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AUTHOR: BABONNEAU, FREDERIC

School Of Business Universidad Adolfo Ibáñez

CO_2 intensity target, flexibility *versus* environmental effectiveness: the Chilean INDC case

Frédéric Babonneau[a], Marc Vielle[b,*]

[a]*Escuela de Negocios, Universidad Adolfo Ibàñez, Santiago, Chile.*
[b]*Laboratoire LEURE, École polytechnique fédérale de Lausanne (EPFL), Station 16, CH-1015 Lausanne, Switzerland.*

Abstract

At the 21[st] session of the Conference of the Parties (COP21) in Paris, among the 161 countries in attendance, Chile was one of seven to submit intensity-based emissions reduction commitments as part of its Intended Nationally Determined Contributions (INDCs). This paper aims at assessing the potential impacts of these intensity-based INDCs on the Chilean economy by 2030 using the computable general equilibrium model GEMINI-E3. We simulate 12 scenarios considering three scenarios of economic growth in Chile and four greenhouse gas intensity targets. Sensitivity analysis shows that emissions intensity targets become less stringent when assuming high levels of economic growth. We also find that the choice of an intensity-based target may result in highly uncertain effective emissions in 2030. Only six of the simulated scenarios lead to emissions below the 2016 levels. The associated domestic CO_2 taxes range from 75 to 279 US$ per ton with an estimated 2030 GDP loss for the Chilean economy of between 0.07% and 1.4%.

Keywords: Chile, COP21, Intensity target, Climate policy, Computable general equilibrium model.

Highlights

- INDCs based on intensity targets result in high uncertainty for effective emissions levels in 2030.

*Corresponding author
Email addresses: `frederic.babonneau@uai.cl` (Frédéric Babonneau), `marc.vielle@epfl.ch` (Marc Vielle)

- A significant increase of the price of CO_2, currently implemented, is required to meet with Chilean INDC commitments.
- The GDP loss is expected to range between 0.07% to 1.43% depending on commitment targets and economic growth scenarios.
- A high level of economic growth makes the emissions intensity target less stringent than in scenarios of low growth. We find that one percent additional growth per year allows increasing the intensity target by 2.5% with unchanged mitigation cost.

1. Introduction

Among the 161 parties to the COP21 in Paris submitting emission reduction commitments for 2030, Chile is one of seven to do so through an intensity target, i.e., between 30% and 45% emissions reduction per unit of gross domestic product (GDP) with respect to 2007 levels. Intensity-based policy instruments have been extensively analyzed since the Kyoto Protocol (See e.g. (Philibert and Pershing, 2001; Pizer, 2005; Jotzo and Pezzey, 2007; Marschinski and Edenhofer, 2010)) to facilitate the participation of developing countries in climate negotiations. Indeed, intensity targets are considered more acceptable commitments for developing countries by reducing uncertainties in mitigation costs and not penalizing future economic development. Chile demonstrates thus its willingness to reduce "*greenhouse gas emissions (GHG) while decreasing poverty and inequality as well as continue advancing toward sustainable, competitive, inclusive and low-carbon development*", as stated in its submitted INDC (Gobierno de Chile, 2015b). In essence, the intensity targets integrate the fact that developing countries would in their economy development naturally decrease their energy intensity, by shifting from energy intensive industries, to sectors producing consumption goods and services, with lower carbon intensity. High economic growth can also provide more low-cost CO_2 mitigation options with the replacement of existing capital stock. Philibert and Pershing (2001) note that Argentina was probably the first country to offer an intensity-based commitment in 1999, calculated as emissions per square root of GDP index (Argentine Republic, 1999). The drawback of this intensity target is that the commitment level set (i.e., effective GHG abatement) is uncertain since it strongly depends on GDP evolution. The purpose of the present paper is thus to analyze and to assess the economic and environmental implications of intensity-based commitments for Chile.

1.1. *The Chilean economy and emissions*

With an average 3.8% GDP annual growth rate between 1997 and 2018, the Chilean economy is considered a model for Latin America (OECD/CAF/ECLAC, 2018). However, this growth rate is highly variable, having fluctuated between as much as -3.9% in 1999, to 9.5% in 2011. Due to its reliance on exports, the variability in the Chilean economy correlates strongly with international copper demands and prices. Otherwise, the main activity sectors in Chile are the services, with 58% of GDP in 2017, and the industry and the agriculture, with 30% and 9.3% of GDP, respectively.

