportation, industry, and waste) and an autonomous part of emissions quasi-independent of GDP. This was the case of Argentina, which as mentioned had adopted a "square root" dynamic cap. What Argentina intended was to approximate its emissions pattern with respect to GDP ($E_t = c + b \cdot GDP_t$) through a square root shaped graph ($E_t = b \cdot GDP_t^{0.5}$).[17]

Assuming that (6) represents the functional form that best depicts the existing link between emissions levels and GDP, it is possible to illustrate the discussion in Section III.1 with an exercise.[18] As a result, allowed emissions levels under the fixed and the standard intensity target vary with GDP (Figure 1). Emissions levels are given for a fixed cap and depend positively on GDP for an intensity cap. Then, for fixed targets, abatement always depends positively on GDP, while it depends on the relationship between emissions levels and GDP in BAU (a) and the stringency in the case of intensity targets (Figure 2). Nevertheless, abatement under a fixed target varies more when GDP changes than does the abatement for an intensity target, since the latter has a mechanism of adjustment to GDP changes. Hence, excess burden and "hot air" can occur for intensity targets, even if that happens in different circumstances than for fixed targets.

[17] There is no reason to believe that the relationship between emissions and GDP is necessarily exponential. It could in fact involve a range of power transformations other than this one. Conte Grand and D´Elia (2013) show, testing against a Box-Cox (1964) transformation, that even if for most countries submitting Copenhagen pledges the emissions-GDP functions follows (6), there are also linear and more complex patterns.

[18] I_B and GDP_B are given and are the same for all graphs.

Figure 1. Allowed emissions under absolute and intensity cap for (6)

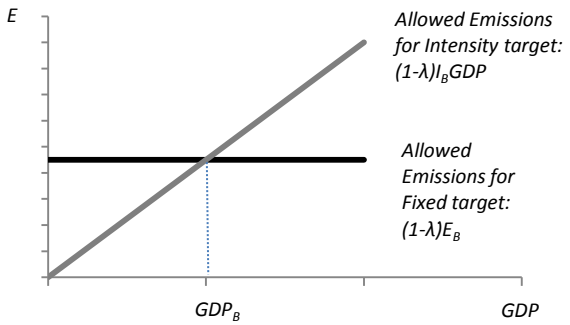
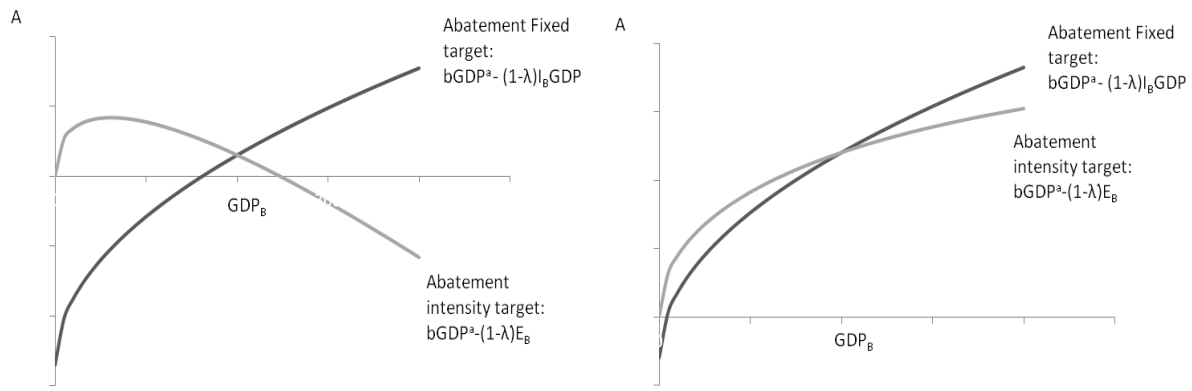


Figure 2. Abatement under fixed and intensity cap for (6)

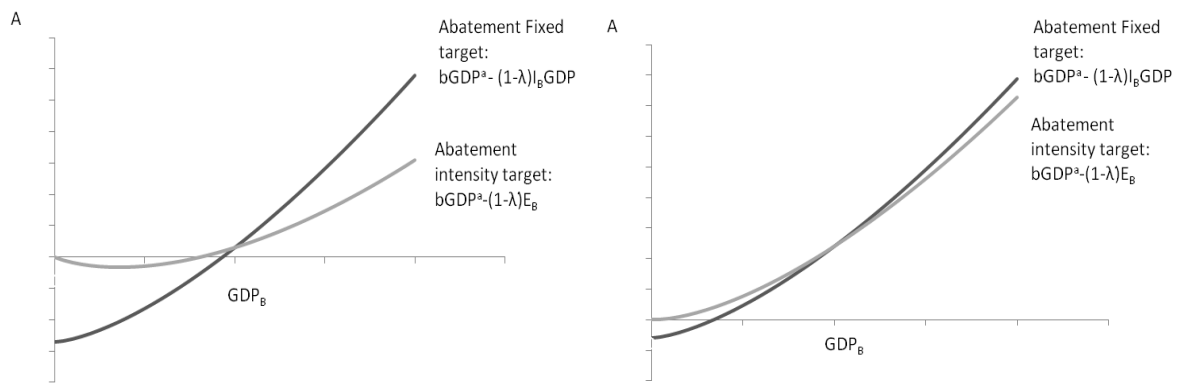
(A) a < 1

Low λ ***High λ***



(B) a > 1

Low λ ***High λ***



Note: The curvature of both fixed and intensity targets´ abatement is the same: concave if a > 1 and convex if a < 1.

