Future Climate Wealth of Nations' Winners and Losers

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Abstract

Mapping Climate Justice proposed a 3-dimensional climate justice approach to share the burden of climate change right, just and fair around the globe. First, climate justice within a country should pay tribute to the fact that low- and high-income households carry the same burden proportional to their dispensable income, for instance, enabled through a progressive carbon taxation. Secondly, fair climate change change burden sharing between countries ensures those countries benefiting more from a warmer environment also bear a higher responsibility regarding climate change mitigation and adaptation efforts. Thirdly, climate justice over time is proposed in an innovative bonds climate change burden sharing strategy. All these recommendations are aimed at ensuring to share the burden but also the benefits of climate change within society in an economically efficient, legally equitable and practically feasible way. Future wealth of nations is introduced by the concept of climate flexibility defined as the range of temperature variation of a country. In a changing climate, temperature range flexibility is portrayed as a future asset for international trade of commodities but also for production flexibility leading to comparative advantages of countries. A broad spectrum of climate zones has never been defined as asset and comparative edge in free trade but climate change will require territories being more flexible in terms of changing economic production. The more climate variation a nation state possesses, this paper argues, the more degrees of freedom a country has in terms of GDP production capabilities in a differing climate. These preliminary insights aid in answering what financial patterns can we expect given predictions the earth will become hotter. Already now, the degree of climate flexibility is found to be related to human migration inflow and is predicted to determine future climate wealth of nations in a climate changing world. The previously defined climate change winner and loser index will be blended with the novel insights on climate flexibility, leading to an unprecedented outlook on future climate wealth of nations. Lastly, future climate change induced market changes are pegged to scarcity of agriculture production and a prospect of commodity price spikes is given.

Key words: Agriculture sector, Business gains, Cardinal temperature, Climate change, Climate change winners and losers, Climate Wealth of Nations, Competitive advantage, Corporate benefits, Economic advantage, Finance industry, Finance prospects, GDP, Global warming, Gross Domestic Product, Industry sector, International trade, Service sector

1. Introduction

Never before in the history of humankind have environmental concerns in the wake of economic growth heralded governance predicaments as we face today (Centeno, Creager, Elga, Felton, Katz, Massey, & Shapiro, 2013; Nordhaus, 1994; Chichilnisky, 2007, 2010). Climate change presents societal, international and intergenerational fairness as challenge for modern economies and contemporary democracies (Bürgenmeier, 1994; Chichilnisky & Bal, 2019). In today's climate change mitigation and adaptation efforts, high and low income households, developed and underdeveloped countries and overlapping generations are affected differently (Chichilnisky & Bal, 2019). Based on insights from the current endeavor to finance the post-COP21 Paris agreement action plan, the *Mapping Climate Justice Project* proposes a 3-dimensional climate justice approach in order to find a universally fair climate strategy (Puaschunder, forthcoming a, b).

Mapping Climate Justice elucidates international climate regimes around the world based on geographic, technological, socio-economic and political factors. An interactive graphic solution highlighting different countries' climate stability efforts targets at finding ways to share the benefits and burdens of climate change equally *within society*, *between countries* and *over time* (Puaschunder, forthcoming a).[1]

Comparing international climate mitigation and adaptation as well as unraveling complex interdependencies is aimed at helping to protect vulnerable communities from variegated climate change risks while opening ways for all to benefit from the upsides of a warming earth (Chichilnisky & Bal, 2019; Chichilnisky & Sheeran, 2018). In this paper, economic and legal analyses unravel how to allocate the burden of climate protection in a fair manner and ensure humankind to feel a fair solution to climate justice was pursued. The article also elucidates climate flexibility as the range of temperatures becoming the source of future wealth of nations. The more varied temperature zones a country offers for agriculture, industry and service production, the more likely a territory will be able to provide trade opportunities. Finally, the paper presents scarcity in light of running out temperature ranges as source of potential price spikes as exhibited in inflated commodity prices. The article ends with a discussion of the presented preliminary model and future perspectives of model extensions.

[1] https://juliampuaschunder.com/mapping-climate-justice/

2. Theory

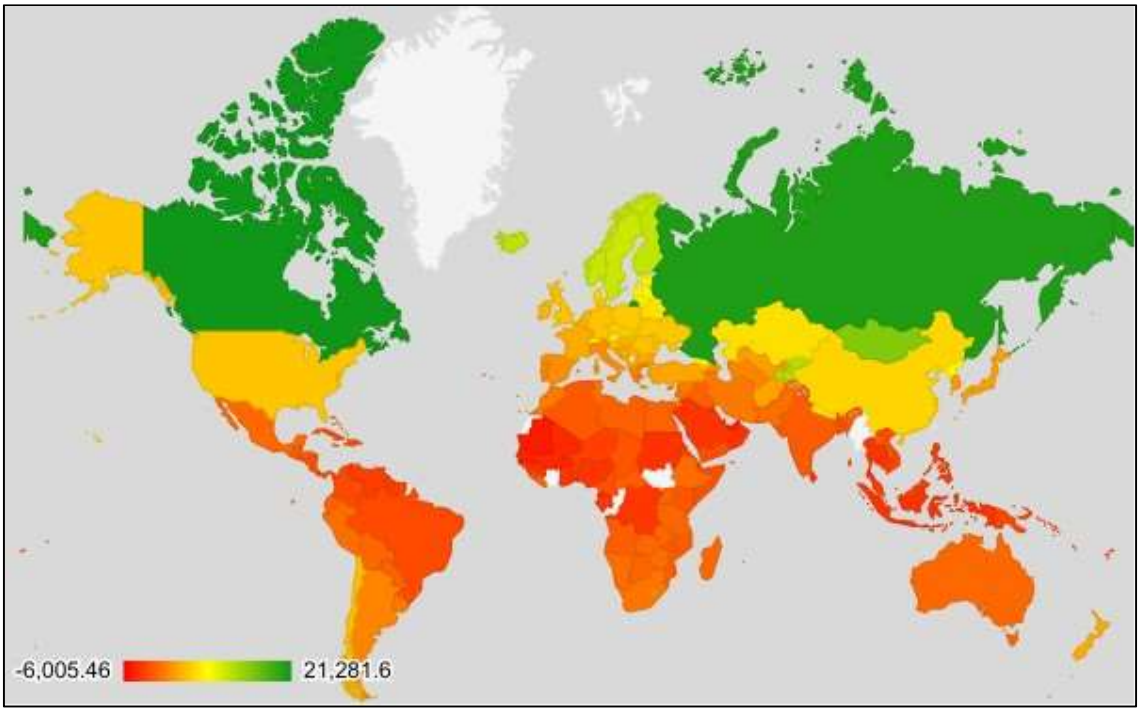
Climate justice *within* countries: In order to finance climate change mitigation and adaptation efforts, a diversified taxation scheme is proposed. To find a fair and just distribution of the burden of climate change, a taxation mix of (1) consumption tax, (2) progressive tax and (3) inheritance tax is recommended. Consumption tax can curb harmful emissions and directly nudge behavior towards sustainability. Yet to place a fair share of the burden of climate change mitigation upon society, these taxes have to be adjusted to the individual disposable income in order to not heavier charge low-income households. Retroactive taxation of past wealth accumulation at the expense of environmental damage can be enacted through inheritance tax of the corporate sector. Industries should be taxed, when a merger or acquisition or a board member change occurs, in order to reap benefits from past wealth accumulation that potentially caused carbon emissions.

Climate justice *between* countries: Following the introduction of the gains from climate change (Puaschunder, 2017a, d), the *Climate Justice in the 21st Century* endeavor proposes a model to distribute the benefits of a warming earth in a fair way. Based on legal subsumptions, argumentations of the those countries having better means of protection and conservation of a stable climate, will lead to the pledge of climate change winners having to bear a higher weight of climate stabilization efforts. A macroeconomic cost-benefit analysis thereby aids to find the optimum solution on how to distribute climate change benefits and burden within society and over time.

Contemporary Gross Domestic Product (GDP) serves as basis for economic estimations about the productivity of the agriculture, industry and service sectors around the world in a changing climate (Puaschunder, forthcoming a).[i] When unidimensionally focusing on estimated GDP growth given a warmer temperature, over all calculated models assuming linear, prospect or hyperbolic gains and losses, the world will be gaining more than losing from a warming earth until the year 2100. Based on the *WL* index of 188 countries of the world, less countries (n=78) will gain more from global warming until 2100 than more countries (n=111) will lose from a warming earth (Puaschunder, 2018a). Graph 1 holds Climate Change Winners (Green & Yellow) and Losers (Orange & Red) until 2100 around the world. Green countries are those with most time ahead until reaching a GDP production peak condition by climate, yellow countries have some time ahead. Orange and red countries will have run out of time by 2100 for GDP production peak. Winning and losing from a warming earth is significantly positively correlated with the Paris COP 21 emissions country percentage of Greenhouse Gas

(GHG) for ratification, leading to the conclusion that the countries with the longest time horizon regarding a warming earth lack motivation to mitigate global climate change (Puaschunder, 2017b; forthcoming a).

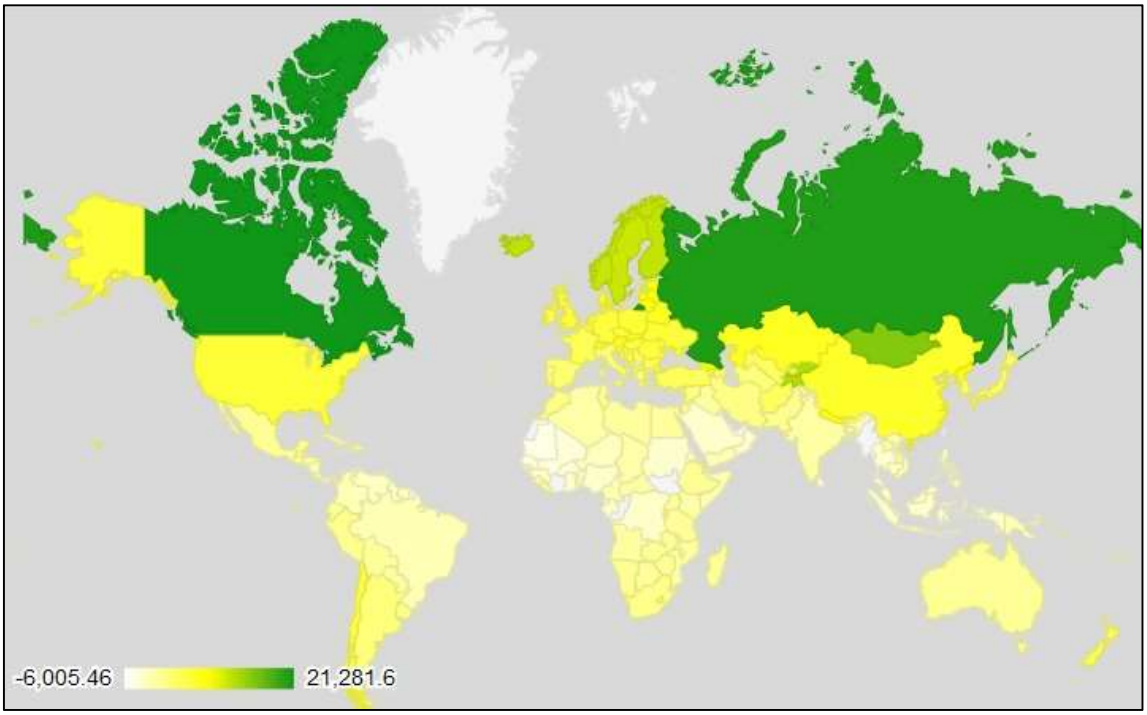
Graph 1: World Climate Change Winners (Green & Yellow) & Losers (Orange & Red) until 2100