Although Chile is responsible for only 0.2% of global GHG emissions, this share has increased significantly by 78.5% during the 1990-2013 period. In 2016, Chilean emissions reached 85.25 Mt CO_2 (OECD/IEA, 2018) and 111.67 Mt CO_2e. According to official Chilean statistics (Ministerio del Medio Ambiental, 2018), GHG emissions from energy uses reached 78% of total emissions in 2016 while agriculture and industrial process emissions represented 10.6% and 6.2%, respectively. Energy emissions were further categorized into the following subitems: energy sector (41.5%); transport (31.3%); manufacturing and construction industries (18.7%) and others (8.5%). Electricity generation was by far the main source of emissions, with 31% of total GHG emissions.

1.2. *Objectives of the Chilean electricity sector*

Over the last five years, Chile has experimented a very rapid increase of its share of renewable production (Simsek et al., 2019). Electricity generation from non-conventional renewable energy sources (RES) (mainly biomass, photovoltaic, wind and small-hydro) has increased by a factor of three, reaching roughly 20% of total production. Conventional hydroelectric plants provide another 35-40% of production, while remaining electricity generation comes from fossil fuels (coal, gas and oil). A detailed review of the energy and electricity sectors can be found in (Simsek et al., 2019). In its 2050 Energy policy (Gobierno de Chile, 2015a), the Chilean government laid out ambitious objectives by 2050, committing to 70% electricity generation from RES, developing smart energy systems for demand management, and implementing energy efficiency measures and green taxes. A summary of these measures, among others, are discussed in Cansino et al. (2018). In Munoz et al. (2017), the authors estimate the costs of reaching the 70% renewables target and highlight the need of a binding renewable policy by 2050.

1.3. Climate and carbon tax policies in Chile

As mentioned in Cansino et al. (2018), the Chilean INDCs have been designed relying on previous studies and sources, like, the Mitigation Actions Plans and Scenarios Chile project (Phase 2), the National Greenhouse Gas Inventory, Public Consultations and reports from the Ministries of Environment, Energy, Agriculture and Finance (e.g., (Gobierno de Chile, 2015a)) . Cansino et al. (2018) propose a decomposition analysis in based on the log-mean divisia index method to evaluate the component effectiveness of measures in complying with Paris objectives. They demonstrated that, for Chile, the energy intensity effect is the main determinant for reaching stringent emissions reduction and for attaining the Paris Commitments.

In Vera and Sauma (2015), the authors evaluate the efficiency of the 5 US$ CO_2 tax voted in 2014 by the Chilean Government and applied in 2017 to power plants and large industrial facilities greater than 50MW (covering 55% of CO_2 emissions). They analyze the impact of this tax-based policy on the Chilean electric system, finding limited reduction of expected annual CO_2 emissions from electricity generation, i.e., about 1% for the 2014-2024 period; and a 3.4% increased marginal cost in power production. They conclude that alternative policies focusing on residential demand reduction would more efficient on emissions reduction and energy prices. Benavides et al. (2015) found similar results using energy sectorial and dynamic stochastic general equilibrium models. The authors assessed the potential economic impact of both the 5 US$ CO_2 tax and its increase over time. They found that a 50 US$ CO_2 tax should lead to annual emissions reduction between 18.5% and 29% from electricity generation with a significant increase of electricity prices and GDP losses. They also showed that similar emissions reduction can be obtained with alternative policies (e.g., introduction of non-conventional renewable sources of energy and sectorial cap) without the aforementioned negative effects. Recently, Diaz et al. (2019) even pointed out that since the current regulation does not allow firms to charge electricity tariffs with emission taxes in real time, the current Chilean CO_2 levy is not actually a tax, but of course, one can assume that it will become a standard carbon tax in a near future.

