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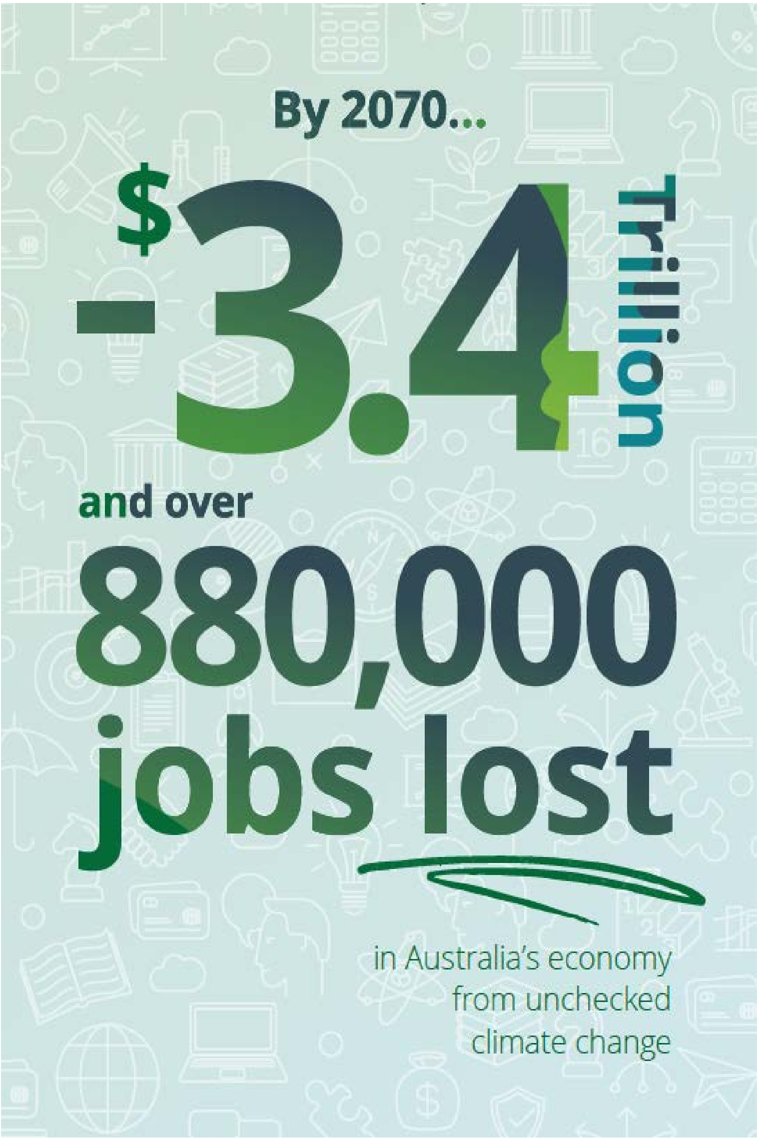
D.CLIMATE

Australian Conference of Economists
July 2021

Deloitte Access Economics

The Context

A New* Choice



By 2070...
$-3.4 Trillion
and over
880,000
jobs lost
in Australia's economy
from unchecked
climate change

By 2070...
$680 Billion
and over
250,000
jobs added
to Australia's economy
from choosing a new
growth pathway

Australia will lose more than $3 trillion and 880,000 jobs over 50 years if climate change is not addressed, Deloitte says

By Kathleen Calderwood
Posted Mon 2 Nov 2020 at 12:15am, updated Mon 2 Nov 2020 at 7:19am

The report warns higher average temperatures will put labour-intensive industries like construction at risk. *(ABC News: Chris Gillette)*

Share

The Australian economy will lose more than $3 trillion over the next 50 years if climate change is not addressed, according to a new report from Deloitte Access Economics.

The report found the economy could shrink by 6 per cent over the next 50 years and 880,000 jobs could be lost.

Report author Pradeep Philip, who was a policy director for former prime minister Kevin Rudd, said there was also a lot to be gained if warming was kept below 1.5 degrees and Australia achieved net zero carbon emissions by 2050.

Key points:

- Report author Pradeep Philip warned that Queensland in 50 years could represent half of Australia's job losses, "if we don't get this right"
- Trade, tourism and mining are

Deloitte climate report more a fearmongering manifesto

ADAM CREIGHTON
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11:00PM NOVEMBER 17, 2020
384 COMMENTS

The Deloitte report doesn't mention nuclear power.

Just when you thought you'd had enough scary and ridiculous predictions for one year, along comes Deloitte Access Economics with claims Australia will lose $3.4 trillion in income and 880,000 jobs by 2070 unless it takes drastic action to reduce carbon dioxide emissions.