2.1 Climate change gains

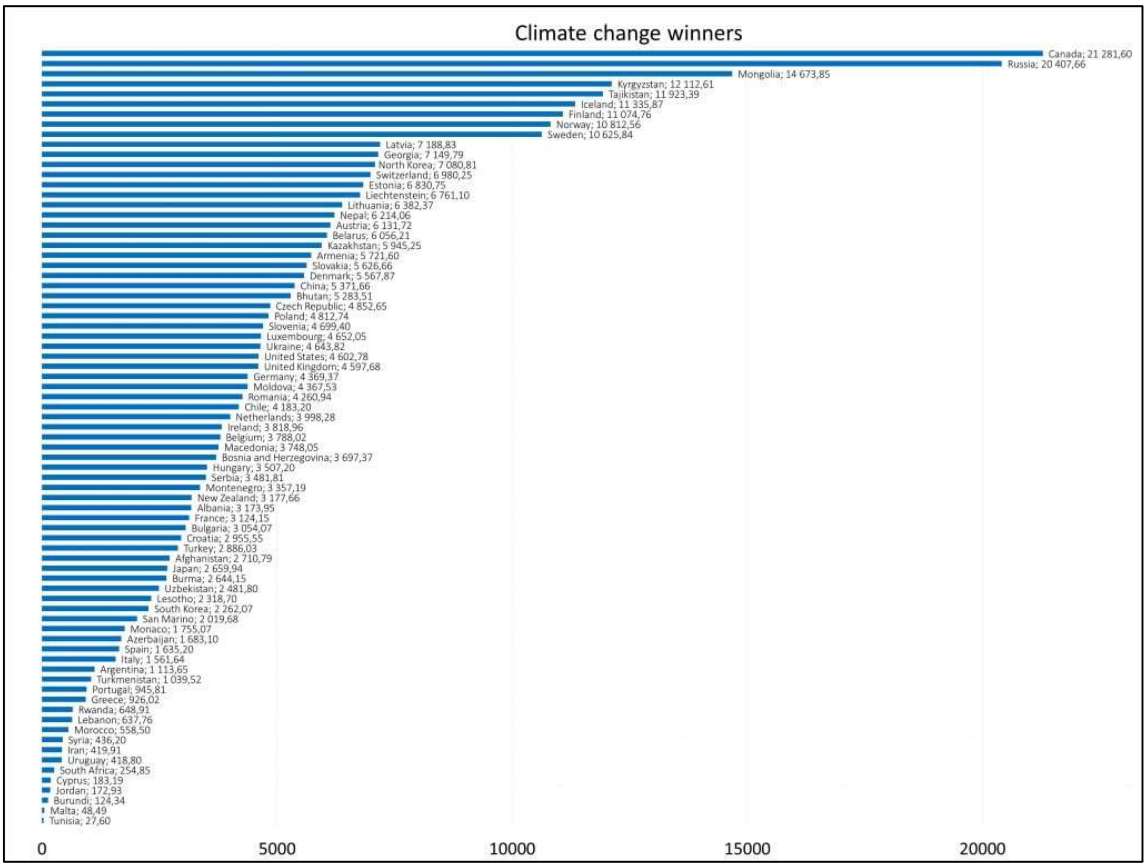
Based on the medium temperature of countries around the world and the optimum temperature for Gross Domestic Product (GDP) production, the world can be divided into climate change gaining and losing territories until the year 2100. Graph 2 holds those countries that have the most time ahead until optimum temperature for GDP production in green and those that are around peak condition in yellow (Puaschunder, forthcoming a).

Graph 2: Climate change winning territories until the year 2100



The climate change winning territories are also outlined in Table 1 ranked by country name.

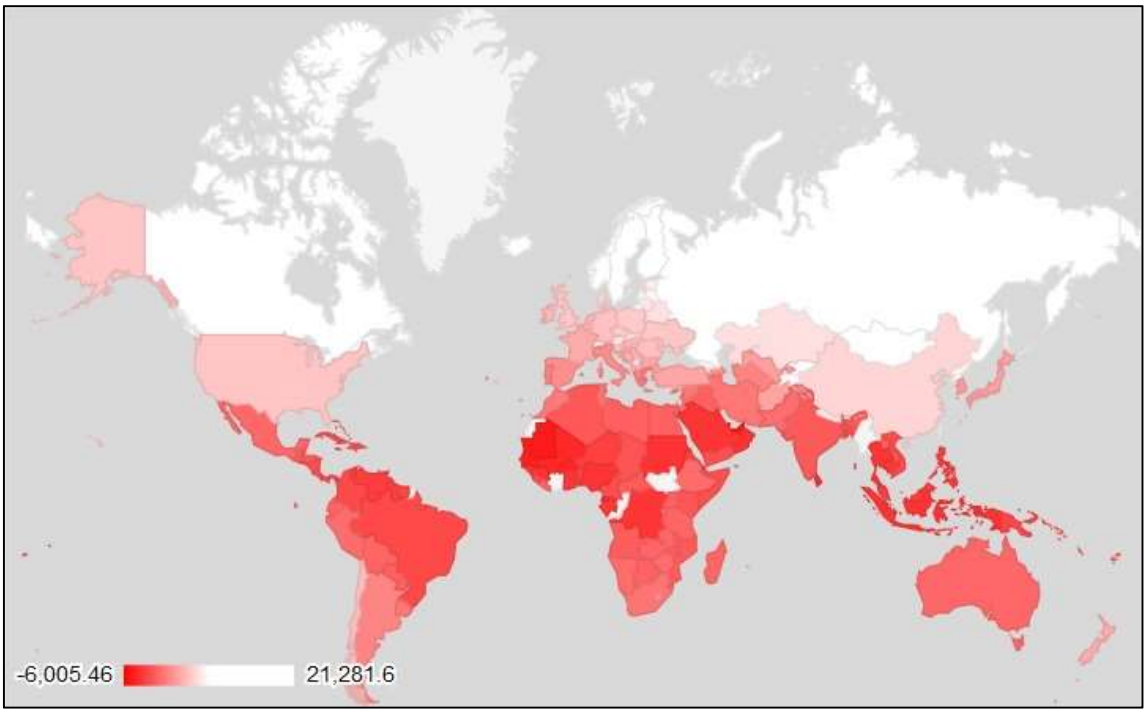
Table 1: Climate change winning territories by country ranked



2.2 Climate change losses

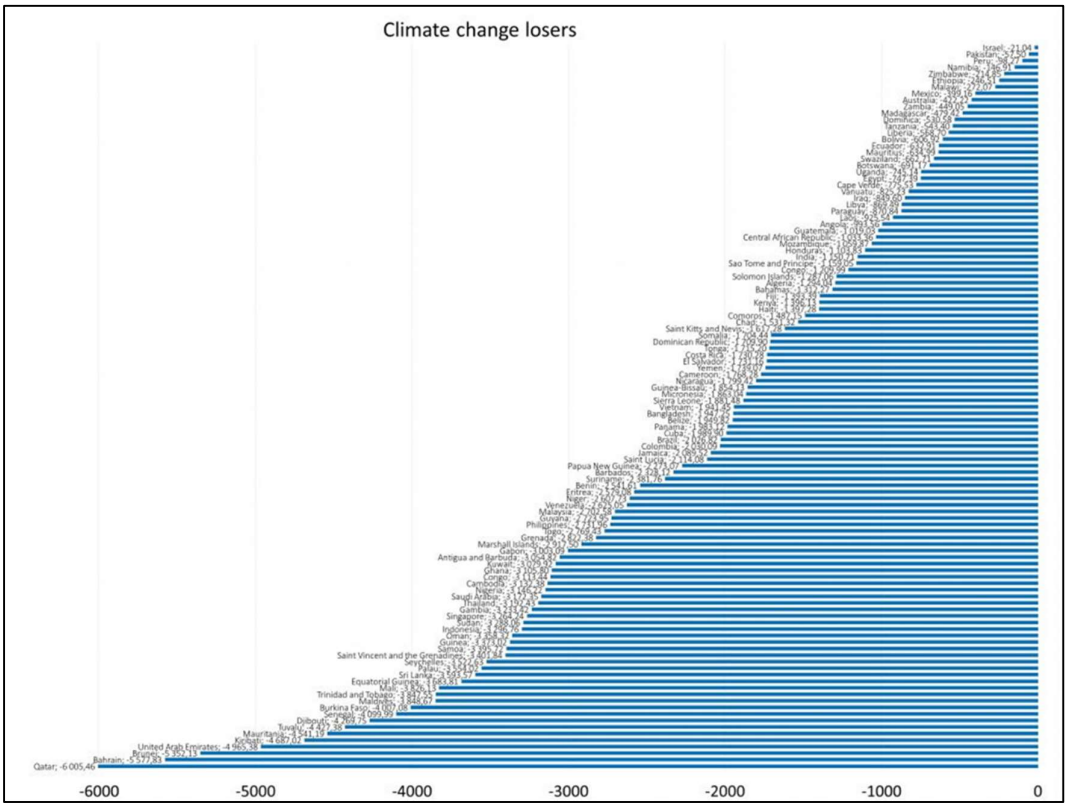
Based on the medium temperature of countries around the world and the optimum temperature for Gross Domestic Product (GDP) production, the world can be divided into climate change gaining and losing territories until the year 2100. Graph 3 holds those countries that have passed the peak temperature for GDP production in red (Puaschunder, forthcoming a).

Graph 3: Climate change losing territories until the year 2100



The climate change losing territories are also outlined in Table 2 ranked by country name.

Table 2: Climate change losing territories by country ranked



The results target at underlining the importance of climate change benefits transfers to offset the losses incurred in the global warming-burdened areas of the world. The philosophical justification is grounded in the climatorial imperative – advocating for the need for fairness in the distribution of the global earth benefits among nations based on Kant's imperative (1788/2003) to only engage in actions one wants to experience being done to oneself. Passive neglect of action on climate mitigation is an active injustice to others (Chichilnisky, 1996, Chichilnisky, Heal & Vercelli, 1998; Puaschunder, 2017b).

2.3 Climate justice *between* generations: Tax-and-transfer-bonds strategy

Having found that there are gains from a warming earth demands to transfer benefits into areas of the world that will be primarily losing from climate change (Chichilnisky, 1996, 2016; Chichilnisky et al., 1998; Chichilnisky & Heal, 2000). Having shed light on the gains of a warming earth allows for the redistribution of climate change benefits to those areas of the world that will be losing from a warming earth. In the implementation, a climate change bonds but also taxation strategies are recommended (Chichilnisky, 1996, 2016).

In order to avoid governmental expenditure on climate change hindering economic growth (Barro, 1990; Chichilnisky, 2007, 2010, 2016); the climate transfers should be enacted through bonds and taxes. The 'Climate in the 21st Century' idea takes these insights into account in order to offer a new way of funding climate change mitigation and adaptation policies but also the transition to renewable energy through broad-based climate stability bonds-and-taxation mix that also involve future generations (Puaschunder, forthcoming a; World Bank 2015 Report, 2015).

In order to finance climate change abatement, a climate bonds financing mix could subsidize the current world industry for transitioning to green solutions. Sharing the costs of climate stabilization between and across generations is a Pareto-optimal strategy to immediately instigate climate action without curbing today's economic growth potentials (Chichilnisky et al., 1998; Chichilnisky & Heal, 2000; Chichilnisky & Sheeran, 2018).

Jeffrey Sachs (2014) proposed an intergenerational burden sharing idea by presenting a 3-model climate change burden sharing through fiscal policy with bond issuing in order to reflect the implementation regarding contemporary finance and growth models with respect for maximizing utility of the model. In an overlapping-generations type model, future research should elucidate climate change abatement and mitigation policies to lead to a fairer solution across generations. The current generation mitigates climate change and provides infrastructure against climate risk financed through climate bonds to be paid by future generations. Since for

future generations the currently created externalities from economic activities – the effects of C02 emissions – are removed, this entails that the current generations remain financially as well off as without mitigation while improving environmental well-being of future generations. As Sachs (2014) shows, this intergenerational tax-and-transfer policy turns climate change mitigation and adaptation policy into a Pareto improving strategy. Shifting the costs for climate abatement to the recipients of the benefits of climate stability appears as novel, feasible and easily-implementable solution to nudge many overlapping generations towards future-oriented loss aversion in the sustainability domain (Puaschunder, 2016).

The respective bonds-and-tax climate stability financing strategy therefore proposes to bear the burden of climate in a right, just and fair way around the globe (Chichilnisky, 1996, 2007, 2010, 2016). In the climate change winner countries, taxation should become the main driver over financing climate stability strategies. Foremost, the industries winning from a warming climate should be taxed. The Winner-Loser-index is based on the cardinal temperatures for all GDP contributing sectors. Based on the cardinal temperatures for the three GDP components agriculture, industry and service, the taxation should be enacted for those sectors having most time ahead. The rational is that these sectors will be gaining the most from a warming earth and will therefore be flourishing.