In another analysis, Benavente (2016) used a Computable General Equilibrium (CGE) model to assess the economic impacts of the official Chilean commitments (Gobierno de Chile, 2013) to reduce emissions by 20% below the 2020 BAU projections. The author showed that a carbon tax of 26 US$ per ton was needed to reach this emissions reduction target. However, Benavente (2016) remarked that this carbon tax is quite below the one estimated in Dessus and

O'Connor (1999) who had estimated a carbon tax of 140 US$ for a 20% CO_2 emission reduction. Moreover, the author quantified the associated GDP loss at around 2%, with contractions in refinery, transport, and electricity productive sectors at between 7% and 9%. He were also expected decreases of 11% in fossil fuel-based electricity and increases of 43% in renewable production.

Following and expanding on Benavente (2016), we analyze, in the present paper, Chilean INDC commitments to the Paris agreements using the CGE model known as GEMINI-E3. In addition, we perform a sensitivity analysis under varied GDP projection and commitment regimes (included in INDCs) by 2030 to determine the impact on carbon taxes, GDP losses, sectorial production, etc, for Chile. Finally, we discuss how the flexibility of the CO_2 intensity-based mechanisms may affect the expected reductions in effective emissions under the different scenarios. These assessments should allow policy makers to design efficient and effective energy and climate policies to meet with global environment goals.

The rest of the paper is organized as follows. In Section 2, we describe the GEMINI-E3 model used to perform the macro-economic analyses. We also translate the INDCs of the regional classification of GEMINI-E3 in terms of CO_2 emissions in 2030 and we discuss environmental effectiveness of Chilean objectives. In Section 3, we present the macroeconomic impacts on Chile given different GDP evolution assumptions and CO_2 intensity reduction targets. Finally Section 4 concludes.

2. The GEMINI-E3 model for assessing Chilean commitments and environmental effectiveness

In this section, we first introduce the GEMINI-E3 CGE model applied to perform macroeconomic analyses, and the reference scenario used for comparison exercises. Then we describe INDCs, in particular the Chilean one, based on the GEMINI-E3 regional classification, and we evaluate their environmental effectiveness in terms of CO_2 emissions.

2.1. The GEMINI-E3 model

GEMINI-E3 is a multi-country, multi-sector, recursive CGE model (Bernard and Vielle, 2008), comparable to other CGE models (e.g., EPPA, OECD-Env-Linkage, etc.) built and implemented by other modeling teams and institutions, and sharing the same long-standing experience in the design of this class of economic models. The standard model is based on the assumption of total flexibility in all markets, i.e., both macroeconomic markets, such as capital and international trade markets (with associated prices being the real rate of interest and the real exchange rate, which are then endogenous), and microeconomic or sector markets (e.g., goods and factors of production).

The current version of GEMINI-E3 is built on the GTAP 9 data base (Aguiar et al., 2016) and the reference year is 2011. The industrial classification used in this study comprises 12 sectors. We describe five energy goods and sectors: coal, oil, natural gas, petroleum products, and electricity. The mining sector in Chile is one of the pillars of its economy representing 11% of gross value added and 56% of total exports during 2010-2016 (OECD, 2018). Therefore, we isolate the mineral products including mining, production and casting of copper. Transport is described by land, sea and air transport sectors. Agriculture, energy-intensive industries, and other goods and services constitute the remaining three sectors. Regarding spatial decomposition, the GEMINI-E3 version has five countries/regions: Chile, USA, China, other American countries (OAC) and Rest of World (ROW). OAC regroups all American countries, except of course USA and Chile, but includes Canada, Mexico, and Central and South American countries.

International trade is represented through the Armington assumption (Armington, 1969), which assumes that domestic and imported goods are not perfectly homogenous. It is worth noting that, in the present version of GEMINI-E3, we only consider CO_2 emissions from energy combustion[1].

2.2. The GEMINI-E3 reference scenario

The GEMINI-E3 reference scenario is built on the time period of 2011-2030 with yearly timesteps. All prices given in this paper are in US$\$_{2017}$. Assumptions on GDP and international energy prices are based on the 2018 World Energy Outlook (International Energy Agency, 2018) and more specifically on the "current policies" scenario.