IV. OTHER PROPOSALS

Other proposals developed to overcome the drawbacks of fixed and intensity caps.

IV.1. GENERALIZED GDP-ADJUSTED TARGETS

GROWTH-INDEXED EMISSIONS LIMITS

Ellerman and Sue Wing (2003), propose a "growth-indexed emissions limit" given by:

$$E_T^p = (1-\eta)\cdot \underbrace{[(1-\lambda)\cdot E_B]}_{FixedTarget} + \eta \cdot \underbrace{\left[(1-\lambda)\cdot I_B \cdot GDP_T\right]}_{IntensityTarget}, 0 \le \eta \le 1 \tag{7}$$

This alternative combines a fixed and an intensity cap. When *η = 1,* allowed emissions levels are those of an intensity cap and when *η = 0,* allowed emissions levels match a fixed cap. Sue Wing et al (2009) introduce a similar equation based on growth rates instead of levels.

The logic is the finding in Section III.1: intensity target abatement is more demanding than that of absolute targets if GDP is less than expected and the other way around for higher than expected GDP. Hence, weighting can neutralize that fact (see Appendix A for a derivation of the properties of this type of target).

But, how should the weighting factor (*η*) be set? According to Ellerman and Sue Wing (2003), this factor should be defined according to the relative merits of both types of targets ("The appropriate degree of indexing should be decided by political scientists and practicing negotiators as they weigh the relative merits of absolute and intensity-based caps, and the continuum of possible combinations thereof.", p. S16). This does not seem to be an easy task. Sue Wing et al. (2009) shed more light on this by showing that η can be chosen to minimize the variability of abatement. To do that, information is needed: the variance of GDP, the covariance between emissions levels and GDP, and a definition of the stringency of the target.

GENERALIZED INTENSITY TARGETS

Another alternative proposed to avoid problems related to intensity targets while preserving the automatic adjustment for GDP is "generalized" intensity targets. They are also called "optimal intensity targets" in Jotzo and Pezzey (2007), to contrast with "standard intensity targets" that generally refer to the one-to-one or linear adjustment of allowed emissions levels to GDP.[19]

Dynamic targets take a general form with GDP adjusted by a parameter (α). Hence, allowable emissions levels vary with the level of GDP as:

$$E_T^p = (1-\lambda)\cdot C_B \cdot GDP_T^{\ \alpha}, \qquad C_B = \frac{E_B}{GDP_B^{\ \alpha}}, \quad \alpha > 0 \tag{8}$$

where E_T^p are allowed emissions levels at *T*, GDP_T is the level of GDP at *T*, λ is the reduction in the target, *α* is the elasticity of emissions levels with respect to GDP (it determines a less or more than proportionate relationship between emissions levels and GDP), and C_B is the ratio between emissions levels and GDP considering *α* in the baseline year.[20]

[19] Note that some authors, such as Herzog et al. (2006), do not make this distinction and call all GDP-linked emissions targets "intensity targets".

[20] Note that C_B is not the intensity indicator since it has to hold that, if GDP forecast is accurate, emissions levels have to be equivalent to those in a fixed cap.

This type of indexing to GDP tries to adjust allowed emissions levels to the way emissions levels usually vary with GDP. But, essentially, the consequences of using a parameter α for a generalized intensity target are similar to those of using a growth-indexed target. As pointed out in Marschinski and Lecocq (2006, p.7): this generalized target is "slightly different but essentially equivalent" to the one proposed by Ellerman and Sue Wing (2003).

Jotzo and Pezzey (2007) show that intensity caps do not always reduce the abatement variance with respect to a fixed cap, but generalized intensity caps always do. In general, the conclusion is that generalized intensity targets perform better than fixed targets and that the desirable rate of indexing varies greatly among countries. Höhne and Harnisch (2002) show that a general intensity cap dominates an intensity cap when the elasticity of emissions levels with respect to GDP is greater than 0.5. Rather differently, (Jotzo and Pezzey 2007), using an 18-region simulation model, conclude that the optimal degree of indexation to GDP includes super indexation in some advanced countries ($\alpha > 1$) and partial indexation ($\alpha < 1$) for most developing countries.

The special case of Argentina

In 1999, Argentina designed a generalized intensity target that was innovative in three respects. It was the first time that a developing country agreed to meet a voluntary quantified GHG limitation target, the target was determined with respect to a BAU baseline, and it varied with the square root of GDP. Of those three innovations, the one that remains (i.e., has not been adopted by any other country up to now) is the target metric.

The origin of that metric is that GHG emissions in Argentina are strongly linked to the activities that emit those gases (energy, industry, and waste management), which in turn, maintain a close relationship with the country's macroeconomic growth as measured by GDP. However, the agricultural sector is not as strongly "coupled" to GDP as are the other sectors, as the country is a price-taker in international markets for crops and livestock products and so the prosperity of this sector depends more on the ups and downs of those markets than on domestic conditions.

