National Roadmap for Adaptation 2100
Portuguese Territorial Climate Change Vulnerability Assessment for XXI Century

REPORT

WP6 – Macroeconomic Impacts

National Roadmap for Adaptation 2100

Portuguese Territorial Climate Change Vulnerability Assessment for XXI Century

Title: RNA2100 – Macroeconomic impacts of different climate scenarios: the case of Portugal

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1. Introduction

The National Roadmap for Adaptation 2100 (RNA 2100 in the Portuguese acronym) is an interdisciplinary project with the aim of assessing how Portugal is impacted by different climate scenarios, with a focus on the geophysical, social, and economic systems. In the case of Work Package 6, the goal is to give a broad-brush picture of possible macroeconomic consequences of different gradations of the atmospheric carbon concentration pathways. As in other work packages of the project, this analysis is conducted in reference to the Representative Concentration Pathways (RCPs) 2.6, 4.5 and 8.5, as characterised in the Fifth Assessment Report of the IPCC. For each of the scenarios, a global tax carbon policy is synthesised to be broadly consistent with its atmospheric carbon concentration trajectory.[1]

Policy aimed at curbing carbon emissions only works if it is applied globally, since atmospheric carbon concentration is a global phenomenon. Policy must be global, but the effects of policy are local and highly heterogeneous. For this reason, the analysis zeroes in on the reality of Portugal, modelled as a small open economy subject to the global carbon tax policies and characterised by different values for selected parameters.[2] In the context of this work, a small open economy is defined as one that has negligible impact on global output and carbon emissions, and with the same marginal productivity of capital as the rest of the world.

An integrated climate assessment model is developed featuring three regional economies (one oil-producing region, Portugal, and the rest of the world), different energy sources (coal, oil, gas, and clean sources), forestry, global carbon taxation policies capable of generating each of the RCP scenarios, and competitive markets for energy, capital, and goods. Long-term carbon sequestration subsidisation is assumed to be symmetrical to the global carbon tax. An additional feature of this analytical framework is the inclusion of adaptation at the local level, which is used to assess its importance in a transition subject to global carbon taxation. We assume that the revenue from the carbon tax, net of subsidies to forests and possible adaptation costs, is rebated lump sum to households. The fiscal neutrality of carbon taxation and subsidisation is particularly important in terms of wellbeing of the households, as it compensates them for the higher energy prices.

[1] This report draws extensively from Adão, Antunes and Lourenço (2024) "Evaluating the economy under different climate scenarios: the case of a small open economy", Banco de Portugal and RNA 2100, monograph. Available from the authors upon request.

[2] Differences relative to the non-oil-producing rest of the world are the intensity of the region-specific economic damage coming from atmospheric carbon concentration, the intensity of energy use in production, the upper bound of area potentially covered by forests, and the cost of forestry development. For details, see Adão et al. (2024).

2. Results

Results show that net carbon emissions significantly decrease with higher carbon taxes, which in turn determine the global level of carbon concentration in the atmosphere. In the model and under simplifying assumptions, the initial carbon tax equivalent needed to attain the optimal allocation would be around 8.7 cents of the dollar per kilo of carbon emitted, or roughly 330 dollars per tonne of carbon dioxide. This value then increases at the same rate as global GDP. We will use this as a reference value to calibrate carbon tax policies in each scenario.

Baseline simulations

To obtain a carbon concentration path consistent with RCP2.6, a much higher carbon tax of around 15 times the optimal tax would be needed in the model. Table 1 presents results for selected variables conditional on this high carbon tax scenario, labelled RCP2.6, both for the world and the Portuguese economies, and assuming no significant adaptation is performed at the national level. The world temperature anomaly hovers around 1.3-1.4 degrees Celsius, with net carbon emissions decreasing from 35.3 GtCO2 in 2020 to 5.2 GtCO2 by 2050, and negative emissions of -2.3 GtCO2 in 2100. This is roughly consistent with the RCP2.6 scenario, which foresees an anomaly in the range 0.3-1.7 degrees Celsius by 2100.[3] With the symmetrical high subsidies to long-term carbon sequestration through forests, the model predicts an expansion of the world forested area of just over 2 percentage points of the land area, currently at 31 percent. This represents a total carbon sequestration of 8.3 GtCO2 by the end of the century, thus contributing to negative net carbon emissions.