The GDP assumption for Chile is based on the ones used in GHG emissions projection done by the Chilean government (Generadoras de Chile, 2017). It supposes that GDP growth will slightly increase to 3% from 2020 to 2030. However, we simulate two other alternative GDP growth scenarios, respectively equal 4% and 5%, to include macro-economic uncertainties as integrated in the Chilean

[1] Other non-CO_2 GHG emissions are not taken into account. However according to Chilean inventory (Gobierno de Chile, 2015b), these emissions account for xx% of Chilean GHG emissions in 2016.

INDC, discussed below. Indeed, the conditional INDC is subject to future economic expansion above the growth experienced by the Chilean economy during the last decade.

The model is calibrated in order to reproduce energy consumption and related CO_2 emissions from 2011 to 2016. It thus considers all previous policies implemented since 2016, and especially those related to energy and climate fields. Tables 1 and 2 show GDP growth and CO_2 emissions, respectively, from 2016 to 2030. Figure 1 gives the evolution of Chilean CO_2 emissions within the three economic scenarios.

Table 1: GDP growth rate in % - Reference scenario

	2016-2020	2020-2030
Chile	2.3%	3.1%
USA	3.0%	3.1%
China	2.4%	3.1%
OAC	2.3%	3.1%
ROW	2.3%	3.1%
World	2.9%	3.1%

Table 2: Carbon emissions in Mt CO_2 - Reference scenario

	2016	2020	2030
Chile*	84	88	103
USA	4,903	4,792	4,757
China	9,168	9,874	10,969
OAC	2,127	2,169	2,230
ROW	15,264	16,048	19,508
World	31,546	32,971	37,567

* 3% GDP growth scenario

2.3. *INDC pledges synthesis*

At COP21, countries have proposed the so-called INDCs that define nationally determined "contribution" (not commitments) on the period 2020-2030. Broadly speaking, INDCs represent targets and actions for the post-2020 period and are expressed in two targets. The first one, called *unconditional target*, refers to an initial objective of GHG emissions for a reference year or period. The second

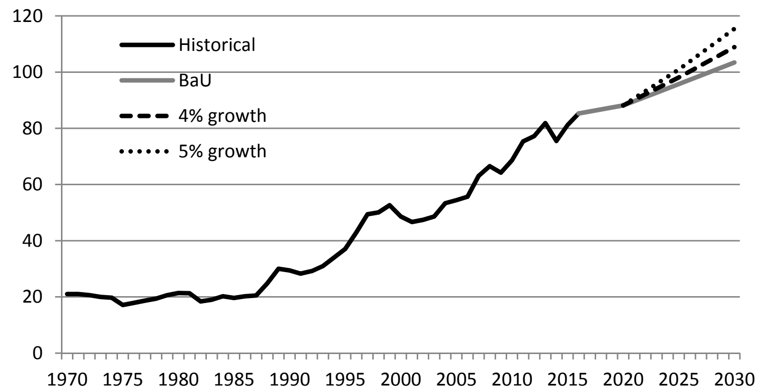

Figure 1: Chilean CO_2 emissions from energy combustion, 1970-2030 (historical values: (OECD/IEA, 2018))

target, called *conditional target*, provides additional GHG abatement efforts conditional on some circumstances or events (e.g., actions of other parties, contingent on broader mitigation efforts of other countries, the provision of financial transfers by other countries, technology or capacity building support, etc). For some countries, only the unconditional target is given. Firstly, we compiled the INDCs available at the UNFCCC website[2] for all countries. The INDCs are computed at country level and then aggregated in the regional classification as summarized in Table 3. The methodology is detailed in Babonneau et al. (2018). Note that these estimations are consistent with the ones published by the International Energy Agency regarding energy related greenhouse gases emissions (International Energy Agency, 2015).