Total emissions are not so closely related to GDP. Hence, a pure intensity target does not have the desired properties, confirming the results in III.1. In the specific case of Argentina, the standard intensity target implied, for the chosen reduction, that abatement effort decreased with GDP, and there would be "hot air" if the economy grew better than expected. Adjusting the target with $\alpha = 0.5$ (equivalent to a square root since $GDP^{1/2}=\sqrt{GDP}$) implied that abatement effort was higher when the GDP increased, and there was no "hot air" in all circumstances (Barros and Conte Grand, 2002).[21]

IV. 2. Hybrid instruments

Other alternatives are not pure quantity instruments as the generalized GDP-adjusted targets, but rather combinations of caps on quantities emitted with prices attached to emissions.

Dual Targets

While dynamic targets had begun to be discussed in the literature, Kim and Baumert (2002) introduced the notion of "dual targets" based on previous work on "non-binding targets" in Philibert and Pershing (2001). The idea is to avoid excessive burden and "hot air" associated with fixed targets through two caps: a "selling target" (the lower target: if emissions levels fall below certain level, emissions permits can be sold, and this acts as an incentive to reduce emissions levels) and a "buying target" (the higher target: above that level, emission permits have to be bought—higher emissions levels are allowed but with a penalty). This means that the selling target is set to give incentives to reduce emissions levels not to "fall" immediately within a negative abatement

[21] Note that this result is obtained from the exercise in Section III.2 if a=1, α=0.5, and part of the emissions is autonomous.

range, while the buying target is defined so that more emissions are allowed (there is a way to avoid high economic harm if the country's economy improves) but with a penalty.[22] There is then a zone in between those two targets in which the country is emitting what is expected and so has neither benefit nor punishment associated with it. The extent of that zone depends on the uncertainty allowed.[23]

The design would require setting two intensity levels (the notation employed by the authors is *I*, but in fact they refer to *C* in the notation in this paper):

In the selling target: $$E_T^p = C_B^1 \cdot GDP_T^{\alpha}$$

In the buying target: $$E_T^p = C_B^2 \cdot GDP_T^{\alpha}, if \quad C_B^1 \leq C_B^2 \qquad (9)$$

Then, emissions permits sold or bought can be calculated as the difference between actual emissions levels and allowed emissions levels defined by (9).[24]

This type of target implies a specification not only of one intensity level, but two. In that sense, it adds more complexity to the design.

SAFETY VALVE

The safety valve was proposed in McKibbin and Wilcoxen (1997), Pizer (1999), and Kopp et al (1998) as an alternative to pure price and quantity instruments to address climate change. Pizer (2002) shows that this hybrid target performs better than fixed ones, while Webster, et al. (2010) make clear when safety-valve–type mechanisms can be better than not only absolute caps, but also than indexed caps.

This hybrid instrument is different from dual targets because its combination with price is only on one side (the higher than expected cost side). This mechanism is such that there is a given amount of emissions permits that are allocated. Then, if economic growth causes costs (permit prices) to be greater than expected, because permit-supply is fixed under the cap and demand is higher, the regulatory authority sells whatever additional quantities of permits are demanded at a predetermined price. The aim is to cap abatement costs (by capping the permit price) if GDP is higher than expected. Hence, one of its advantages is that it offers a more predictable alternative than fixed cap (Pizer 2002). It also introduces the discussion of a carbon tax, avoiding the resistance usually encountered in that kind of scheme from businesses who do not want to be taxed more and from environmental groups who prefer to have fixed emissions quantities guaranteed. However, there are also problems with the safety-valve approach, as the fact that prices should be harmonized to avoid countries´ incentives to print permits that can be sold in countries with higher prices and in that way affect the international GHG permits market (see Jacoby and Ellerman 2004 on this).

[22] Strictly, in Philibert and Pershing (2001, p. 218) "non binding targets" have to do with the "selling target" and not the buying one. What those authors propose is to assign an emissions budget to countries and if their emissions fall below it, they can sell what remains. However, there is no cost for noncompliance.

[23] That uncertainty is calculated by setting a given confidence interval (see the computation in Kim and Baumert 2002 Box. 5.1).

[24] The idea of a combination of a quantity cap with subsidies and taxes was first proposed for domestic regulation by Robert and Spence (1976).

V. SUMMARY AND DISCUSSION CONCERNING THE FUTURE OF INTENSITY TARGETS:

There is a consensus that absolute targets carry with them "twin uncertainties": economic risk (when GDP turns out to be high, abatement burden would be high) and environmental risk (when GDP is lower than expected, there could be "hot air"). Any country is interested in avoiding risks to its economy. More so is the case of developing countries, which feel that they do not have historical responsibility for climate change.

Intensity targets entered the debate around 15 years ago as a way to promote the adoption of quantitative limits on emissions by developing countries. Among general audiences, there is the belief that intensity targets have a sort of "double dividend": allowing growth and, at the same time, reducing emissions. In that sense, an accessible, detailed comparison of what each type of target implies deserves more attention.