The macroeconomic consequences of climate change in this scenario are mild. Relative to the current situation, damages increase by 0.3 percent of GDP by 2050 and remain at that value until the end of the century. What does this mean in terms of households' welfare? To answer that question, economists have long resorted to the notion of equivalent consumption variation. In this specific case, it is defined as the increase in consumption that agents living in an economy where mitigation policy is unchanged would have to experience to leave them, in utility terms, as well off as in the economy subject to the carbon tax policy. An important caveat of this measure is in order here. Given that the direct utility or disutility coming from the effects of climate change on biodiversity, climate comfort, and migrations, for example, is disregarded, this measure does not

[3] Since the model only accounts for carbon emissions resulting from carbon energy use plus the carbon sequestration of forests, the reference value is taken as the part of greenhouse gas emissions coming from CO2, net of land use change and forestry effects, which are also modelled, at least partly. Total GHG emissions in 2020 are roughly 30 percent higher. It is thus advisable to look at the values of Table 1 as conservative estimates of the actual values.

capture all the relevant effects affecting households' welfare. If such effects are, in net utility terms, deleterious to agents, the equivalent consumption variation would be higher. [4]

Table 1 indicates that individuals are in general better off by the end of the century, but slightly worse off by 2050. The model also suggests that initially individuals will experience a relatively large fall in equivalent consumption of 0.5 percent (not shown in the table), which suggests that policymakers will likely face opposition to the high carbon tax policy, even if, as assumed, the tax carbon revenue net of subsidies and possible adaptation costs is rebated back to the households.

Table 1. Main results without adaptation policy for the world and Portugal.

World		**RCP2.6**		**RCP4.5**		**RCP8.5**	
	2020	**2050**	**2100**	**2050**	**2100**	**2050**	**2100**
Net emissions (GtCO2 per year)	35.3	5.2	-2.3	26.7	24.8	42.0	110.9
Temperature anomaly (C)	1.0	1.3	1.4	1.5	2.2	1.6	2.9
Consumption gain (%)	-	-0.2	0.3	0.1	0.7	0.1	0.7
Economic damage (%)	0.6	0.9	0.9	1.2	1.8	1.4	3.1

Portugal		**RCP2.6**		**RCP4.5**		**RCP8.5**	
	2020	**2050**	**2100**	**2050**	**2100**	**2050**	**2100**
Net emissions (MtCO2 per year)	36.4	0.2	-7.8	17.8	9.7	25.0	41.3
Temperature anomaly (C)	1.2	1.6	1.7	1.8	2.6	1.9	3.5
Consumption gain (%)	-	0.7	2.0	0.3	1.6	0.1	1.1
Economic damage (%)	1.0	1.0	1.0	1.3	1.9	1.5	3.3

Sources: UN Climate Change and authors' calculations.

For Portugal, the situation is comparable but there are notable differences. The temperature anomaly is higher than globally, which is not surprising since that is one of the results of WP2 of RNA 2100. The temperature anomaly will stabilise close to 1.7 degrees Celsius from a current value of 1.2 degrees Celsius. Net emissions in Portugal are zero roughly by the middle of the century, and firmly negative towards its end, propelled by an increase in forest land of 3 percent of the Portuguese territory, from 39 percent. Forest carbon sequestration in 2100 will increase by 0.8 MtCO2, from the current 10 MtCO2.

[4] In the RCP2.6 scenario, the direct utility effects of climate change should be minimal, as the scenario embeds a halt to the increase of atmospheric carbon concentration. The equivalent consumption measure would probably change much more had those effects been considered. This is not the case with scenarios RCP4.5 and especially RCP8.5. In the latter case, the higher level of disruption would probably imply higher direct disutility effects, and thus even lower equivalent consumption.

As shown in the applicable scientific and policy literature, the global externality has a larger macroeconomic impact in Portugal than in the rest of the world. Therefore, a carbon tax much higher than the reference value is more beneficial for Portugal than for the rest of the world. The macroeconomic damage for Portugal, estimated at 1 percent of GDP throughout the projection horizon, will be comparable to what it already is. This is also reflected in the equivalent consumption gains of the policy, which are consistently positive, and even large, at 2.0 percent by 2100.

The second and more likely scenario mimics RCP4.5. Carbon taxation is about two thirds of the reference value and produces a global temperature anomaly of 1.5 and 2.2 degrees Celsius in 2050 and 2100, respectively. This is roughly consistent with RCP4.5, which features a temperature anomaly at the endpoint of the projection horizon in the range 1.1-2.6 degrees Celsius. World CO2 emissions attain a maximum of around 29 GtCO2 in 2080, and then slowly decline. Under this policy, forests are little affected by subsidisation and the world forest coverage increases by less than 0.5 percent of the world land territory. Likewise, long-term carbon sequestration through forests increases only 0.1 GtCO2, from 8 GtCO2 currently.