Table 3: Intended Nationally Determined Contributions of the rest of the World in Mt CO_2 in 2030

	Unconditional	Conditional
USA	3,479	3,308
China	10,806	9,455
OAC	1,643	1,595
ROW	15,400	14,764

[2]See `http://www4.unfccc.int/submissions/indc/Submission%20Pages/submissions.aspx`

2.4. The Chile INDC proposal and environmental effectiveness

Within INDCs submitted at COP21, only seven included intensity targets to reduce GHG emissions per unit of GDP (United Nations, Framework Convention on Climate Change, 2016). Chile is among this group, along with China, India, Malaysia, Singapore, Tunisia and Uzbekistan. The Chilean INDC (Gobierno de Chile, 2015b) includes both conditional and unconditional objectives:

- The unconditional target proposes to reduce GHG emissions per GDP unit by 30% below their 2007 levels by 2030, based on projected economic growth that allows adequate measures to reach this commitment.

- The conditional objective is subject to international support and appropriate economic growth. The reduction target is increased to an objective of 35% to 45% below 2007 levels by 2030.

The chilean INDC excludes contributions from land use, land-use change and forestry (LULUCF), due to the high annual variability of sinks and emissions from this sector. Rather, Chile has agreed to a specific objective for LULUCF, committing to reforest 100,000 hectares annually, representing between 0.9 to 1.2 millions ton of CO_2 sequestration.

Table 4 compares the Chilean INDC with the six other intensity targets submitted to COP21. The Chilean INDC is similar to the other six, with the exception of China whose the target seems more ambitious but considering only CO_2 emissions[3]. One distinction is that the Chilean conditional pledge refers to a range of commitments (from -35% to -45%) and not to a single percentage. That gives some flexibilities to Chile, but also add more uncertainty on its commitment per se. The OECD (2016) noticed that “ambiguity” and requested the Chilean government clarify:

1. The economic growth conditions enabling to increase the commitment,
2. The level of international funding needed to also increase the target.

It is not straightforward to integrate an intensity target into a modeling framework . As noted by Cai et al. (2017), if the emission intensity target is translated

[3]The simulation, but also other studies (Aldy et al., 2016; Vandyck et al., 2016; Jacoby et al., 2017), show that the Chinese INDC is in fact not really constraining at least for the unconditional pledges.

Table 4: INDCs submitted through intensity target

Country	Base year	Gases covered	Unconditional	Conditional
Chile	2007	Kyoto basket	-30%	-35% to -45%
China	2005	CO_2	-60%	-65%
India	2005	Kyoto basket	-33%	-35%
Malaysia	2005	CO_2, CH_4 and N_2O	-35%	-45%
Singapore	2005	Kyoto basket	-36%	-36%
Tunisia	2010	CO_2, CH_4 and N_2O	-13%	-41%
Uzbekistan	2010	Kyoto basket	-10%	-10%

into an emission level based on the reference scenario, the simulation will underestimate the carbon price and the welfare impact. Indeed, the mitigation policy usually induces a GDP decrease with respect to the reference scenario, and a higher intensity than expected. In this paper, we directly solve the scenario using the intensity target itself as an objective and not the emission level computed from the reference scenario.

Table 5 shows the *ex-post* Chilean pledges under three economic growth scenarios, 3%, 4% and 5%, respectively, and the four emissions reductions objectives, i.e., the unconditional target of 30% and three conditional targets of 35%, 40% and 45%. The unconditional commitment leads to 2030 emission levels between 87 and 104 Mt CO_2, representing an effective abatement[4] of between 10% and 16%. Simulations indicate that when economic growth increases, the effective abatement decreases. Indeed, the elasticity between CO_2 emissions and GDP is equal to approximately 0.6. This decoupling is explained by two factors. First, economic growth in Chile will benefit from consumption goods and services, less CO_2 intensive than other industrial products, like copper production. Second, the Chilean currency is devalued to maintain the surplus of the trade balance unchanged that in turn increases imported fossil energy prices. The 12 scenarios are presented in Table 5. Of these, only six lead to CO_2 emissions levels below the 2016 figure. This confirms the OECD (2016) remark that the Chilean INDCs imply slowing the CO_2 emissions rather than reducing GHG emissions in absolute terms.

[4]i.e., the commitment divided by the CO_2 emissions in the reference scenario.