The taxation models should aid to share the burden of climate change within society in a fair way. Regarding concrete climate taxation strategies, a carbon tax on top of the existing tax system should be used to reduce the burden of climate change and encourage economic growth through subsidies (Chancel & Piketty, 2015). Within a country, high and low income households should face the same burden of climate stabilization adjusted for their disposable income. First, climate justice within a country should pay tribute to the fact that low- and high income households share the same burden proportional to their dispensable income, for instance enabled through a progressive carbon taxation. Those who caused climate change could be regulated to bear a higher cost through carbon tax in combination with retroactive billing through inheritance tax. But also developed and underdeveloped countries as well as various overlapping generations are affected differently. Besides progressive taxation schemes to imbue a sense of fairness in climate change burden sharing, inheritance taxation is also a flexible means to reap past wealth accumulation, which potentially caused environmental damage. The burden of climate change mitigation and adaptation could also be allocated in a fair way within society through contemporary corporate inheritance tax in order to reap benefits of past wealth accumulation. But in order to determine a fair corporate inheritance tax grantors and beneficiaries, one needs information on what countries and what sectors of the economy

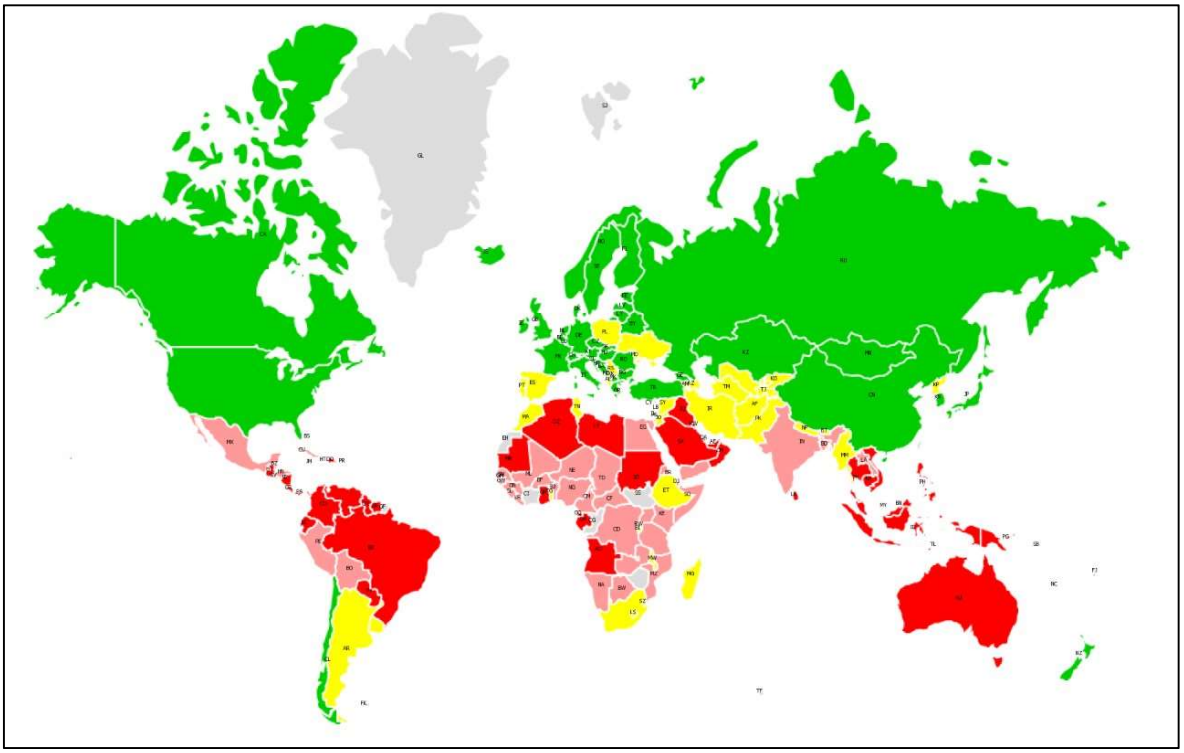
have a rising or declining economic prospect in light of climate change (Chichilnisky, 1996, 2007).

In addition, finding the optimum balance between consumption tax adjusted for disposable income through a progressive tax scheme will aid to unravel drivers of tax compliance in the sustainability domain. If climate taxation is perceived as fair and just allocation of the climate burden, this could convince tax payers to pay one's share. A novel 'service-and-client' atmosphere could promote taxpayers as cooperative citizens who are willing to comply if they feel their share as fair contribution to the environment (Puaschunder, 2015). Taxpayers as cooperative citizens would then be willing to comply voluntarily following the greater goal to promote taxpayer collaboration and enhance tax morale in the environmental domain. International comparisons of tax behavior also reveal tax norms being related to different stages of institutional development of the government, which is an essential consideration in sharing the climate change burden in a fair manner between countries. A completely novel approach is to shed light on the benefits of a warming earth in order to derive fair climate gains distribution strategies around the world (Puaschunder, 2017a, c, e).

In climate change winner countries weighted by GDP per capita (Graph 4 Green & Yellow), taxation should become the main climate stability financialization strategy. Foremost, the industries winning from a warming climate should be taxed. Regarding concrete climate taxation strategies, a carbon tax on top of the existing tax system should be used to reduce the burden of climate change and encourage economic growth through subsidies. Within a country, high and low income households should face the same burden of climate stabilization adjusted for their disposable income. Finding the optimum balance between consumption tax adjusted for disposable income through a progressive tax scheme will aid to unravel drivers of tax compliance in the sustainability domain.

Governments in global warming loser countries weighted by GDP per capita (Graph 4 Orange & Red) should receive tax transfers in the present from the winning countries. The climate change loser countries should also borrow by loans or issuing of bonds to be paid back by future generations. Taxing future generations is justified as for the assumed preferences of future generations to avoid higher costs of climate change long-term damages and environmental irreversible lock-ins.

Graph 4: Climate stabilization transfers grantors (Green & Yellow) & beneficiaries (Orange & Red) until 2100



Concluding, climate change winning countries are advised to use taxation of the gaining GDP sectors to raise revenues to offset the losses incurred by climate change (Chichilnisky, 2010, 2016). Climate change losers should issue bonds to be paid back by taxing future generations. **Tax-and-bonds transfers** could be used to subsidize industry actors for choosing clean energy in order to shift the general race-to-the-bottom price cutting behavior to a race-to-the-top hunt for subsidies going into clean energy.

2.4 Future climate wealth of nations

This paper builds on the established climate change winning and losing prospects but adds a novel perspective on climate flexibility as the range of different temperatures a country can offer to produce in. Climate flexibility is captured around the globe and production ranges analyzed based on flexibility of agricultural crops production. A climate-finance nexus is introduced based on expectations of scarcity driving up prices and inflating value of goods that may become scarce in a global warming scenario (Puaschunder, 2018c). Lastly, this theoretical model will be backtested on actual commodity market prices.

3. Method

3.1 Overall model assumptions

3.1.1 Study 1: Climate change induced market flows

Most recently, a trend has been become apparent to demand a shift in focus from the poor to the rich in climate economics (Otto, Kim, Dubrovsky & Lucht, 2019). Puaschunder's work started around 2016 with a model is built on GDP optimal cardinal temperature for production. The GDP pillars of agriculture, industry and service are the foundation of the model. The model divides the world nation states into climate change winning and losing territories (Puaschunder, forthcoming a). This is in accordance with research of the International Monetary Fund (IMF) research division. Contemporary IMF research concludes that in low temperature countries, an increase in temperature boosts economic activity, while in higher temperature countries, an increase in temperature will dampen economic activity (Acevedo, Mrkaic, Novta, Poplawski-Ribeiro, Pugacheva & Topalova, 2018; Chichilnisky, 1996, 2007, 2010, 2016; Chichilnisky & Bal, 2019). The findings of uneven economic effects of climate change around the globe are robust over the different models and backed by regional cluster analysis and geographic case studies (Burke, Hsiang & Miguel, 2015; Chichilnisky, 2010, 2016; Somanathan, Somanathan, Sudarshan & Tewari, 2014; Topalova, in speech, 2018).[2] The IMF model now sophisticates these findings with insights about the effect of temperature on productivity, capital and labor (Topalova, in speech, 2018).[3]

In order to consolidate the finding of unequal climate change gains and losses and derive implications for economic and financial market performance, three market-focused hypotheses tested whether climate change winning and losing territories attract different levels of human capital inflow, finance inflow and internet connectivity.

Overall geographical mobility is expected to increase and thus should be supported, especially when massive shifts of the industry structure result from green industrial policies. This may be the case, for example, when shifting from fossil to renewable energy: Fossil energy plants are usually located next to energy-intensive industries and cities, whereas renewable power plants are located where the respective power resources are abundant. Shifting energy systems will therefore affect spatial distribution and workers are therefore expected to move physically (Chichilnisky, 2007, 2010; Chichilnisky & Bal, 2019; Chichilnisky et al., 1998).

Hypothesis $H_{1.1}$ investigates if countries that economically benefit from climate change feature a significant foreign human capital inflow (Puaschunder, forthcoming a).

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2 http://www.economicpolicyresearch.org/events/upcoming-events/the-economic-impacts-of-weather-shocks-and-climate-change-how-can-countries-cope

3 http://www.economicpolicyresearch.org/events/upcoming-events/the-economic-impacts-of-weather-shocks-and-climate-change-how-can-countries-cope

Hypothesis $H_{2.1}$ investigates if countries that economically benefit from climate change feature a significant foreign capital inflow that does not correspond with remittance outflow from the FDI receiving territories into the FDI sponsoring countries (Puaschunder, forthcoming a).

Hypothesis $H_{3.1}$ investigates if countries that economically benefit from climate change feature a significant higher level of internet connectivity.

3.1.2 Study 2: Climate flexibility

In a model extension of the original calculation of climate change winners and losers around the world based on GDP prospects (Puaschunder, forthcoming a), Puaschunder (work in progress) focuses on agriculture, industry and service sector representing economic growth factors. Methologically, the optimum cardinal temperatures for specific agriculture products, industry representations and service sector providers were retrieved from literature sources (Puaschunder, work in progress). A future market prospect in light of global temperature rising was then given based on the mean temperature of the world now and as estimated in the year 2100. Prospective market shifts in the GDP composition but also agricultural products, industry sector representatives and service providers were provided. Underlying to all these future prospects is the idea that GDP production and its manifold components is enabled at best at a certain temperature and therefore specific markets will follow and gravitate towards these temperatures (Puaschunder, work in progress).

In light of global warming, an influx of labor and mobility of corporations are predicted. These insights fortify the idea that the world will become more globalized and location-flexible due to climate change. Those corporations and individuals realizing this and seeking the gains of a warming globe – maybe beyond their own inhabited territories are prospected to become market winners.

3.1.3 Study 3: Climate change expectations driving commodity bubbles

Since the turn of the millennium, the United Nations (UN) detected an unprecedented agriculture products commodities bubbles trend especially in countries around the equator belt, which are the worst off regarding climate change due to a natural high base mean temperature (United Nations Report on the World Social Situation, 2011). There also seems to be a recent and unprecedented credit risk and bubble behavior in the corporate energy sector – such as oil-supply shocks and stock prices – that may be related to the demand for a transition to renewable energy (Figuerola-Ferretti & Cervera, 2018; Kaabia, Dhaoui, Abid & Guesmi, 2018; Lips, 2018). In the oil energy sector, price spikes have been found around procurement shortages, which are expected to be occurring in all climate-related extinction cases (Roberts, Barbier &

van't Veld, 2018). Research also already pits food versus fuel and finds evidence of a contemporary predicament in nation state's investment allocations in either one resource (Filip, Janda, Kristoufek & Zilberman, 2018; Trinks, Mulder & Scholtens, 2017). There is also already evidence for sector competition for energy resources in a carbon constrained hoteling model (Renz, 2018). This may only be a first sign of agricultural products becoming more precious and valuable for economic production given a longer durability in a warming climate (Wenger, Orttung & Perovic, 2009). Energy prices and mitigation policies also impact on Foreign Direct Investment (FDI) locations (Saussay & Sato, 2018; The World Economic Forum 2015 Report, 2015; World Investment Report, 2015).

The following financial market model now estimates prices centered around agriculture, industry and service sector transitions. Based on evidence from the energy sector, the relation of a price of a good and time to extinction of a resource is not linear but hyperbolically tilted towards the end before extinction (Roberts et al., 2018). When a resource is about to go extinct, the market value of this resource will in general rise shortly before the good goes away from the market forever. For instance, if we run out of a natural resource, no alternatives may exist, so scarcity will drive up the price, shortly before the good extinguishes (Roberts et al., 2018; Yarlik, Filis, Lloyd & Degiannakis, 2018; Zhang, 2018). Derived from this insight, the model will be based on the maximum temperature for agricultural goods and industry production as well as time for extinction of natural resources, cooling and storage maximum temperatures in order to determine market transition and shifting trends but also price spikes and peaks based on the world and regional temperatures.