The global macroeconomic impacts of this scenario are sizeable. Relative to 2020, they represent an additional 0.6 percent of GDP in 2050, and 1.2 percent of GDP in 2100. The long-term additional economic losses from climate change are thus roughly equivalent to losing the current GDP of the Netherlands every year. Unsurprisingly, the equivalent consumption gains are larger than under the RCP2.6, high carbon taxation scenario. This is because the level of carbon taxation is only moderately below the reference value. Gains are positive throughout the century, albeit close to zero in the decade after 2070. However, the gains are not exceedingly high, with at most a value of 0.7 percent at the end of the century, and below 0.25 percent well beyond the 2080s.

In Portugal, the situation is comparable to that of the rest of the world. Net emissions decrease from 36.4 MtCO2 in 2020 to 9.7 MtCO2 in 2100, without ever attaining net zero. The temperature anomaly reaches 2.6 degrees Celsius in 2100, a considerable increase. The forest coverage increases modestly by 1 percent of the Portuguese land surface. Carbon sequestration increases by 0.3 MtCO2 relative to the current situation.

Under this scenario, the impacts on the Portuguese economy are sizeable. Relative to 2020, they go from an additional loss of 0.3 percent of GDP in 2050 to an additional loss of 0.9 percent of GDP in 2100. At current prices, the latter value is roughly 2.5 billion euros lost every year. The equivalent consumption gains go from 0.3 percent in 2050 to 1.6 percent in 2100. This is lower than the high carbon taxation scenario because, as mentioned above, the climate externality is economically more harmful in Portugal than in the rest of the world. Thus, from Portugal’s standpoint, lower global taxation is probably not preferable to higher global taxation.

The low carbon taxation scenario corresponds to the unmitigated carbon concentration pathway RCP8.5. In the model, a global carbon tax of 15 percent of the reference value is used. This produces, in 2100, a temperature anomaly of 2.9 degrees Celsius and carbon dioxide emissions to the tune of 110 GtCO2 and increasing. The temperature anomaly is still within the RCP8.5 range of 2.6-4.8 degrees Celsius, albeit at its lower end.[5] Given the low subsidies to forestry, the model produces a negligible impact on the land surface area covered by forests.

The global economy is severely affected by the intense climate externality. By mid-century, its impact is roughly 0.8 percent of GDP higher than currently, only to grow to 2.5 percent of the world GDP at the end of the century. At current prices, this is an additional loss roughly the size of Brazil's economy. Surprisingly, equivalent consumption gains are comparable to those of the intermediate carbon taxation, at 0.1 and 0.7 percent in 2050 and 2100, respectively. The reason is that, by taxing carbon emissions mildly, the economy continues to be driven by fossil fuel sources, which emit carbon but are abundant and cheap. And while the economic damages are larger than in the RCP4.5 scenario, equivalent consumption is little affected. It is a more wasteful economy with a more short-sighted consumption pattern. After 2100, this scenario produces lower equivalent consumption gains than both the RCP2.6 and the RCP4.5 scenarios.

In Portugal, the low carbon tax scenario produces the expected results: a temperature anomaly reaching 3.5 degrees Celsius in 2100, with carbon net emissions at 41.3 MtCO2 and increasing. Economic damages increase by 2.3 percent of GDP during the entire simulation horizon. At current prices this is roughly 6.1 billion euros every year. Equivalent consumption gains relative to the no-change economy would be significantly smaller than under the RCP2.6 and RCP4.5 scenarios, although still positive. Consideration of direct utility effects from the climate externality would worsen this scenario relative to RCP4.5 and RCP2.6 even within the simulation horizon.

Adaptation in Portugal

Embedding adaptation policies in the model produces results quantitatively different from the baseline simulations. Adaptation has two effects. First, it reduces the impact on the economy of the climate externality, subsumed by carbon concentration in the atmosphere. Second, it absorbs resources that could be allocated to other uses, including investment and consumption. A successful adaptation strategy optimises this trade-off. The results are presented in Table 2, as differences relative to the no-adaptation case.

[5] This model estimate may be viewed as conservative; see footnote 3 for an explanation.

Table 2. Results with optimal adaptation policy in Portugal.