Table 5: Chilean CO_2 emissions and Intended Nationally Determined Contributions in Mt CO_2 in 2030

	CO_2 emissions 2030	Unconditional 30%	Conditional 35%	40%	45%
3% GDP growth	103	87	80	74	67
4% GDP growth	109	95	88	81	74
5% GDP growth	115	104	97	89	81

3. Economic analyses

The section below discuss the economic assessments performed with GEMINI-E3. First, we consider the unconditional and conditional objectives assuming a 3% GDP growth scenario. Then we perform a sensitivity analysis for alternative future levels of GDP growth.

3.1. INDCs pledges within a 3% GDP growth scenario

We implement the pledges described in Tables 3 and 5 through a carbon tax in each country/region assuming a future economic growth in Chile of 3% from 2020 to 2030. The revenue coming from the carbon taxation is redistributed to households through a lump sum transfer in order to maintain the deficit/surplus of the government unchanged. The scenario also considers the US withdrawal from Paris Agreement combined with the "most optimistic scenario", excluding a domino effect resulting in additional country withdrawals (Kemp, 2017).

Table 6 gives the resulting Chilean abatements and the associated CO_2 taxes within the four conditional and unconditional scenarios. Under the unconditional pledge, the effective abatement is 16% and the CO_2 price reaches 75 US$ per ton in 2030. This CO_2 tax is within the upper bound of previous estimates (Dessus and O'Connor, 1999; Vera and Sauma, 2015; Benavides et al., 2015; Benavente, 2016), though it is noteworthy that, unlike those studies, we assume the implementation of an international climate policy (i.e., COP21 agreement). It means that worldwide energy consumption decreases that in turn induces a drop of international fossil energy prices which requires an increasing of carbon prices. Without CO_2 mitigation from other countries, the Chilean CO_2 price computed by GEMINI-E3 would be equal to 60 US$ per ton.

Compared to that of other regions, the Chilean carbon price is mid-range: the lowest among comparison groups, the China tax, is to 3 US$, and that of OAC and ROW CO_2 taxes are equal to 205 and 117 US$, respectively. Increasing the intensity target by five percentage points (i.e., from 30% to 35%) increases effective abatement by six percentage points. Similarly, effective CO_2 emissions are divided by 2 between the two targets 30% and 45%, with a CO_2 tax multiplied by 3.7 (from 75 to 279US$), belying the ambitiousness of the higher target. The macroeconomic impacts result in a 0.27% GDP loss under the unconditional pledge, and jump to 1.35%, for the 45% CO_2 emissions reduction scenario. It is worth noting that regarding welfare change, the simulations show welfare improvements stemming from gains in terms of trade. Indeed, worldwide decreases in fossil energy consumption result in a decrease of international energy prices that benefit Chile, a net importer of fossil energies. This result would not have occurred of course, if other countries were not implementing the COP21 agreement. Subtracting to welfare change the gains from terms of trade (GTT) gives a deadweight loss of taxation (DWL)[5] that increases with the CO_2 abatements which is consistent with economic theory.

Figure 2 gives fossil energy consumption under the different scenarios. As expected, energy forms with the highest carbon content (i.e. coal) are the most impacted. Coal consumption drops down by 50% in the unconditional scenario, and by, at most, 75% in conditional pledge scenarios. Natural gas consumption decreases by 10% to 18%. In contrast, the consumption of petroleum products is less impacted with a reduction by 4% to 18%, mainly because substitutions are more difficult, especially in transportation uses.

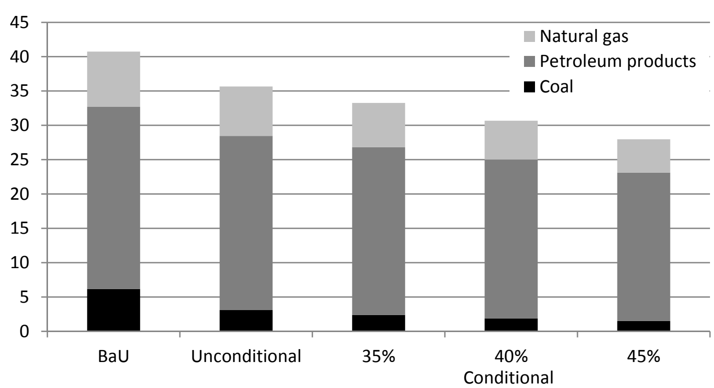

Figure 2: Chilean fossil energy consumption in Mtoe in 2030

Figure 3 shows the contribution of the Chilean economic sectors to carbon

[5]Bernard and Vielle (2003) explain how this decomposition is performed with GEMINI-E3.