4. Operationalization

4.1 Data study 1: Climate change induced market flows

In order to operationalize and consolidate the underlying premise that countries that economically benefit from climate change feature a better market prospects, worldwide Foreign Direct Investment (FDI) flows[4] (Hypothesis $H_{1.1}$), remittances[5] (Hypothesis $H_{2.1}$), and internet connectivity[6] (Hypothesis $H_{3.1}$), were retrieved online form the World Bank database for the year 2015 as well as the *Global Connectivity Index* homepage as an indicator of market relevance and innovation potential.

[4] http://data.worldbank.org/indicator/BX.KLT.DINV.CD.WD

[5] http://data.worldbank.org/indicator/BX.TRF.PWKR.CD.DT

[6] http://www.huawei.com/minisite/gci/en/country-rankings.html

4.2 Results study 1: Climate change induced market flows

4.2.1 Climate change winners and losers model

The relation of climate change gains and losses and market prospects was investigated. Based on the climate change winners and losers model (Puaschunder, forthcoming b), gaining and losing from climate change was related to human migration, financial inflows as well as innovation.

Human migration: When investigating the relation of human migration and climate change winners and losers in 187 countries of the world, a highly significant correlation (rPearson(187)=.184, p<.006), is found between being climate change winner and human migration inflows. A highly significant independent t-test with t(185)=-2.401, p=0.017 of 110 climate change loser and 77 winner countries consolidates the finding (Puaschunder, forthcoming a).

Financial inflows: When investigating the relation of financial inflows and climate change winners and losers including 181 countries of the world, a significant correlation (rPearson(181)=.180, p<.016), is found between being climate change winner and FDI inflows. A highly significant independent t-test with t(179)=2.680, p=0.008 of 110 climate change loser and 77 winner countries consolidates the finding. As a cross validation of lasting financial inflows into climate change winner countries, a non-significant correlation and non-significant independent t-tests are reported (Puaschunder, forthcoming a).

Innovation: When investigating the innovation potential currently prevalent in climate change winners and losers including 79 countries of the world, a significant correlation (rPearson(79)=.507, p <.000), is found between being climate change winner and global connectivity as measured by the 2018 *Global Connectivity Index*.[7] A highly significant independent t-test with t(77)=6.306, p=0.000 of 33 climate change loser and 46 winner countries consolidates the finding.

4.3 Data study 2: Climate flexibility

Climate change was recently found to affect countries differently (Puaschunder, forthcoming a). Given different mean temperatures and GDP compositions, countries around the globe will be affected differently by a warming climate (Puaschunder, forthcoming b). In the determination into climate change gain and loss prospects, climate flexibility needs to be integrated. Climate flexibility is defined as leeway countries have in coping with a changing

[7] http://www.huawei.com/minisite/gci/en/country-rankings.html

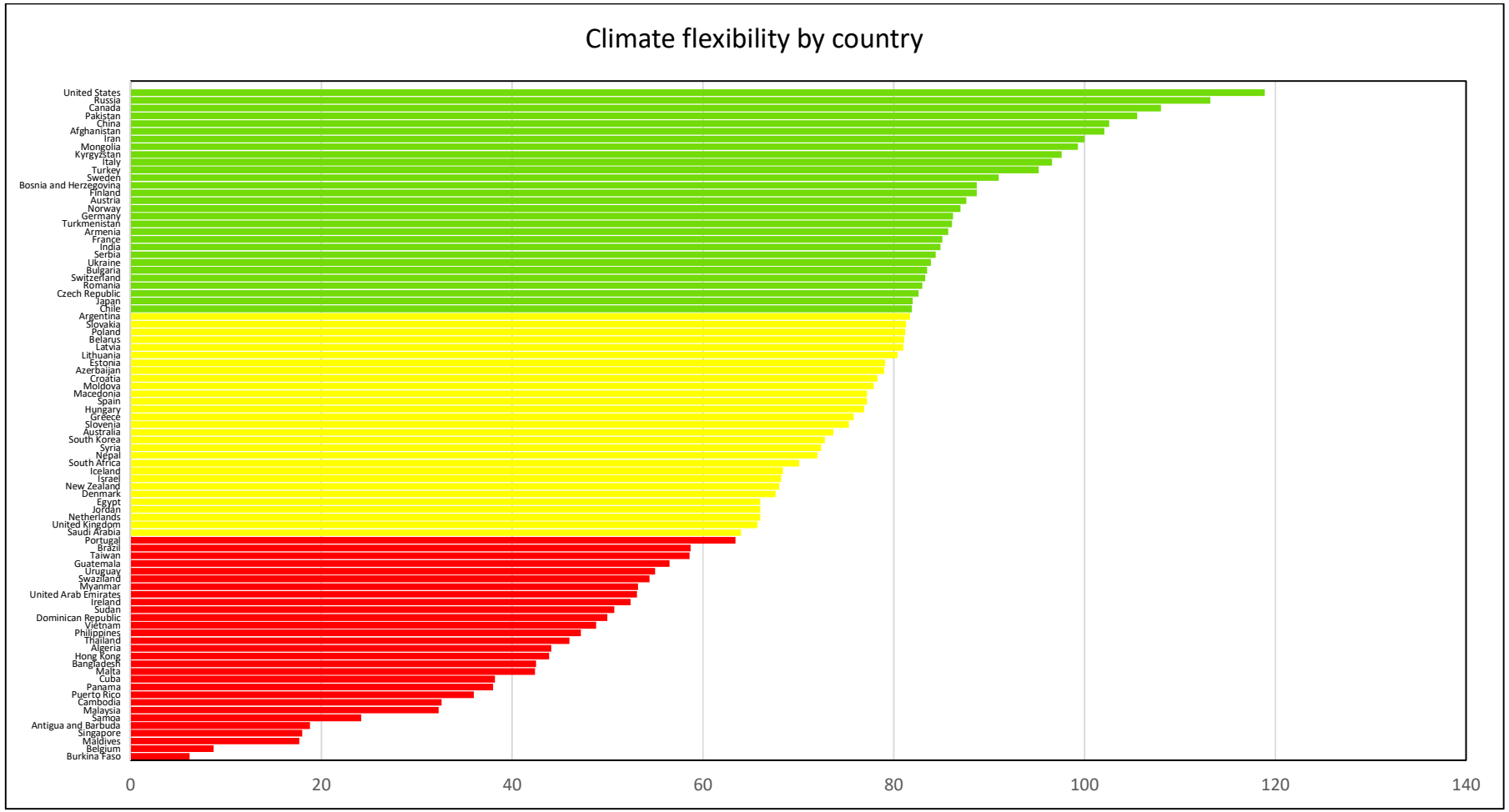
climate due to a range of climate zones prevalent in their territory. Climate flexibility can be grounded on the relative latitude and altitude of countries around the globe. The wider the range of latitude and altitude within a nation state, the more climate flexibility and favorable economic leeway of degrees of freedom for multiple production peaks is assumed. When dividing the world given temperature ranges prevalent calculated based on the *List of Countries by Extreme Temperatures*,[8] the following temperature ranges are found as exhibited in table 3.

4.4 Results study 2: Climate flexibility

Table 3 exhibits 87 countries' temperature range in comparison to each other. One third of the sample features countries with the widest temperature range and therefore most flexible in green color, one third of the sample features medium temperature range of climate flexibility in yellow color and one third of the sample with lowest temperature range and relative climate inflexibility in red color.

[8] https://en.wikipedia.org/wiki/List_of_countries_by_extreme_temperatures

Table 3: Temperature range (in Celsius) by country determining climate flexibility



The United States (US) leads on climate flexibility with a temperature range of *r*=118.9°C based on [-62.2 having been the lowest temperature ever recorded in the US and 56.7°C the highest temperature ever recorded in the US], followed by Russia *r*=113.2°C based on [-67.8; 45.4°C], Canada *r*=108°C based on [-63; 45°C], Pakistan *r*=105.5°C based on [-52; 53.5°C], China *r*=102.6°C based on [-52.3; 50.3°C], Afghanistan *r*=102.1°C based on [-52.2; 49.9°C], Iran *r*=100°C based on [-46; 54°C], Mongolia *r*=99.3°C based on [-55.3; 44°C], Kyrgyzstan *r*=97.6°C based on [-53.6; 44°C], Italy *r*=96.6°C based on [-49.6; 47°C], Turkey *r*=95.2°C based on [-46.4; 48.8°C], Sweden *r*=91°C based on [-53; 38°C], Bosnia and Herzegovina *r*=88.7°C based on [-42.5; 46.2°C], Finland *r*=88.7°C based on [-51.5; 37.2°C], Austria *r*=87.6°C based on [-47.1; 40.5°C], Norway *r*=87°C based on [-51.4; 35.6°C], Germany *r*=86.2°C based on [-45.9; 40.3°C], Turkmenistan *r*=86.1°C based on [-36; 50.1°C], Armenia *r*=85.7°C based on [-42; 43.7°C], France *r*=85.1°C based on [-41; 44.1°C], India *r*=84.9°C based on [-33.9; 51°C], Serbia *r*=84.4°C based on [-39.5; 44.9°C], Ukraine *r*=83.9°C based on [-41.9; 42°C], Bulgaria *r*=83.5°C based on [-38.3; 45.2°C], Switzerland *r*=83.3°C based on [-41.8; 41.5°C], Romania *r*=83°C based on [-38.5; 44.5°C], Czech Republic *r*=82.6°C based on [-42.2; 40.4°C], Japan *r*=82°C based on [-41; 41°C] and Chile *r*=81.9°C based on [-37; 44.9°C].

In the medium climate flexibility range are Argentina with *r*=81.7°C based on [-32.8; 48.9°C], Slovakia *r*=81.3°C based on [-41; 40.3°C], Poland *r*=81.2°C based on [-41; 40.2°C], Belarus *r*=81.1°C based on [-42.2; 38.9°C], Latvia *r*=81°C based on [-43.2; 37.8°C], Lithuania *r*=80.4°C based on [-42.9; 37.5°C], Estonia *r*=79.1°C based on [-43.5; 35.6°C], Azerbaijan *r*=79°C based on [-33; 46°C], Croatia *r*=78.3°C based on [-35.5; 42.8°C], Moldova *r*=77.9°C based on [-35.5; 42.4°C], Macedonia *r*=77.2°C based on [-31.5; 45.7°C], Spain *r*=77.2°C based on [-30; 47.2°C], Hungary *r*=76.9°C based on [-35; 41.9°C], Greece *r*=75.8°C based on [-27.8; 48°C], Slovenia *r*=75.3°C based on [-34.5; 40.8°C], Australia *r*=73.7°C based on [-23; 50.7°C], South Korea *r*=72.8°C based on [-32.8; 40°C], Syria *r*=72.4°C based on [-23; 49.4°C], Nepal *r*=72°C based on [-26; 46°C], South Africa *r*=70.1°C based on [-20.1; 50°C], Iceland *r*=68.4°C based on [-37.9; 30.5°C], Israel *r*=68.2°C based on [-14.2; 54°C], New Zealand *r*=68°C based on [-25.6; 42.4°C], Denmark *r*=67.6°C based on [-31.2; 36.4°C], Egypt *r*=66°C based on [-15; 51°C], Jordan *r*=66°C based on [-16; 50°C], Netherlands *r*=66°C based on [-27.4; 38.6°C], United Kingdom *r*=65.7°C based on [-27.2; 38.5°C], and Saudi Arabia *r*=64°C based on [-12; 52°C].