Absolute and GDP-linked caps differ in many aspects. First, the former have allowed emissions levels that are fixed and so known from the moment that the target is designed, while for the latter, committed emissions levels take into consideration economic growth (GDP is higher, more emissions are allowed) and, as a consequence, are uncertain. Second, under a fixed cap, abatement increases with GDP because the level of emissions tend to increase, but the level of commitment does not change, hence, there is high abatement burden for the country if GDP turns out to be high. For intensity targets, abatement levels decrease with GDP when emissions levels are not very reactive to GDP changes and the stringency of the target is low. Then, BAU emissions increase less than allowed emissions. Under intensity targets, there may also be specific circumstances under which abatement increases with GDP. However, even for those cases, abatement under intensity targets is always more (less) demanding than that of fixed targets if GDP is lower (higher) than expected. If countries reach higher than expected GDP levels, the economic burden under intensity targets is always lower than under fixed targets.

Third, fixed targets can imply "hot air" if countries face an unexpected slowdown of their economy, because BAU emissions levels are low in that case and allowed emissions levels are fixed. "Hot air" can occur under very different circumstances when intensity targets are in place. If the emissions-GDP link is weak and the stringency of the target is low, allowed emissions levels may be higher than BAU emissions levels, and there can be "hot air" at high levels of development. "Hot air" could also occur for low GDP levels.

Fourth, under fixed targets, abatement variability depends on BAU emissions uncertainty. Uncertainty about the degree of abatement effort under intensity caps can be higher or lower than that for fixed targets, depending on the relationship between the stringency of the target, the emissions-GDP link, and the forecast errors of GDP and emissions levels. If uncertainty about future GDP is much higher than uncertainty about future emissions levels, then a coupling of the target to the GDP introduces more uncertainty instead of less. Similarly, if the correlation between emissions levels and GDP is low, then there is not much advantage to coupling allowed emissions levels to GDP. Hence, intensity targets do not work in economies where parts of emissions levels are independent of GDP (i.e., non-CO_2 GHG emissions and emissions from land use change).

This paper analyzes the four main differences between fixed and intensity targets, but intensity targets have received additional support and criticism. In favor is intensity being a performance standard that is more comparable across countries than emissions levels (if a homogeneous measure of GDP is agreed on). Moreover, as discussed in Baumert et al. (1999) and Pizer (2005), emissions intensity is a good indicator of countries´ "climate performance." Emissions intensity is a signal of decoupling economic development and emissions growth. Emissions intensity decreases as long as emissions levels change less than GDP: This should provide

incentives to achieve technological change that allows that decrease.[25] On the other hand, the main argument against intensity targets is complexity (Dudek and Golub 2003; Müller and Müller-Fürstenberger 2003). It is fair to say that using another variable in the target (GDP) makes design, monitoring, and administration of the target more difficult. There is no doubt that for intensity targets the homogeneity and reliability of emissions levels and GDP data matters greatly (Pizer 2005; Höhne and Harnisch 2002; Zhang 2011). Regarding homogeneity, it should be clear which currency is used to denominate GDP (local money in Purchasing Power Parity) and if GDP should be in constant or current prices.[26] But, transparency of GDP statistics is as important as data homogeneity. The International Monetary Fund (IMF) is an expert in national account statistics and, as such, could be considered the reference for GDP information used for intensity targets. However, some developing countries have problems with the statistics that they report to that organization, which creates difficulties in monitoring intensity targets.[27] Hence, GDP may not be an entirely reliable indicator, and so may compromise both the design of intensity targets and follow-up monitoring.

Concerning the more sophisticated alternatives (generalized GDP-adjusted targets as growth-indexed limits and generalized intensity targets) and hybrid formats (as dual targets and safety-valve mechanisms), even if they could work, they also require more complexity. Growth-index limits add the design of a weighting parameter (η), generalized intensity requires defining the emissions-GDP elasticity (α), dual targets imply the choice of two baselines related to emissions intensity (C_1,C_2), and the safety-valve mechanism needs a definition of the predetermined price at which the regulator would issue permits if costs exceed expectations. Those additional indicators would need to be different for each country.

The problem with complexity is that the design should be transparent and easy to monitor (external reviewers should understand how it was designed). Intensity targets add some complexity, but involve less abatement burden than fixed targets for countries that grow more than expected and have the potential to lower abatement variability if sufficiently stringent targets are designed for those countries with high emissions-GDP linkage and lower variability in GDP than in emissions levels. For sufficiently high stringency levels, "hot air" could also be avoided under intensity targets.

However, there are countries for which intensity targets do not work. In those cases, alternative mechanisms should be given a chance. Given that intensity targets and the other alternatives reviewed here have the potential to reduce the twin uncertainties of fixed targets, their adoption could be justified even if it implies hard work in defining homogenous and reliable measurement of GDP and increased complexity. As stated by Goulder and Parry (2008, p. 1), "selecting the "best" instrument involves art as well as science." It is true that uncertainty has the potential to alter the stringency of emissions targets, in the sense that the resulting abatement is potentially different than forecasted. But, it should be kept in mind that the ultimate objective of the new round of climate negotiations, based on the Durban Platform, is to engage all countries in

---

[25] As shown in Kolstad (2005), it can be easily seen that emissions intensity (emissions per unit of GDP) changes depend on the change of emissions and the change in GDP. Taking logarithms and then differentiating emissions intensity: $\ln I = \ln E - \ln GDP$ and $\frac{\partial I}{I} = \frac{\partial E}{E} - \frac{\partial GDP}{GDP}$. Höhne and Harnisch (2002) observe that the relationship between emissions and GDP has four different stages, one of which is decarbonization (when economy grows with activities that are low-emissions intensive: the GDP grows faster than emissions, and so emissions intensity declines).