abatements. The decrease of fossil energy production (due to fossil energy consumption contraction) induces a CO_2 emissions reduction in these sectors. Electricity generation is a significant contributor to the total CO_2 abatement. Within the unconditional pledge, it represents 71% of the Chilean abatement and their emissions decrease by 35% mainly done by a reduction of electricity generation from coal power plants. In non-energy sectors, CO_2 emissions decrease by similar percentages, even if the contribution of energy intensives industries and copper sectors are slightly more significant.

Table 6: Carbon tax and welfare impacts in 2030

	Unconditional	Conditional		
	30%	35%	40%	45%
Effective CO_2 abatement	-16%	-22%	-28%	-34%
CO_2 tax	75	123	188	279
GDP change	-0.28%	-0.53%	-0.91%	-1.43%
Welfare cost	0.48%	0.57%	0.55%	0.50%
GTT	0.61%	0.85%	1.07%	1.33%
DWL	-0.13%	-0.29%	-0.51%	-0.82%

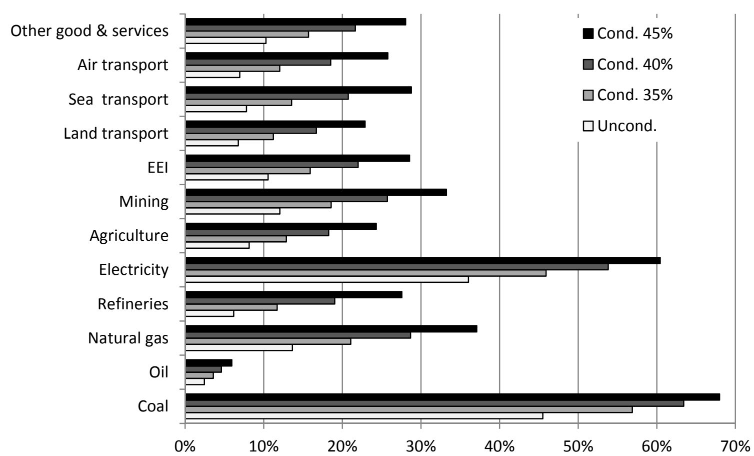

Figure 3: Chilean CO_2 emissions abatement per sector in 2030

3.2. Uncertainty on economic growth

We now consider two other economic growth assumptions over the next decade and evaluate the impact on the mitigation policies. Indeed, Chile has submitted INDCs that take into account future economic growth which would allow the country to implement additional GHG abatements. We simulate the intensity targes implementations ranging from 30% to 45% under 4% and 5% annual GDP growth scenarios for the 2020-2030 period. Figure 4 shows the resulting CO_2 taxes under all 12 mitigation scenarios that consider three economic growth (including the 3% GDP scenario) and four intensity targets. As our results indicate, in the case of Chile, when the economic growth is increasing, the emissions intensity target becomes less stringent, and more severe with economic slowdown. This result, as pointed out in Aldy et al. (2017), is a consequence of the decoupling of CO_2 emissions with respect to GDP growth and its impact on the effective carbon abatement that the model shows for the next decade. Moreover, the results show that a 45% intensity target induces rather high CO_2 price levels, ranging from 237 to 279 US$.

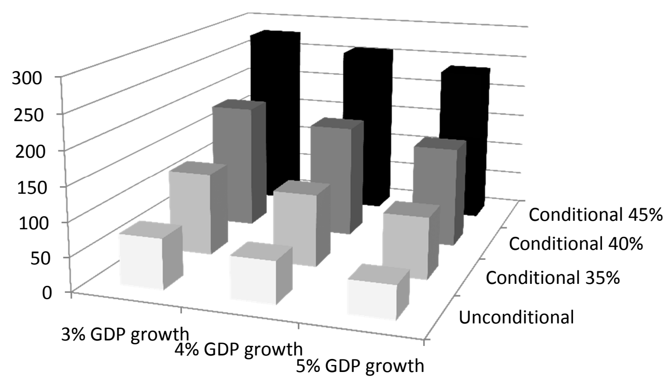

Figure 4: Chilean CO_2 taxes in $US

Figure 5 displays impact on 2030 GDP under the 12 scenarios. It is interesting to analyse the relationship linking the GDP cost (i.e., the decrease of GDP with respect to the BAU scenario) with the intensity target and economic growth for the year 2030. We perform an econometric estimation described in the equation 1.