The least climate flexibility have Portugal *r*=63.4°C based on [-16; 47.4°C], Brazil *r*=58.7°C based on [-14; 44.7°C], Taiwan *r*=58.6°C based on [-18.4; 40.2°C], Guatemala *r*=56.5°C based on [-11.5; 45°C], Uruguay *r*=55°C based on [-11; 44°C], Swaziland *r*=54.4°C

based on [-6.7; 47.7°C], Myanmar *r*=53.2°C based on [-6; 47.2°C], United Arab Emirates *r*=53.1°C based on [-1; 52.1°C], Ireland *r*=52.4°C based on [-19.1; 33.3°C], Sudan *r*=50.7°C based on [-1; 49.7°C], Dominican Republic *r*=50°C based on [-7; 43°C], Vietnam *r*=48.8°C based on [-6.1; 42.7°C], Philippines *r*=47.2°C based on [-5; 42.2°C], Thailand *r*=46°C based on [-1.4; 44.6°C], Algeria *r*=44.1°C based on [7.2; 51.3°C], Hong Kong *r*=43.9°C based on [-6; 37.9°C], Bangladesh *r*=42.5°C based on [2.6; 45.1°C], Malta *r*=42.4°C based on [1.4; 43.8°C], Cuba *r*=38.2°C based on [0.6; 38.8°C], Panama *r*=38°C based on [2; 40°C], Puerto Rico *r*=36°C based on [4; 40°C], Cambodia *r*=32.6°C based on [10; 42.6°C], Malaysia *r*=32.3°C based on [7.8; 40.1°C], Samoa *r*=24.2°C based on [11.1; 35.3°C], Antigua and Barbuda *r*=18.8°C based on [16.1; 34.9°C], Singapore *r*=18°C based on [19; 37°C], Maldives *r*=17.7°C based on [17.2; 34.9°C], Belgium *r*=8.7°C based on [30.1; 38.8°C] and Burkina Faso *r*=6.2°C based on [41; 47.2°C].

Climate flexibility is prospected to open a gate for productivity. Countries with climate flexibility are likely be productive grounds for agriculture, industry and service production at all different temperature levels.

4.4.1 Climate flexibility model

The relation of climate flexibility and market prospects was investigated. Based on the determined climate flexibility, the range of temperature variability – as retrieved and calculated based on the *List of Countries by Extreme Temperatures*[9] – was related to human migration.

Human migration: When investigating the relation of human migration and climate flexibility in 86 countries of the world, a highly significant correlation (rPearson(86)=.319, p<.002), is found between being climate flexible and human migration inflows. No significant relation is reported for financial inflows as well as innovation.

4.5 Future Climate Wealth of Nations' Winners and Losers

The insights gained from the climate change winners and losers model (see Appendix A) and the climate flexibility model demand to be blended into a Future Climate Wealth of Nations' Winners and Losers model. This new model will pay attention to the GDP prospects of countries around the globe in a changing temperature as well as the climate flexibility based on individual country's latitude and altitude naturally determining extreme temperatures. The novel Future Climate Wealth of Nations' Winners and Losers (W_xWL_{TT}) Index derives from the factoring of the Climate Change Winner and Loser (WL_{TT}) Index as defined by Puaschunder

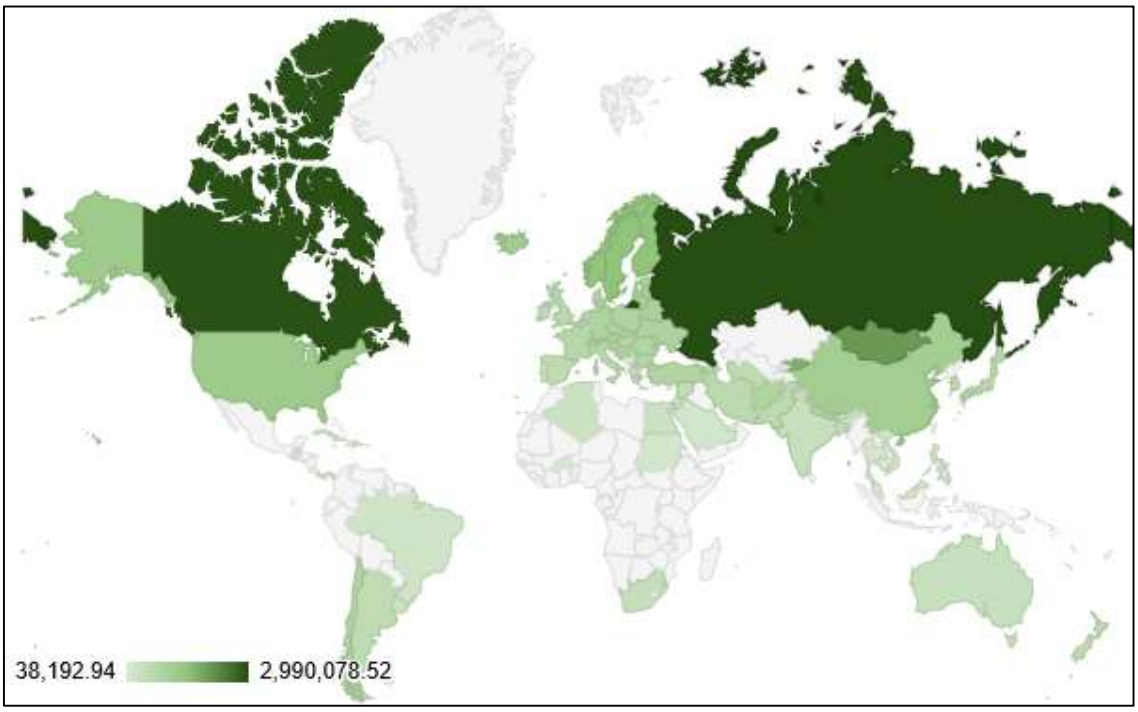
[9] https://en.wikipedia.org/wiki/List_of_countries_by_extreme_temperatures

(forthcoming a) and the climate flexibility index (Wx). The Future Climate Wealth of Nations' Winners and Losers (W_xWL_{TT}) Index derives from formula 4.1.

$$W_xWL_{TT} = W_x * WL_{TT} \quad (4.1)$$

If applying the new W_xWL_{TT} Index to a world dataset, Graph 5 reveals as dark green colored countries those nation states that can expect to be climate flexible climate change winning territories, whereas the light green colored countries are the climate inflexible climate change losing territories.

Graph 5: Future Climate Wealth of Nations' Winners and Losers



Limitations of this model may stem from the different time perspectives as climate change winners and losers are projections in 2100 and climate flexibility is measured on past temperature recordings. In addition, the temperature extremes should be controlled for outliers and over time temperature fluctuations separated from special temperature differences.

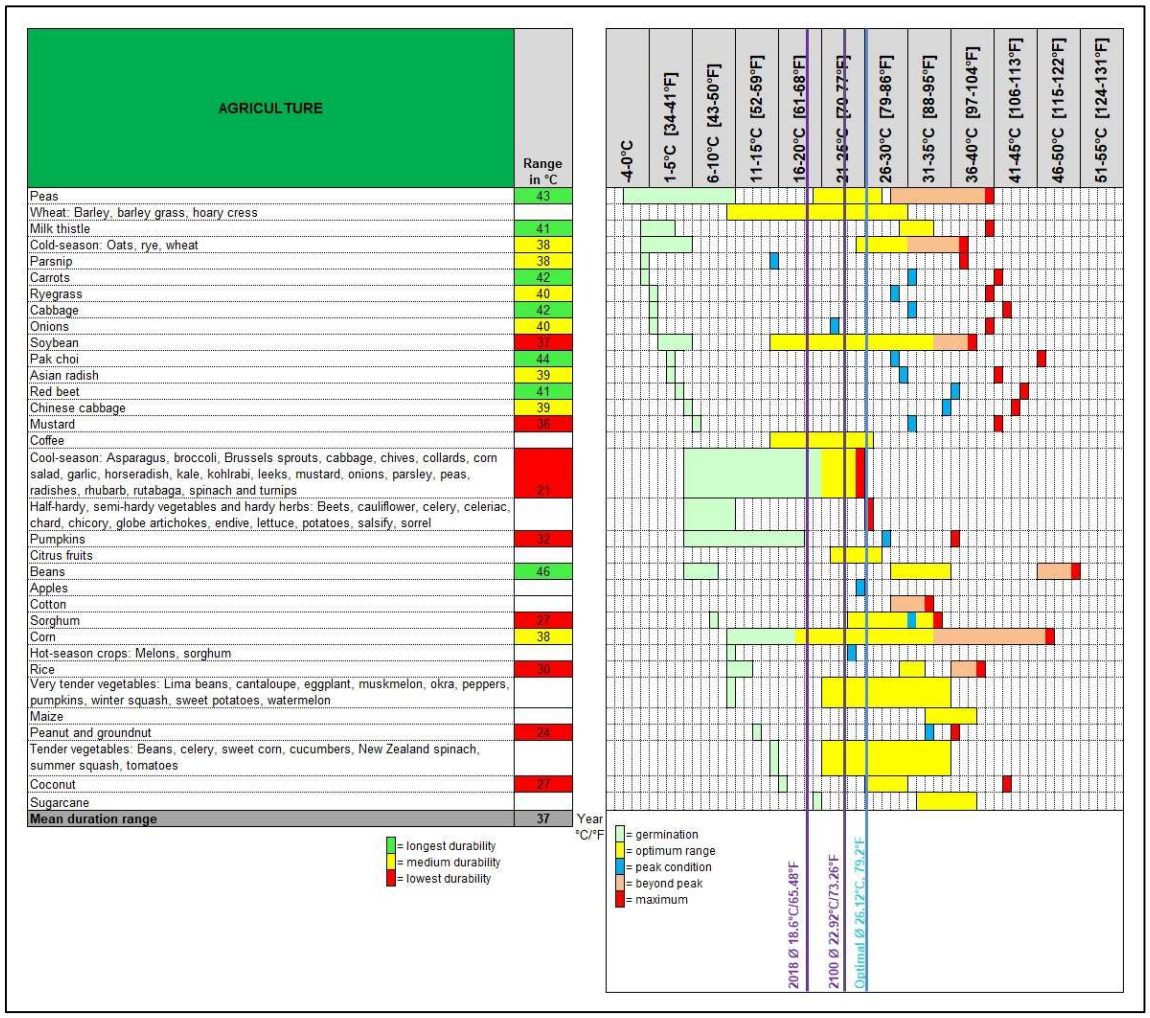
4.6 Data study 3: Climate change expectations driving commodity bubbles

Recent research has defined climate change winners and losers by GDP prospects in a changing climate (Puaschunder, forthcoming b). Now by stepping aside from national territories, climate change winning industries and sectors were unraveled most recently (Puaschunder, work in progress).

4.7 Results study 3: Climate change expectations driving commodity bubbles

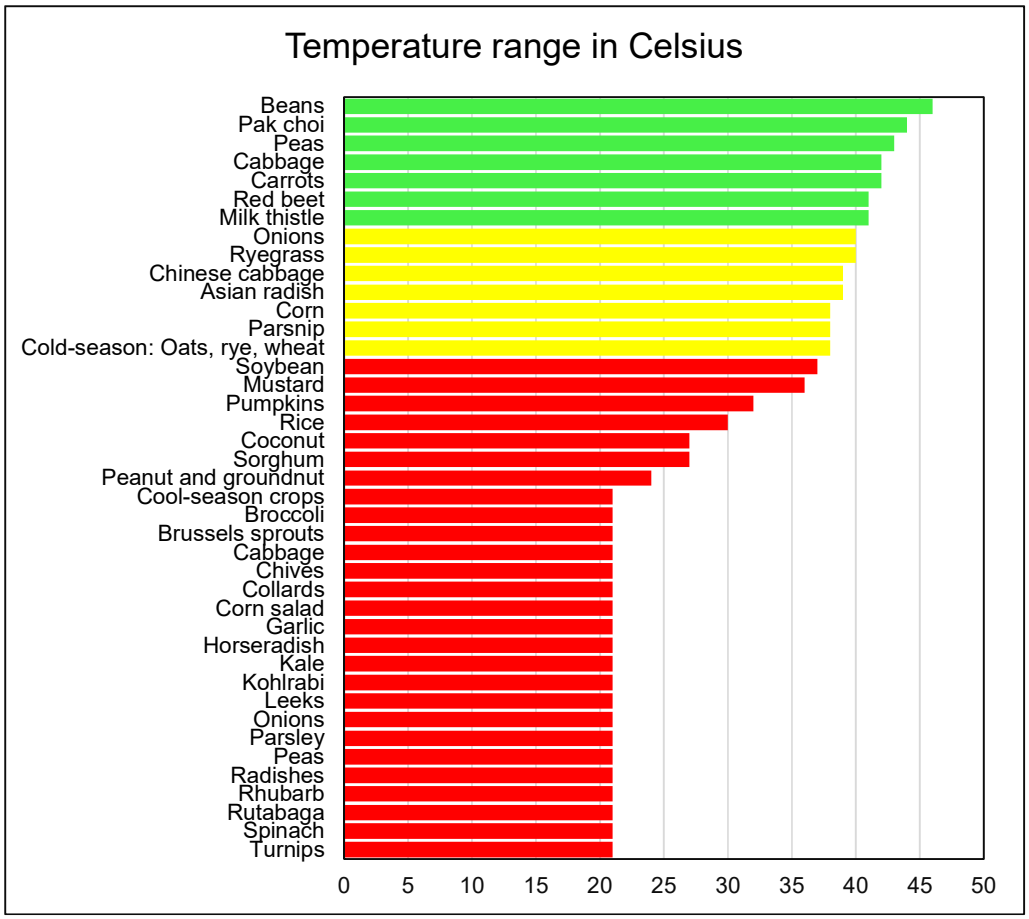
For the GDP comprising pillars of agriculture, industry and service sectors, the peak temperatures for production were derived from a meta-analysis of literature sources. For agriculture, crop durability – meaning how long crops can prosper in a changing climate – was determined based on literature resources. Graph 6 holds crops and their germination temperature, peak performance temperature and maximum possible temperature.