[26] Note GDP was measured in constant (base 1993) Argentinian pesos in Argentina (1999), and the GDP was denominated in 1999–2000 rupees (India, 2011).

[27] For example, on February 1, 2013, the IMF set a "motion of censure" on Argentina for not complying with the Fund's rules on the reporting of statistics (http://www.imf.org/external/np/sec/pr/2013/pr1333.htm, last accessed April 8, 2013). Developing countries´ statistics agencies may be captured by the executive power and so may be not that truthful in measuring the GDP.

actions that can alleviate climate change, through one type of target or another. Errors are possible, but the biggest error can be taking no action.

APPENDIX A. SIMPLE ANALYTICS OF FIXED, INTENSITY, AND "GROWTH-INDEXED" TARGETS

Allowed emissions levels depend on target metrics as shown in (1) and (2) in the text.

Relationship Allowed emissions and GDP for fixed targets (from (1)): $\frac{\partial E_T^p}{\partial GDP} = 0$ (A.1)

Relationship Allowed emissions and GDP for intensity targets (from (2)) $\frac{\partial E_T^p}{\partial GDP} = (1-\lambda)\cdot I_B > 0$ (A.2)

The relationship between allowed emissions levels and GDP is always linear since the second derivative of (A.1) and (A.2) is 0.

The adoption of a target implies reducing (abating) emissions with respect to what they would have been without the target as shown in equation (3) in the text.

Relationship Abatement and GDP for fixed targets: $\frac{\partial A_T}{\partial GDP} = \frac{\partial E_T^{BAU}}{\partial GDP} - 0 > 0$ (A.3)

Relationship Abatement and GDP for intensity targets: $\frac{\partial A_T}{\partial GDP} = \frac{\partial E_T^{BAU}}{\partial GDP} - (1-\lambda)\cdot I_B > 0 \quad or \quad < 0$ (A.4)

It always holds that abatement is lower (higher) under intensity targets than under fixed targets if GDP is higher (lower) than expected. Moreover, the curvature of the relationship between abatement and GDP depends only on the curvature of BAU emissions with respect to GDP, and so is the same for both types of targets (i.e., from (A.3) and (A.4), $\frac{\partial^2 A_T}{\partial GDP^2} = \frac{\partial^2 E_T^{BAU}}{\partial GDP^2}$).

"Hot air" can occur if $A_T < 0$ as shown in (4) and (5) in the text, and is related to the sign (A.3) and (A.4). For fixed targets, since that relationship is positive, the risk of "hot air" occurs for low GDP while for (A.4), if the link between abatement and GDP is negative, "hot air" can occur for high GDP levels.

In terms of the uncertainty of each type of target as measured by the variance of the abatement:

Abatement variance for fixed targets: $Var\left(A_T\right) = Var\left(E_T^{BAU}\right)$ (A.5)

Abatement variance for intensity targets:

$$Var(A_T) = Var\left(E_T^{BAU}\right) + \left[(1-\lambda)\cdot I_B\right]^2 \cdot Var\left(GDP_T\right) - 2\cdot\left[(1-\lambda)\cdot I_B\right]\cdot Cov(E_T^{BAU}, GDP_T) \quad \text{(A.6)}$$

Hence, intensity targets reduce abatement uncertainty if (A6) is lower than (A5), so when: [28]

[28] This equation is similar to equation (25) in Newell and Pizer (2008) and equation (4) in Marschinski and Edenhofer (2010).

$$\frac{\left[(1-\lambda)\cdot I_B\right]}{2} < \frac{Cov(E_T^{BAU}, GDP_T)}{Var\left(GDP_T\right)} \equiv \qquad \frac{(1-\lambda)}{2}\cdot\frac{\frac{\sigma\left(GDP_T\right)}{GDP_B}}{\frac{\sigma\left(E_T^{BAU}\right)}{E_B}} < \rho(E_T^{BAU}, GDP_T) \tag{A.7}$$

The second expression comes from applying the definition of covariance as the correlation between emissions and GDP (ρ) and their variability (σ are the errors in GDP and emissions forecasts).[29]

Finally, for the growth-indexed limit, using the same notation as the simple mathematical analysis for fixed and intensity targets, for $0 \leq \eta \leq 1$, implies that:

1. Allowed emissions under this rule increase with GDP : $\partial E_T^p / \partial GDP = \eta\cdot(1-\lambda)\cdot I_B > 0$
2. Abatement varies with GDP according to: $\frac{\partial A_T}{\partial GDP} = \frac{\partial E_T^{BAU}}{\partial GDP} - \eta\cdot(1-\lambda)\cdot I_B$. Hence, there are more chances for A to depend positively on GDP since the second term can be made lower than the second term in (A.4).
3. Similarly, there will be less likely hot air since $A_T = E_T^{BAU} - \eta\cdot(1-\lambda)\cdot I_B\cdot GDP_T$. So, the second term of this equation can be made lower than that of (5).
4. By adjusting the weighting factor η, the variance of abatement can always be made lower for this type of cap than for fixed targets :

   $$Var\left(A_T\right) = Var\left(E_T^{BAU}\right) + \left[\eta\cdot(1-\lambda)\cdot I_B\right]^2\cdot Var\left(GDP_T\right) - 2\cdot\left[\eta\cdot(1-\lambda)\cdot I_B\right]\cdot Cov(E_T^{BAU}, GDP_T)$$

   when:

   $$\frac{\left[\eta\cdot(1-\lambda)\cdot I_B\right]}{2} < \frac{Cov(E_T^{BAU}, GDP_T)}{Var\left(GDP_T\right)}\ .$$