Portugal		**RCP2.6**		**RCP4.5**		**RCP8.5**	
	2020	**2050**	**2100**	**2050**	**2100**	**2050**	**2100**
Net emissions (MtCO2 per year)	36	0	-8	18	10	25	42
Temperature anomaly (C)	1.2	1.6	1.7	1.8	2.6	1.9	3.5
Consumption gain (%)	-	0.8	2.0	0.4	2.1	0.3	2.2
Economic damage (%)	1.0	1.0	0.9	1.1	1.3	1.2	1.9
Adaptation costs (%)	-	0.1	0.0	0.2	0.4	0.2	0.7

Difference to no-adaptation scenario		**RCP2.6**		**RCP4.5**		**RCP8.5**	
	2020	**2050**	**2100**	**2050**	**2100**	**2050**	**2100**
Net emissions (MtCO2 per year)	0	0.0	0.0	0.1	0.2	0.1	1.0
Consumption gain (pp)	-	0.0	0.0	0.1	0.4	0.2	1.2
Economic damage (pp)	0	-0.1	0.0	-0.2	-0.6	-0.3	-1.4

Sources: UN Climate Change and authors' calculations.

In the high tax scenario – the most favourable for Portugal in equivalent consumption terms – the effects of adaptation are small but have the expected direction. For example, adaptation can reduce economic damages by 0.1 percent of GDP, with no discernible effects on wellbeing. Adaptation costs are negligible.

The intermediate scenario has adaptation reducing economic damage by a significant amount: 0.2 and 0.6 percent of GDP in 2050 and 2100, respectively. The adaptation costs are commensurate with the economic damage reduction in 2050, but smaller by 0.2 percent of GDP in 2100. This increases equivalent consumption, as expected, and increases emissions by relatively small amounts. These results are interesting for at least two reasons. First, the optimality of adaptation means that, relative to the same no-adaptation economy, equivalent consumption gains will always be non-negative. Second, adaptation does not per se imply lower emissions; it could well be that the opposite is true. To understand this result, note that, by reducing the damages from the climate externality to the economy, but not reducing the externality itself, adaptation allows the economy to operate at a higher level, and therefore with additional emissions.

The unmitigated climate scenario corresponding to RCP8.5 with adaptation reduces economic damages by 1.4 percent of GDP in 2100 and produces an equivalent consumption gain of 1.2 percent relative to the no-adaptation case. The adaptation costs in 2100 are 0.7 percent of GDP, significantly smaller than the economic damage reduction. This is enough to make total equivalent consumption gains similar to scenarios RCP2.6 and RCP4.5 in 2100.[6] This surprising result shows

[6] The important caveat mentioned in footnote 4 also applies here. To the extent that the non-economic effects of the carbon externality are, in net terms, deleterious to households, it is reasonable to guess that consumption gains in scenarios with large atmospheric carbon concentration would be smaller.

that adaptation is a powerful tool to compensate possible insufficiencies in mitigation, which is only effective if global policies are in place.

Taking these results together, one concludes that the higher the mitigation effort – that is, the higher the global carbon tax or equivalent measures – the less local adaptation is needed. This suggests a powerful role for adaptation to improve welfare at the local level for any given carbon tax policy.

3. Concluding remarks

The results presented in this report suggest a few useful ideas in relation to the macroeconomic impact of climate change and the related mitigation and adaptation policies.

The first idea is that economic efficiency is not a monotonic function of the global carbon tax level (or equivalent measures). Extremely high levels of carbon taxation may translate in sizeable losses of consumption and lack of acceptance of such policies. Likewise, a very low carbon tax policy will lead to an inefficient economy and substantial loss of welfare in the very long run, not to mention effects not explicitly modelled such as loss of biodiversity, climate discomfort, and chaotic migrations.

The second idea is that the effects of mitigation impinge on local economies in heterogeneous ways. Using Portugal as the epitome of a small open advanced economy, model simulations suggest that a high global carbon taxation policy (or equivalent policy) consistent with RCP2.6 is better, in equivalent consumption terms, than a milder carbon taxation scenario as embedded in RCP4.5, which is not the case for the world economy.

The third idea is that adaptation could be a powerful tool to locally compensate the effects of global carbon taxation or equivalent policies. On a more negative note, large adaptation needs could be a sign of failure to address climate change through mitigation.

This analysis has three main shortcomings. The first is the inherent uncertainty related to the model specification, its parameters, and adherence to reality of the approach.

The second is the modelling of carbon emissions alone, without explicitly considering other sources of GHG emissions. For this reason, the results presented here should be viewed as conservative model estimates.

The last caveat is the reliance on consumption alone as a yardstick of the welfare consequences of the climate externality and climate mitigation policies. Aspects such as biodiversity, climate comfort, and migrations are not explicitly considered because they would introduce additional layers of complexity in the analysis. Tackling these issues is a worthy endeavour left for further research.