Graph 6: Agriculture sector temperature-based condition in relation to world mean temperature



The temperature ranges are outlined in Graph 7, which holds the crop durability. Longest temperature range crops are indicated by green color, medium temperature range in yellow color and shortest temperature range in red color.

Graph 7: Temperature ranges for outlining agriculture durability



Beans, pak choi, peas, cabbage, carrots, red beet and milk thistle will have the widest application range – as outlined in green color – regarding temperature. Onions, ryegrass, Chinese cabbage, Asian radish, corn, parsnips and cold-season crops such as oats, rye and wheat have a medium flexibility range – as exhibited in yellow color – when it comes to temperature. Soybean, mustard, pumpkins, rice, coconut, sorghum, peanut and groundnut but also all the cool-season crops such as broccoli, Brussels sprouts, cabbage, chieves, collards, corn salad, garlic, horseradish, kale, kohlrabi, leeks, onions, parsley, peas, radishes, rhubarb, rutabaga, spinach and turnips will run out of time first as outlined in red coloring of the smallest temperature range. The latter's cultivation is expected to become the most expensive first, then the medium and then the longest temperature-ranged crops.

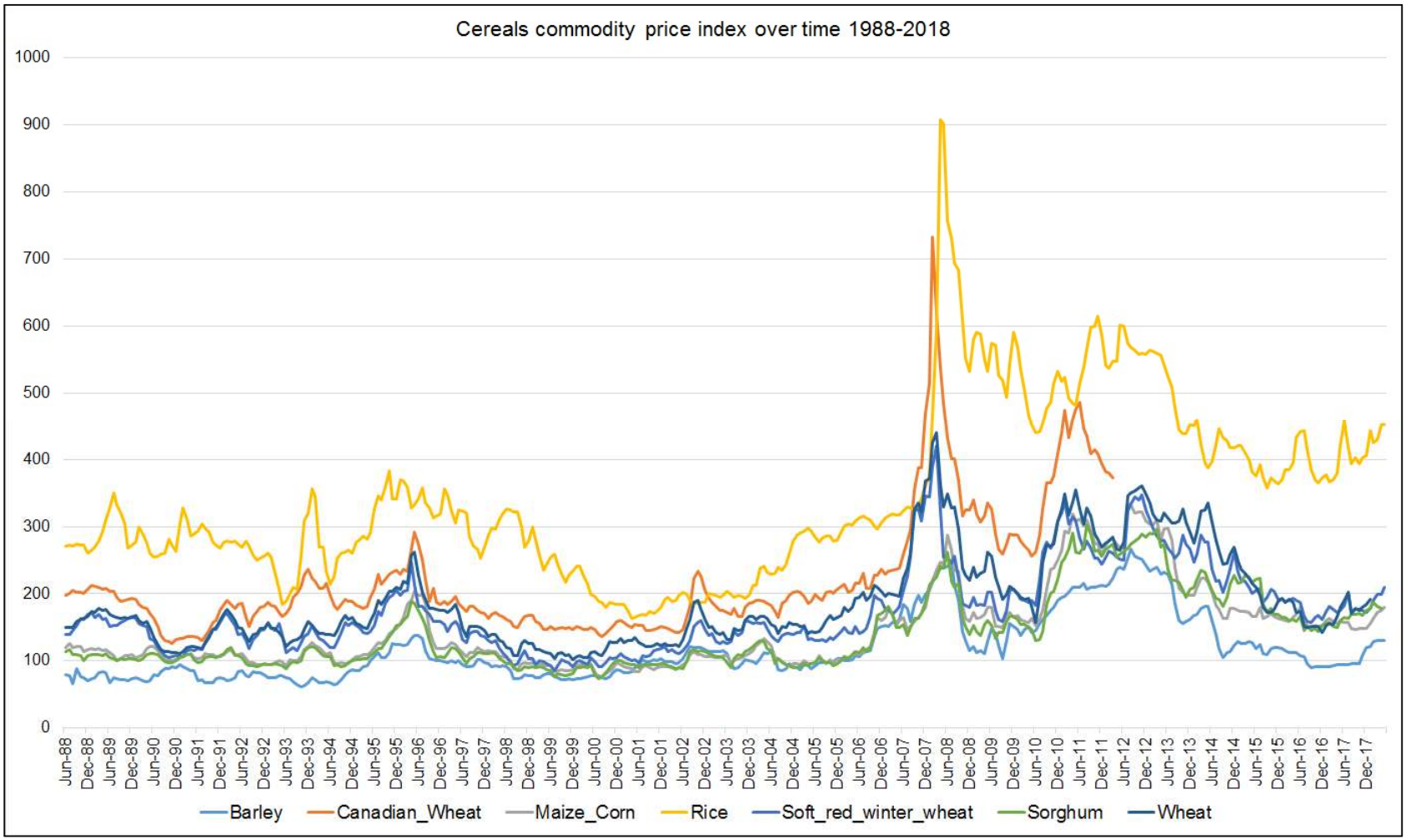
Given the assumption of price increases around scarcity, a model for crops' extinction and price mechanism is sketched out (Figuerola-Ferretti & Cervera, 2018; Kaabia et al., 2018; Lips, 2018). In the oil energy sector, price spikes have been found around procurement

shortages, which are expected to be occurring in all climate-related extinction cases (Roberts et al., 2018).

Time series of commodity price indices from June 1989 to 2017 retrieved from Index Mundi,[10] allowed to determine the price development of commodity prices for food and beverages. Since the turn of the millennium, temperature records have skyrocketed, which fueled vast communication about global warming. Price expectations are therefore assumed to have spiraled a commodities bubble for food and beverages. As outlined in Graph 8, commodity prices for food as represented by barley, Canadian wheat, maize/corn, rice, soft red winter wheat, and sorghum have risen extraordinarily since 2000.

[10] https://www.indexmundi.com/commodities/?commodity=wheat&months=360

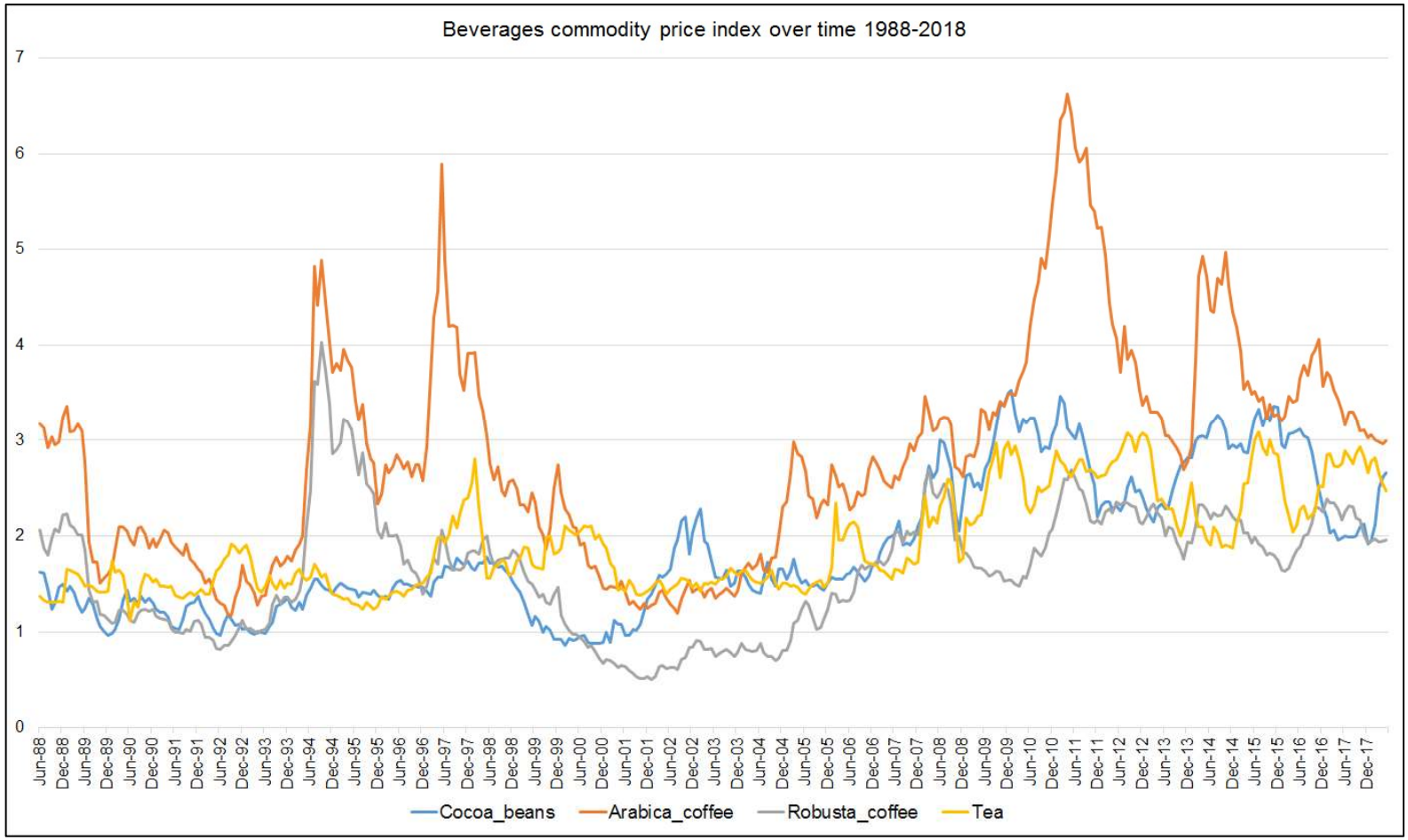
Graph 8: Commodity price index retrieved from Index Mundi[11] for food



[11] https://www.indexmundi.com/commodities/?commodity=wheat&months=360

As outlined in Graph 9, commodity prices for beverages as represented by Arabica coffee as well as tea have risen extraordinarily since 2000.

Graph 9: Commodity price index retrieved from Index Mundi[12] for food



[12] https://www.indexmundi.com/commodities/?commodity=wheat&months=360

Highly significant independent t-tests comparing the price index per crop prior to 2000 and thereafter consolidate the extraordinary price rise in commodities for barley with $t(358)=-11.984$, $p=0.000$ of 139 data points in the previous millennium and 221 observations in the current millennium based on monthly price indices measurement; Canadian wheat with $t(284)=-7.502$, $p=0.000$ of 139 data points in the previous millennium and 147 observations in the current millennium based on monthly price indices measurement; maize/corn with $t(358)=-8.82$, $p=0.000$ of 139 data points in the previous millennium and 221 observations in the current millennium based on monthly price indices measurement; rice with $t(358)=-7.331$, $p=0.000$ of 139 data points in the previous millennium and 221 observations in the current millennium based on monthly price indices measurement; soft red winter wheat with $t(358)=-8.786$, $p=0.000$ of 139 data points in the previous millennium and 221 observations in the current millennium based on monthly price indices measurement; sorghum with $t(357)=-10.352$, $p=0.000$ of 139 data points in the previous millennium and 220 observations in the current millennium based on monthly price indices measurement; wheat with $t(355)=-9.209$, $p=0.000$ of 139 data points in the previous millennium and 218 observations in the current millennium based on monthly price indices measurement; cocoa bean with $t(358)=-13.702$, $p=0.000$ of 139 data points in the previous millennium and 221 observations in the current millennium based on monthly price indices measurement; Arabica coffee with $t(358)=-3.631$, $p=0.000$ of 139 data points in the previous millennium and 221 observations in the current millennium based on monthly price indices measurement; and tea with $t(358)=-11.493$, $p=0.000$ of 139 data points in the previous millennium and 221 observations in the current millennium based on monthly price indices measurement. Out of all commodity indices for food and beverage reported in the Index Mundi database[13] with sufficient data points, Robusta coffee was the only good with non-significant price increases for the period after the turn of the millennium. To cross-validate the findings, price indices for gasoline, medical care, fast food, soda, jewelry, new cars and computers[14] were eyeballed and no stringent pattern of increased prices could be found for these goods and services since turn of the millennium.