   For optimal η, the variance of the growth indexed target is minimized when:[30]

   $$\eta = \frac{Cov(E_T^{BAU}, GDP_T)}{(1-\lambda)\cdot I_B\cdot Var\left(GDP_T\right)}\cdot$$

APPENDIX B. EMISSIONS REDUCTIONS THAT YIELD EQUIVALENT TARGETS

The equations for allowed emissions levels in the case of fixed and intensity targets, for past $\underline{B}$ or expected business as usual (BAU) future $\overline{B}$ baselines are:

[29] The pieces needed to apply this formula to actual climate policy have been calculated by several authors. Jotzo (2006) calculates standard deviations based on forecast errors of IEA and U.S. EIA 22 countries' data for 2000 (errors are the difference between 1995 forecasts for 2000 and actual 2000 data). They find that the standard error of emissions is 0.15 and 0.17 for OECD and non-OECD countries and the standard error of GDP is 0.10 and 0.11 respectively. Marschinski and Edenhofer (2010) calculate those deviations based on 1999 U.S. EIA forecasts for 2010 and conclude that: forecast errors for GDP and CO_2 emissions are nearly equal for China; while for India, GDP was underestimated and emissions levels were overestimated; and for Russia, both emissions levels and GDP were overestimated but GDP was more overestimated than emissions. In the same vein, Newell and Pizer (2008) calculate for 19 high-emitting countries using 2002 values of GDP coefficient of variations fluctuating from 0.01 to 0.07, emissions coefficient of variation from 0.02 (United States) to 0.07 (Poland), and emissions-to-GDP correlation from 0.01 (France) to 0.74 (China), and approximate for each of those countries which target would be preferred. With respect to the correlation between emissions and GDP, Pizer (2005) using U.S. EIA CO_2 data finds negative correlations from minus 0.42 to minus 0.02 for seven industrialized countries (United States, France, Spain, Sweden, United Kingdom, and Japan).

[30] This equation is identical to equation (20) in Sue Wing et al. (2009).

Fixed target with baseline in the past: $E_T^P = (1-\lambda_1)\cdot E_{\underline{B}}$ (B.1)

Fixed target with baseline in the expected business as usual: $E_T^P = (1-\lambda_2)\cdot E_{\overline{B}}$ (B.2)

Intensity target with baseline in the past: $E_T^P = (1-\lambda_3)\cdot \frac{E_{\underline{B}}}{GDP_{\underline{B}}}\cdot GDP_T$ (B.3)

Intensity target with baseline in the future: $E_T^P = (1-\lambda_4)\cdot \frac{E_{\overline{B}}}{GDP_{\overline{B}}}\cdot GDP_T$ (B.4)

For the stringency of fixed target with baseline in BAU to be equivalent to a fixed target with baseline in the past, it has to be true that:

$$(1-\lambda_2) = (1-\lambda_1)\cdot \frac{E_{\underline{B}}}{E_{\overline{B}}}; if\ E_{\overline{B}} > E_{\underline{B}}, (1-\lambda_2) < (1-\lambda_1) \rightarrow \lambda_2 > \lambda_1 \quad \text{(B.5)}$$

As expected, if the cap is fixed with respect to a baseline in the future, the reduction has to be higher if it needs to be equivalent to reducing emissions levels with respect to a baseline in the past.

As this paper's purpose is the comparison between fixed and intensity targets, two cases are emphasized: the equivalence between fixed and intensity targets anchored to the past and those with a baseline in a future BAU scenario.

To get equivalence in emissions between the fixed target and the intensity target that is anchored in the past:

$$(1-\lambda_3) = (1-\lambda_1)\cdot \frac{GDP_{\underline{B}}}{GDP_T} \quad \text{(B.6)}$$

Hence, the equivalence between fixed and intensity targets based on a past baseline is not that easy to set. The issue here is that, to obtain equivalence of allowed emissions, λ_3 needs to be determined as a function of GDP_T, which is not known in advance.

On the other side, for the equivalence between in fixed targets and intensity targets with baseline in the future:

$$(1-\lambda_4) = (1-\lambda_2)\cdot \frac{GDP_{\overline{B}}}{GDP_T}. \quad \text{(B.7)}$$

There GDP_T is not known at the moment the cap is defined, but the situation is different than the one in (B.6) since $GDP_{\overline{B}}$ is forecasted. As a result, it is possible to state that if the forecast matches real GDP (i.e., $GDP_{\overline{B}} = GDP_T$), then $\lambda_2 = \lambda_4$. This can be the reason why this equivalence is generally the one considered in the literature to compare fixed and intensity targets (Ellerman and Sue Wing 2003, p. S9; Jotzo and Pezzey 2007, p. 264; Sue Wing et al. 2009). Note that intensity targets with baselines in the future have not being adopted in climate negotiations. So, this does not seem to be the most relevant comparison even if it is the clearest one.