$$\frac{\text{GDP}^{\text{scenario}} - \text{GDP}^{\text{reference}}}{\text{GDP}^{\text{reference}}} = \underset{(5.49)}{0.18} \cdot \text{Economic growth} - \underset{(-15.07)}{0.07} \cdot \text{Intensity target} + \underset{(5.49)}{1.20} \quad (1)$$

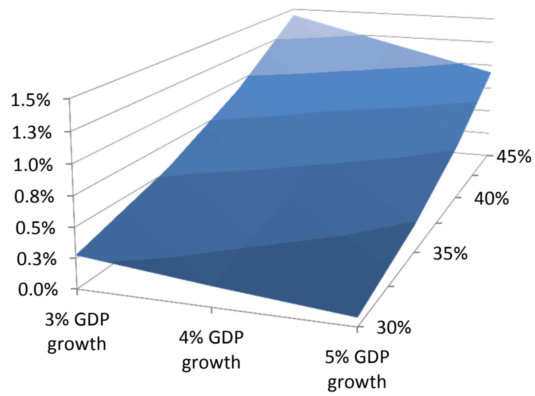

Figure 5: GDP decrease in percentage with respect to economic growth and intensity target in 2030

R^2=0.96

Based on that estimation, we compute the tradeoff between economic growth and intensity target. We find that one percent of additional growth per year would allow the intensity target to be increased by 2.5% with unchanged GDP cost. We also measure the loss of GDP in US$ induced for 1 percent point increase of the intensity target and thus quantify the financial international compensation that could be requested by Chile to increase its pledges. The GDP loss is estimated at 300 million US$. All else equal, increasing the intensity target from 35% to 45% would require an additional financial transfer estimated at three billion US$ for 2030. This result implies a shadow price of 220 US$ per ton of CO_2 avoided.

4. Conclusion

Analyses performed in this paper show that Chilean INDCs designed around emission intensity yield significant uncertainties for 2030 emissions levels. Our results indicate that annual emissions may range from 67 to 115 Mt CO_2 depending on several factors, e.g., economic growth, level of CO_2 intensity target and international cooperation. Moreover, effective abatement ranges between -10% from -35%. It is therefore quite difficult to conclude on the environmental effectiveness of the Chilean pledges, especially, for economic growth above current trends, and thus higher emissions. This result confirms and illustrates the OECD comment on the Chilean climate policy (OECD, 2016) asking for clarifications on the conditional pledges. Of course, one might argue that for a country like Chile that accounts only for 0.2% of global GHG emissions, such result does not represent an issue at a global level. In contrast, for countries like China and India, it could be among the contentious issues affecting the outcomes of post COP21 subsequent climate negotiations (Zhang, 2017).

Nevertheless, simulation outcomes indicate that the Chilean unconditional commitment induces a significant increase of the existing carbon tax quite above 75 US$. Although the GDP cost associated with climate policies is rather small for low and medium intensity targets, the impact on GDP increases very much for high intensity targets and low economic growth assumptions. In that context, international support will be crucial in attaining policy objectives. This macroeconomic analysis does not allow us to conclude about the distributional incidence of the carbon tax and on a potential opposition by the Chilean citizens against high tax levels. Assessing how carbon tax revenue is redistributed and its impacts on households will require additional research, using for example household budget survey (e.g. Agostini and Jiménez (2015)).

The present paper confirms and expands on previous theoretical analyses of CO_2 intensity targets (Pizer, 2005; Jotzo and Pezzey, 2007; Aldy et al., 2017). We show that emission intensity targets are less stringent under higher economic growth, and more severe under economic slowdown. This result is, of course, linked to the decoupling of CO_2 emissions with respect to GDP growth.

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