Given the back-testing results consolidating inflated commodity prices since the turn of the millennium, future prospects of price deviations based on the extinction temperature are drawn as stylized, hypothetical estimation. Graph 10 holds prospective extinction based market price predictions as deviations from normal prices. As one can see, the world with medium

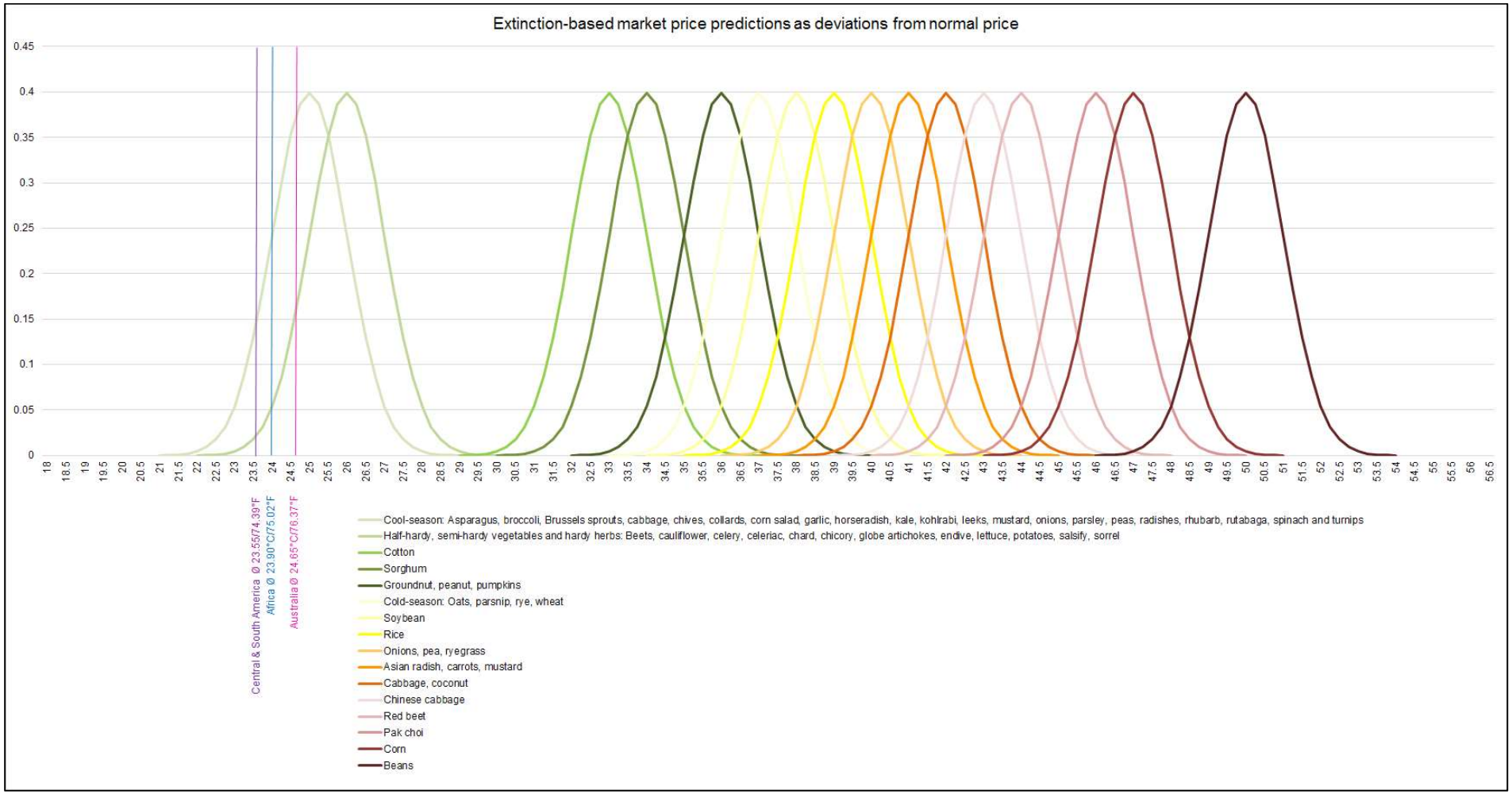
[13] https://www.indexmundi.com/commodities/?commodity=wheat&months=360

[14] https://people.duke.edu/~rnau/411infla.htm

temperature of 18.6°C is not at the efficiency frontier yet (Foley, 2007). In addition, the mean temperature for continents was derived from the literature and critical mean continental temperature in Central and South America, Africa and Australia put into perspective.[15]

[15] https://simple.wikipedia.org/wiki/List_of_countries_by_continents

Graph 10: Extinction based market price predictions as deviations from normal prices



5. Results discussion

Climate change is reality. The implementation of climate stability accounts for the most challenging contemporary global governance predicament that seems to pit world countries but also today's generation against future world inhabitants. In a trade-off of economic growth versus sustainability, a broad-based international coalition could establish climate stability. As a novel angle towards climate justice, the attention to global warming gains and losses being distributed unequally around the globe (Puaschunder, 2017b) allows to propose to search for a well-balanced climate mitigation and adaptation public policy mix guided by micro- and macroeconomic analysis results.

A 3-dimensional Mapping Climate Justice approach was introduced to share the burden of climate change right, just and fair around the globe. Climate justice within a country should pay tribute to the fact that low- and high-income households carry the same burden proportional to their dispensable income. Climate change change burden sharing between countries ensures those countries benefiting more from a warmer environment also bear a higher responsibility regarding climate change mitigation and adaptation efforts. Climate justice over time can innovatively be enabled by sharing the gains in climate change benefitting territories via taxation to redistribution in climate change loser countries that issue climate stability bonds. All these recommendations are aimed at ensuring to share the burden but also the benefits of climate change within society in an economically efficient, legally equitable and practically feasible way.

Future wealth of nations was prospected by the concept of climate flexibility defined as the range of temperature variation of a country. In a changing climate, temperature range flexibility is a future asset for international trade of commodities but also for production flexibility leading to comparative advantages of countries (Ricardo, 1817/1951). A broad spectrum of climate zones has never been defined as asset and comparative edge in free trade but climate change will require territories being more flexible in terms of changing economic production. The more climate variation a nation state possesses, this paper argued, the more degrees of freedom a country has in terms of GDP production capabilities in a differing climate. Already now, the degree of climate flexibility was outlined to be related to human migration inflow and is predicted to determine future climate wealth of nations in a climate changing world. Future climate change induced market changes were featured based on scarcity of agriculture production prospects.

Climate change induced market flows were outlined to be already existent in terms of human capital, FDI inflows and internet connectivity as predictor of technological superiority being prevalent those areas of the world that gain from global warming. Climate flexibility was introduced as future market asset for offering a range of economic possibilities as a basis for future climate wealth of nations. Climate flexibility as comparative advantage was already shown to be positively related to human migration. Migration and monetary flows are argued to vividly outline the competitive advantages of the climate change winner countries (Puaschunder, a). The first introduction of climate-induced financial flows serves as unique justification for climate benefits transfers around the globe and demands for recognition of climate refugees under the Geneva Convention in order to alleviate the negative consequences of climate hegemony in the 21st century.

Behavioral economics found people to be risk-averse and their loss prospects loom larger than gains (Kahneman & Tversky, 1979; Tversky & Shafir, 1992). Changing individual temperature conditions make people afraid and there is an immediate loss of the status-quo visible. But in reality, the world by itself will be winning from a warming globe for quite some time, just needs to relocate and transfer skills and production into those areas that will become newly arable and pleasant to stay and work in (Puaschunder, forthcoming b, work in progress). Climate change-induced expectations of climate scarcity were associated with unnatural price spikes in the commodities market.

The presented results may shed light on the climate change from a different angle and grant hope but also alleviate the contemporary reported predicament of economic growth versus sustainability (Zhou, Smulders & Gerlagh, 2018; Täuber, van Zomeren & Kutlaca, 2015). Looking forward to world peak condition in regards to a favorable climate for GDP production, the future wealth of nations may be determined by countries' access to global markets (e.g., via infrastructure such as airports and ports, trade relations such as general agreements and trade unions and practiced customs such as openness to take in migrants or a favorable easily to obtain language like English or Spanish) as well as natural propensities to temperature flexibility by being either a wide-spread country (like Canada or Russia) or featuring different temperature zones due to tectonic landscape formation and altitude (e.g., like Italy, New Zealand, Luxembourg or Switzerland featuring mountains).

Future favorable market operations appear to be (1) investments in insurances specializing on climate change and capitalizing the collective fear that has been built around the change in temperature, which actually also features positive aspects (Puaschunder,

forthcoming b, work in progress). (2) Mergers and conglomerates of multiple entities to diversify from climate-related risks and shortages with higher economies of scale (Emmert, 2018). (3) Surge price strategies as ticket prices that can offer a discount during shoulder seasons disrupted from unfavorable climate and high prices during peak seasons. The winter sports industry appears to heading towards a direction of high luxury price and low customer base due to snow shortages and shortened winter seasons (Emmert, 2018; Puaschunder, forthcoming b). Mountain ownership by insurance agencies is another trend that is seen in the winter industry (Emmert, 2018). Resorts have immensely high insurance costs, both for bodily injury and weather. If a resort can farm their insurance in house, they can save in the long run. This trend may also be extended onto other industries that may become more intwined with insurances as climate change causes weather unpredictability. Consumer lock-in strategies but also weather-related loss exemptions for satisfaction guarantee clauses may be additional trends we are heading towards in the age of global warming. Revenue off weather-dependent sales are potential other areas that are prospected to see economic growth in times of weather uncertainty caused by climate change. For instance, in the skiing industry buy now half of the revenue is made up with food, lodging, rentals and lesson sales (Emmert, 2018).

6. Discussion and future outlook

Overall, the market-driven results of price mechanisms but also FDI and market streams underline the importance of research on the effect of climate change on market mechanisms. This first preliminary introduction of the idea of climate flexibility as future determinant of competitive advantage and wealth of nations opens a door for future research on climate impacts on international trade (Ricardo, 1817/1951). The impact of climate on markets also implicitly calls for a further investigation of industrial policies that rest on the fundamental insight that market prices are not often not sufficient in allocating scarce resources in a humane society (Altenburg & Assmann, 2018). For instance, preferenes of future generations cannot be fully reflected in market prices (Altenburg & Rodrik, 2018; Chichilnisky & Bal, 2019; Chichilnisky & Heal, 2010).

As a caveat to the presented results, it deserves mentioning that price expectations – to this day – are hard to predict and the actual temporal flow of these recurrent patterns is hard to measure quantitatively. While there is a pattern of the economy, problem of agents remain to distinguish between noise and information, distinguish between shocks and change. In the ever-changing nature of capitalism, having evolved from industrialization to post-World War booms

to globalization and the new media revolution, the cycles have become more fuzzy and unpredictable (Held & McGrew, 2007).

Future research may investigate climate change impacts on the "demand" side of economic pricing behavior. As studies have shown, demand preferences are sticky as habits usually form over a long time and therefore do not change quickly. Future studies may unravel how climate changes preferences for specific goods and services in the long run. Thereby, especially the role of critical life events and external climate shocks in changing preferences immediately and definitively should be scrutinized. Behavioral insight specialists may find innovative ways how to align the demand side with the supply side of climate policies from an inter-disciplinary perspective. Future studies may also focus on how to teach the gains of a warming earth in applied business cases (Gonglewski & Helm, 2010; Helm, 2009). All these presented insights gained may help administer the transition to new technologies and renewable energy as well as reap the economic benefits of a warming globe. In addition, climate transfer taxation could be proposed to reap the benefits from climate flexibility and redistribute these gains to territories that hit climate flexibility shortage. In addition, in the Climate Wealth of Nations' Winners and Losers model, the temperature extremes should be controlled for outliers and over time temperature fluctuations separated from special temperature differences in order to find more sophisticated market predictions on the dominance of climate trade. Future public policy recommendations should start focusing away from the climate losses to redistributing the gains of a warming earth so that they can be enjoyed equally within societies, around the world and over time.