Report	Damages	Scenario	Year	Region
Tol (2012)	4%	4^oC	2100	Global
Roson & van der Mensbrugghe (2012)	5%	4^oC+	2100	China*
Newbold & Martin (2014)	8%	4^oC	2100	Global
Howard & Sterner (2017)	20%	4^oC	2100	Global
Burke et al (2018)	30%	4^oC	2100	Global
Kompas et al (2019)	10%	RCP8.5	2100	Australia
NGFS (2020)	25%	3^oC	2100	Global
Deloitte (2020)	**6%**	**RCP8.5**	**2070**	**Australia**
McKibbin (2021)	4%	RCP8.5	2100	Australia
SwisseRE (2021)	17%	RCP8.5	2048	Global

Notes: Tol (2012) and Newbold & Martin (2014) is taken from figure 1 in Howard & Sterner (2017). The figure for China is chosen from Roson & van der Mensbrugghe (2012) is taken as it lies close the Australian figure in recent work we've done. The figure for Kompas et al (2019) is derived based on the quoted NPV cumulative deviation in dollars.

D.CLIMATE

| Economic scenario modelling for a changing climate and decarbonising economies

Deloitte Access Economics' approach to modelling climate change and decarbonisation

Deloitte Access Economics has significantly invested in developing an in-house Regional CGE Climate Integrated Assessment Model (D.CLIMATE). D.CLIMATE is a modelling method and policy analysis technique that accounts for various climate change and emissions reduction scenarios.

D.CLIMATE is built on an economic modelling framework that can account for the economic impacts of climate change and alternative emissions profiles aligned to the National Greenhouse Gas Inventory. The model can establish reference cases for policy analysis out to the year 2100. The D.CLIMATE process and logic is summarised as follows:

1. Modelling a projected economic output (as measured by Gross Domestic Product) which causes emissions to reflect a Representative Concentrative Pathway (RCP) ranging between RCP6.0 and RCP8.5;
2. Increased concentration of emissions causes global warming above pre-industrial levels;
3. Warming causes anthropogenic climate change and results damages to the factors of production;
4. These damages to the factors of production are distributed across the economy, impacting Gross Domestic Product.

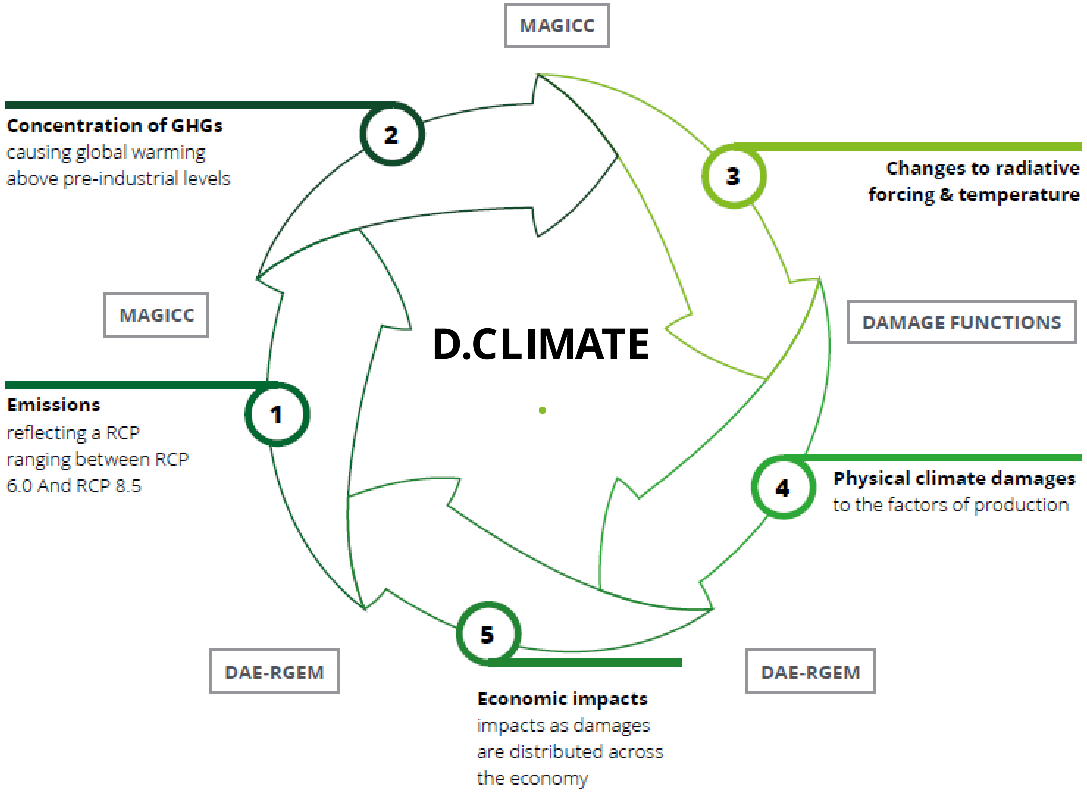
To translate this concept into a modelling process, it involves understanding three models which link to each other through three key outputs.