REFERENCES

Argentine Republic (1999), Revision of the First National Communication. Available at http://unfccc.int/resource/docs/natc/argnc1e.pdf. Last access: May 12, 2013.

Barros V. and M. Conte Grand (2002), "Implications of a Dynamic Target of GHG emissions reduction: the case of Argentina," *Environment and Development Economics* 7(3): 547-569, doi: 10.1017/S1355770X02000323

Baumert, K., R. Bhandari and N. Kete (1999), What Might A Developing Country Climate Commitment Look Like? Washington, DC: World Resources Institute. May. www.wri.org/publication/what-might-developing-country-climate-commitment-look

Bouille D. and O. Girardín (2002), "Learning from the Argentine Voluntary Commitment", in Baumert, Kevin A. (ed.), *Options for Protecting the Climate*, World Resource Institute, Washington D.C., 135-156, http://pdf.wri.org/opc_full.pdf

Box, G. E. P. and Cox, D. R. (1964), "An analysis of transformations," *Journal of the Royal Statistical Society*, Series B, 26: 211-252.

Conte Grand M. and D´Elia (2013), "Using the Box-Cox transformation to approximate the shape of the relationship between greenhouse gases emissions and GDP," Working Paper # 513, Universidad del CEMA, July. Available at: http://www.ucema.edu.ar/publicaciones/doc_trabajo.php..

den Elzen M. and N. Höhne (2008), "Reductions of greenhous gas emissions in Annex I and non-Annex I countries for meeting concentration stabilisation targets," *Climatic Change* 91(3-4): 249–274, doi: 10.1007/s10584-008-9484-z

den Elzen M. G. J., A. Hof, M. A. Mendoza Beltran, M. Roelfsema, B. van Ruijven, J. van Vliet, D. P. van Vuuren, N. Höhne and S. Moltmann (2010), *Evaluation of the Copenhagen Accord: Chances and Risks for the 2C Climate Goal* (Biltoven: Netherlands Environmental Assessment Agency). www.pbl.nl/en/publications/2010/Evaluation-of-the-Copenhagen-Accord-Chances-and-risks-for-the-2C-climate-goal

Dudek, D., and A. Golub (2003), "'Intensity' targets: Pathway or roadblock to preventing climate change while enhancing economic growth?" *Climate Policy* 3 (Supplement 2): S21–S28.

Ellerman, A.D. and I. Sue Wing (2003), "Absolute v. Intensity-Based Emission Caps," *Climate Policy* 3 (Supplement 2): S7-S20.

Frankel, J. (1999), "Greenhouse Gas Emissions," Policy Brief no. 52, The Brookings Institution, Washington, DC, June. www.brookings.edu/research/papers/1999/06/energy-frankel

Goulder, L. H. and I. W. H. Parry (2008), "Instrument Choice in Environmental Policy," *Review of Environmental Economics and Policy*, 2(2): 152-174, doi: 10.1093/reep/ren005

Herzog, T., J. Pershing, and K. Baumert (2006), *Target: Intensity. An Analysis of Greenhouse Gas Intensity Targets*, November, World Resources Institute, www.wri.org/publication/target-intensity

Höhne, N. and J. Harnisch (2002), *Greenhouse gas intensity targets vs. absolute emission targets; Proceedings of the 6th International Conference on Greenhouse Gas Control Technologies* (GHGT-6) Kyoto (Japan), October 2002, Eds. J. Gale and Y. Kasa, Pergamon Press, Vol. II, pp. 1145-1150.

India (2011), "Low Carbon Strategies for Inclusive Growth: An Interim Report," Planning Commission Government of India, May. Tables 4.1 (page 107), http://moef.nic.in/downloads/public-information/Interim%20Report%20of%20the%20Expert%20Group.pdf. Last access: May 9 2013.

Jacoby H. D. and A. D. Ellerman (2004), "The safety valve and climate policy," *Energy Policy*, 32(4): 481-491, doi: 10.1016/S0301-4215(03)00150-2

Jotzo, F. (2006), "Quantifying uncertainties for emission targets," Economics and Environment Network Working Papers 0603, Australian National University. http://een.anu.edu.au/download_files/een0603.pdf

Jotzo, F. and Pezzey, J. (2007), "Optimal intensity targets for greenhouse emissions trading under uncertainty," *Environmental and Resource Economics*, 38(2): 259–284, doi: 10.1007/s10640-006-9078-z

Keohane, N. O., R. L. Revesz, and R. Stavins (1998), "The Choice of Regulatory Instruments in Environmental Policy." *Harvard Environmental Law Review*, 22(2):313-67.