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[i] Appendix A

A.1 Method

A.1.1 Overall model assumptions

Economic output was measured under projected conditions of a warming earth. For 189 world countries the Gross Domestic Product (GDP) agriculture, industry and service sector composition was retrieved from the Central Intelligence Agency (CIA) World Factbook (https://www.cia.gov/library/publications/the-world-factbook/). *Agricultural output* is the

component of the GDP of a nation that describes the process of producing food, feed, fiber and other goods by the systematic raising of plants and animals. *Industry* is the GDP segment of the economy concerned with production of goods including fuels and fertilizers, mining and extraction sectors. The *service* sector is the non-material equivalent of a good. Service provision is defined as an economic activity that does not result in ownership of physical goods. It is a process that creates benefits by facilitating either a change in customers, a change in their physical possessions, or a change in their intangible assets. Service output is a component of the GDP of a nation that also includes – but is not limited to – farm and factory related activities.

Contemporary climate change projections estimate a mean temperature rise of approximately 4.24 degrees Celsius. The cardinal or optimal temperature per sector was related to the prospected temperature in 2100 per country. The cardinal age or optimal temperature for agriculture is 28.5 degree Celsius for growing wheat and rice (http://agritech.tnau.ac.in/agriculture/agri_agrometeorology_temp.html). The cardinal temperature for the industry sector comprising of construction, automotive, airframe, locomotive, petroleum, coal and chemicals was found to be 21 degree Celsius (Russell, 1957). The cardinal temperature for the service sector lies at 25 degree Celsius (Somanathan, Somanathan, Sudarshan & Tewari, 2014).

From the current world temperature mean per country and the estimate of a 4.25 degree Celsius climate change until 2100, the closeness to cardinal temperature per sector was calculated for each country by using the following formula A.1:

$$T_A = C_A - T_e \quad \text{(A.1)}$$

Whereby T_A represents the closeness to the optimum cardinal temperature for agriculture calculated by the cardinal temperature for agriculture C_A, which equals to 28.5 degrees Celsius, subtracted by T_e as the temperature estimated for the year 2100 per country.

For calculating each country's time to optimum economic output in the industry sector, equation A.2 was used:

$$T_I = C_I - T_e \quad \text{(A.2)}$$

Whereby T_I represents the closeness to the optimum cardinal temperature for the industry sector calculated by the cardinal temperature for the industry sector C_I, which equals to 21 degrees Celsius, subtracted by T_e as the temperature estimated for the year 2100 per country.

For calculating each country's time to optimum economic output in the service sector, equation A.3 was used:

$$T_S = C_S - T_e \quad \text{(A.3)}$$

whereby T_S represents the closeness to the optimum cardinal temperature for the service sector calculated by the cardinal temperature for service sector C_S, which equals to 25 degrees Celsius, subtracted by T_e as the temperature estimated for the year 2100 per country.

The result for the distance to the optimum temperature for each sector for each country was then multiplied by the GDP contribution percentage of the sector using the following formula A.4-A.6:

For the agricultural sector, formula A.4 reads

$$WL_A = T_A * GDP_A, \quad \text{(A.4)}$$

whereby WL_A stands for the climate change winner and loser index for agriculture per country comprised of the distance to the optimum cardinal temperature per GDP sector T_A multiplied by the percentage of agriculture contributing to the overall GDP indicated by GDP_A.

For the industry sector, formula A.5 reads

$$WL_I = T_I * GDP_I, \quad \text{(A.5)}$$

whereby WL_A stands for the climate change winner and loser index for industry per country comprised of the distance to the optimum cardinal temperature per GDP sector T_I multiplied by the percentage of industry contributing to the overall GDP indicated by GDP_I.

For the service sector, formula A.6 reads

$$WL_S = T_S * GDP_S \quad \text{(A.6)}$$

whereby WL_A describes the climate change winner and loser index for service per country comprised of the distance to the optimum cardinal temperature per GDP sector T_S multiplied by the percentage of the service sector contributing to the overall GDP indicated by GDP_S.

The overall Winner-Loser WL_T index was calculated per GDP sector leading the sector-specific Winner-Loser indices WL_A for the agriculture sector, WL_I for the industry sector, and WL_S for the service sector, that were then added up into the Winner-Loser total index WL_T based on the following formula A.7:

$$WL_T = WL_A + WL_I + WL_S \quad \text{(A.7)}$$

whereby WL_A denotes the Winner-Loser index for the agriculture sector, WL_I the index for the industry sector and WL_S the index for the service sector. All indices were calculated per country for the year 2100 under a business-as-usual projection.

Overall, a positive WL index result would indicate a long distance to the optimum from now until the year 2100, whereas a negative index would be considered as negative prospect. Basically the more positive the index, the longer time the country could expect to be having a favorable climate for agriculture, industries or service production until peak condition and the more negative the index, the sooner the country would (have) run out of efficiency time. In sum, the Winner-Loser index is an indicator how much cool time a country still has ahead from now in prospect of an optimum GDP productivity temperature and the assumption that the earth is warming.

A.1.2 Model variants

In order to derive the overall GDP gains and losses until the year 2100 and paying attention to literature controversies over the mathematical representation of wins and losses, three model variants of linear model, prospect model and hyperbolic model are calculated (Burke, Hsiang & Miguel, 2015).

A.1.2.1Linear model

Model 1 assumes linear gain and loss functions to capture the earth's warming related GDP prospects based on the following formula 5.8, 5.9 and 5.10. The winners' index W is calculated by multiplying the distance to the optimum cardinal temperature per GDP sector T_A for agriculture and GDP_A for GDP contribution to agriculture, T_I for industry sector and GDP_I for GDP contribution to industry, and T_S for service sector and GDP_S for GDP contribution to service using the formula A.1, A.2 and A.3 multiplied by the respective GDP per sector contributions as exhibited in formulas A.8, A.9 and A.10:

$$W_A = {T_A}^1 * GDP_A \quad \text{(A.8)}$$

$$W_I = {T_I}^1 * GDP_I \quad \text{(A.9)}$$

$$W_S = {T_S}^1 * GDP_S \quad \text{(A.10)}$$

For the losers' index L a linear growth is assumed by calculated by formula A.11, A.12 and A.13 for each respective sector:

$$L_A = -{T_A}^1 * GDP_A \quad \text{(A.11)}$$

$$L_I = -{T_I}^1 * GDP_I \quad \text{(A.12)}$$

$$L_S = -{T_S}^1 * GDP_S \quad \text{(A.13)}$$

per country and per GDP sector. The overall Winner-Loser WL index was calculated per GDP sector leading the sector-specific Winner-Loser indices WL_A for the agriculture sector,

WL_I for the industry sector, and WL_S for the service sector, that were then added up into the Winner-Loser total index WL_T based on formula A.7.

A.1.2.2 Concave gains and convex losses prospect model

Model 2 assumes concave gain and convex loss functions to capture the earth's warming related GDP prospects based on the following formula A.14, A.15 and A.16. The winners' index W is calculated by multiplying the distance to the optimum cardinal temperature per GDP sector T_A for agriculture, T_I for industry sector and T_S for service sector using the formula A.1, A.2 and A.3 multiplied by the respective GDP per sector contributions as exhibited in formulas A.14, A.15 and A.16:

$$W_A = {T_A}^{0.5} * GDP_A \quad (A.14)$$

$$W_I = {T_I}^{0.5} * GDP_I \quad (A.15)$$

$$W_S = {T_S}^{0.5} * GDP_S \quad (A.16)$$

For the losers' index L a convex growth is assumed by calculated by formula A.17, A.18 and A.19 for each respective sector:

$$L_A = -{T_A}^2 * GDP_A \quad (A.17)$$

$$L_I = -{T_I}^2 * GDP_I \quad (A.18)$$

$$L_S = -{T_S}^2 * GDP_S \quad (A.19)$$

per country and per GDP sector. The overall Winner-Loser WL index was calculated per GDP sector leading the sector-specific Winner-Loser indices WL_A for the agriculture sector, WL_I for the industry sector, and WL_S for the service sector, that were then added up into the Winner-Loser total index WL_T based on formula A.7.

A.1.2.3 Hyperbolic model

Model 3 assumes hyperbolic gain and loss functions with the cardinal temperature equaling the maximum point to capture the earth's warming related GDP prospects based on the following formula A.20, A.21 and A.22. The winners' index W is calculated by multiplying the distance to the optimum cardinal temperature per GDP sector T_A for agriculture, T_I for industry sector and T_S for service sector using the formula A.1, A.2 and A.3 multiplied by the respective GDP per sector contributions as exhibited in formulas A.20, A.21 and A.22:

$$W_A = {T_A}^2 * GDP_A \quad (A.20)$$

$$W_I = {T_I}^2 * GDP_I \quad (A.21)$$

$$W_S = {T_S}^2 * GDP_S \quad \text{(A.22)}$$

For the losers' index L a hyperbolic growth is assumed by calculated by formula A.23, A.24 and A.25 for each respective sector:

$$L_A = -{T_A}^2 * GDP_A \quad \text{(A.23)}$$

$$L_I = -{T_I}^2 * GDP_I \quad \text{(A.24)}$$

$$L_S = -{T_S}^2 * GDP_S \quad \text{(A.25)}$$

per country and per GDP sector. The overall Winner-Loser WL index was calculated per GDP sector leading the sector-specific Winner-Loser indices WL_A for the agriculture sector, WL_I for the industry sector, and WL_S for the service sector, that were then added up into the Winner-Loser total index WL_T based on formula A.7.

A.2 Results

A.2.1 Overall GDP gains and losses until 2100

A.2.1.1Linear model

When unidimensionally focusing on estimated GDP growth given a warmer temperature and estimating a linear growth of losses and wins, overall the world will be gaining more than losing until 2100. Based on the WL index of 198 countries of the world and under the assumption of linear gains and losses in light of climate change, less countries (n=79) will win more from global warming until 2100 than more countries (n=119) will lose from a warming earth. In particular, 79 countries of the world will gain WL_L=78139.08 in GDP output, whereas 119 countries of the world will lose estimated WL_L=-52061.

A.2.1.2Prospect convex losses and concave gains model

When unidimensionally focusing on estimated GDP growth given a warmer temperature and estimating an exponential growth of losses and concave wins, overall the world will be losing more than gaining until 2100. Based on the WL index of 188 countries of the world, more countries (n=113) will lose more from global warming until 2100 than less countries (n=75) will win from a warming earth. In particular, 75 countries of the world will gain WL_P=22717.161 in GDP output, whereas 113 countries of the world will lose estimated WL_P=-353175.32.

A.2.1.3Hyperbolic model

When unidimensionally focusing on estimated GDP growth given a warmer temperature and estimating a hyperbolic growth, overall the world will be gaining more than losing until 2100. Based on the WL index of 188 countries of the world, less countries (n=79) will gain more from global warming until 2100 than more countries (n=109) will lose from a warming earth. In particular, 79 countries of the world will gain WL_H=1037192 in GDP output, whereas 109 countries of the world will lose estimated WL_H=-352088.

A.2.1.4Total estimate

The total Winner-Loser WL index was calculated per country based on the mean of the overall Winner-Loser index WL_L for the linear model, the overall Winner-Loser index WL_P for the prospect model, and the overall Winner-Loser index WL_H for the hyperbolic model that were then added up into the Winner-Loser total index WL_{TT} and divided by the number of models calculated (n) to gain the mean based on the following formula A.26:

$$WL_{TT} = (WL_L + WL_P + WL_H)/n \quad \text{(A.26)}$$

Whereby WL_L denotes the Winner-Loser index for the linear model, WL_P the index for the prospect model and WL_H the index for the hyperbolic model and $n = 3$. All indices were calculated per country for the year 2100 business-as-usual projection.

When unidimensionally focusing on estimated GDP growth given a warmer temperature, over all calculated models the world will be gaining more than losing until 2100. Based on the WL index of 188 countries of the world, less countries (n=77) will gain more from global warming until 2100 than more countries (n=111) will lose from a warming earth. In particular, 77 countries of the world will gain WL_H=354039.6345 in GDP output, whereas 111 countries of the world will lose estimated WL_H=-235726.6280.