Kim, Y. and K. Baumert (2002), "Reducing uncertainty through dual intensity targets", in K. Baumert (ed.), *Building on the Kyoto Protocol, Options for protecting the climate*, World Resources Institute, Washington, USA, http://pubs.wri.org/pubs_pdf.cfm?PubID=3762

Kolstad, C. (2005), "The Simple Analytics of Greenhouse Gas Intensity Reduction Targets," *Energy Policy*, 33(17): 2231-36, doi: 10.1016/j.enpol.2004.05.001

Levin, K. and J. Finnegan (2011), "Assessing Non-Annex I Pledges: Building a Case for Clarification," WRI Working Paper. World Resources Institute, Washington D.C. December. www.wri.org/publication/assessing_non_annexi_pledges

Levin, K. and R. Bradley (2010), "Comparability of Annex I Emission Reduction Pledges," WRI Working Paper. World Resources Institute, Washington DC. February, www.wri.org/publication/comparability-of-annexi-emission-reduction-pledges

Lutter, R. (2000), "Developing Countries' Greenhouse Emissions: Uncertainty and Implications for Participation in the Kyoto Agreement," *Energy Journal*, 21(4): 93- 120.

Macintosh A. (2010), "Keeping warming within the 2°C limit after Copenhagen," *Energy Policy*, 38(6): 2964–75, doi: 10.1016/j.enpol.2010.01.034

Marschinski, R. and F. Lecocq (2006), "Do Intensity Targets Control Uncertainty Better than Quotas? Conditions, Calibrations, and Caveats." World Bank Policy Research Working Paper No. 4033. http://elibrary.worldbank.org/content/workingpaper/10.1596/1813-9450-4033

Marschinski, R. and O. Edenhofer (2010), "Revisiting the Case for Intensity Targets: Better Incentives and Less Uncertainty for Developing Countries?" *Energy Policy*, 38(9): 5048-5058, doi: 10.1016/j.enpol.2010.04.033

McKibbin W. and P. Wilcoxen (1997), "A Better Way to Slow Global Climate Change," Brookings Policy Brief No. 17. www.brookings.edu/research/papers/1997/06/energy-mckibbin

Müller, B. and G. Müller-Fürstenberger (2003), "Price-related sensitivities of greenhouse gas intensity targets," *Climate Policy* 3 (Supplement 2): S59–S74.

Newell, R. G. and W. A. Pizer (2008), "Indexed regulation," *Journal of Environmental Economics and Management*, 56(3): 221-233, doi: 10.1016/j.jeem.2008.07.001

Philibert, C. and J. Pershing (2001), "Considering the Options: Climate Targets for All Countries," *Climate Policy* 1(2): 211-227, doi: 10.3763/cpol.2001.0123

Pizer, W. A. (2002), "Combining price and quantity controls to mitigate global climate change," *Journal of Public Economics*, 85(3): 409-434, doi: 10.1016/S0047-2727(01)00118-9

Pizer W. A. (2005), "The Case for Intensity Targets," *Climate Policy* 5(4): 455-462, doi: 10.1080/14693062.2005.9685570

Rogelj, J., C. Chen, J. Nabel, K. Macey, W. Hare, M. Schaeffer, K. Markmann, N. Höhne, K. Krogh Andersen, and M. Meinshausen (2010), "Analysis of the Copenhagen Accord pledges and its global climatic impacts—a snapshot of dissonant ambitions," *Environmental Research Letters* 5(3): 1-9, doi: 10.1088/1748-9326/5/3/034013

Qiu J. (2009), "China´s climate target: is it achievable?" *Nature* 462: 550-551, doi: 10.1038/462550a

Roberts, M.J., and M. Spence (1976). Effluent Charges and Licenses under Uncertainty. Journal of Public Economics 5(3–4): 193–208, doi: 10.1016/0047-2727(76)90014-1.

Steckel, J., M. Jakob, R. Marschinski, and G. Luderer (2011), "From Carbonization To Decarbonization? - Past Trends and Future Scenarios for China's CO_2 Emissions," *Energy Policy* 39 (6): 3443-3455 (2011), doi: 10.1016/j.enpol.2011.03.042

Stern, D.I. and Jotzo, F. (2010), "How Ambitious are China and India's Emissions Intensity Targets?" *Energy Policy*, 38(11): 6776-6783, doi: 10.1016/j.enpol.2010.06.049

Sue Wing, I., A.D. Ellerman and J.M. Song (2009), "Absolute vs. Intensity Limits for CO_2 Emission Control: Performance Under Uncertainty," in H. Tulkens and R. Guesnerie (eds.), *The Design of Climate Policy*, MIT Press, 221-252.

UNEP (2010), "How Close are We to the Two Degree Limit?" United Nations Environmental Program. http://www.unep.org/PDF/PressReleases/temperature-briefing-21-02-10-final-e.pdf

Webster, M., I. Sue Wing and L. Jakobovits (2010), "Second-Best Instruments for Near-Term Climate Policy: Intensity Targets vs. the Safety Valve," *Journal of Environmental Economics and Management* 59: 250-259, doi: 10.1016/j.jeem.2010.01.002

Weitzman, M. (1974), "Prices vs. Quantities," *Review of Economic Studies* 41:477-491.

White House (2002), "U.S. Climate Strategy: A New Approach," Policy Briefing Book, Washington D.C. USA, February 14.

Zhang, ZhongXiang (2011), "Assessing China's carbon intensity pledge for 2020: stringency and credibility issues and their implications," *Environmental Economics and Policy Studies,* 13(3): 219-235, doi: 10.1007/s10018-011-0012-4