Deloitte Access Economics' **approach extends methods adopted by** the Australian Bureau of Agricultural and Resource Economics and Sciences (**ABARES**), the International Panel on Climate Change (**IPCC**) and **academia**. The method is extended by necessity for practical public policy purposes and our modelling is regionalised – allowing **results and insights to be produced at the regional level** (such as Australian Bureau of Statistics statistical areas or local government boundaries). The modelling process is summarised below:

1. Deloitte's in-house regional Computable General Equilibrium model (DAE-RGEM) is used to produce a **projected path for economic output and emissions** that align to reflect a decided RCP range between RCP6.0 and RCP8.5.
2. This emissions pathway is modelled separately in a climate change model (Model for the Assessment of Greenhouse Gas Induced Climate Change - MAGICC) for the **assessment of the physical damages** which follow from projected shifts in global and regional temperatures.
3. These then feed into a **damage function** to inform how shifts in temperature may play out in terms of impacts on the productivity of labour and capital in each sector/region. Unlike most other models, we model a broad range of damages, including capital damages, sea level rise damages to land stock, heat stress damages on labour productivity, human health damages to labour productivity, agricultural damages from changes in crop yields and tourism damages to net inflow of foreign currency.

| D.CLIMATE scenario modelling captures the full range of emissions profiles, industries, energy mixes and economic impacts to economies to inform the baseline and net zero pathways. This is the basis to determine the level of investment required in alternative future states.

D.CLIMATE modelling framework and process



Sources: Deloitte Access Economics; Meinshausen, Wigley & Raper (2011)

DAMAGE FUNCTIONS

| DAMAGES

Conceptual framework

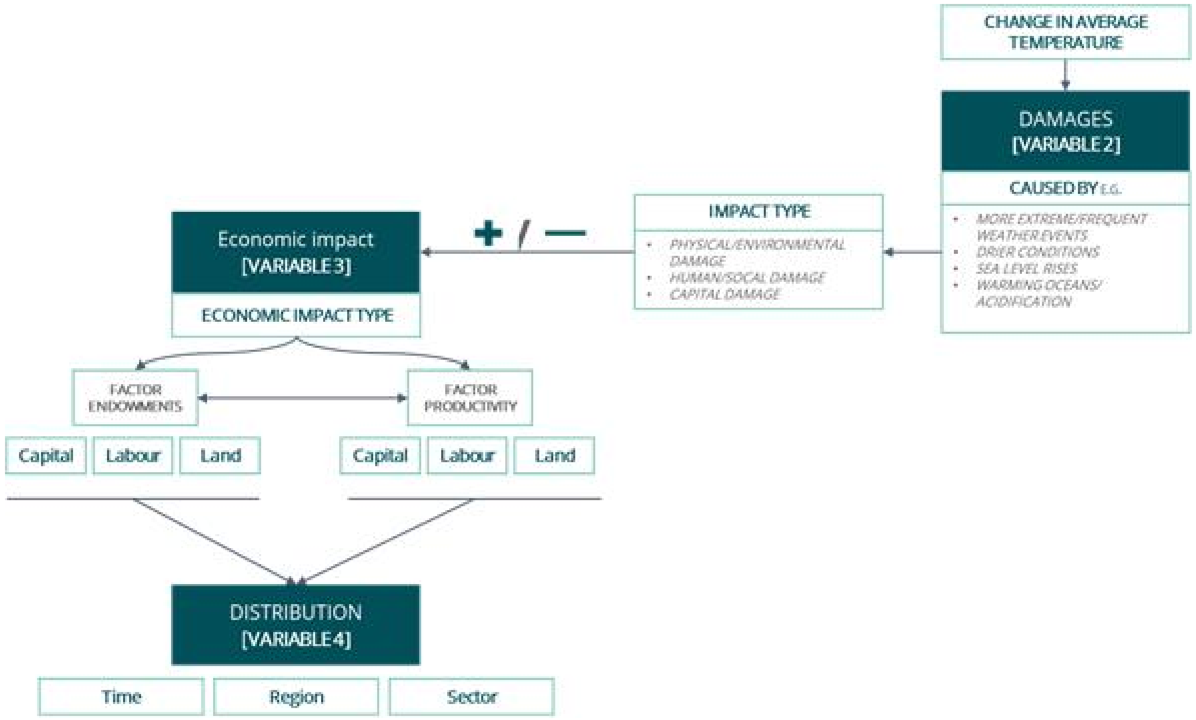
The specification of damage functions is used to translate a given temperature increase into economic damages by sector, region and over time. These are then fed back into D.CLIMATE resulting in a change in the level of emissions and re-starting the process.

The figure to the right describes the relationship between changes in average temperature, damages, the (positive or negative) impacts on factors of production and the distribution of those impacts by sector, region and over time.

The fundamental 'driver' of climate-related economic damages is changes in average temperature (globally or by region), through a "two-stage" process:

The scientific relationships between average temperature and the range of damages ("stage 1") are, in general, well established in academia and form an implicit basis for D.CLIMATE damage functions.

There are numerous damages resulting from changes in average temperature. The development of the damage functions in D.CLIMATE has focussed on "stage 2", the impact of damages on the factors of production.



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Overview of the existing literature

Integrated Assessment Model (IAM) Literature

- Most well known IAMs are DICE, FUND, PAGE, ENVISAGE: with conventional damage functions modelled as percentage impacts on total economic output (GDP) (e.g. Nordhaus, 2010, Tol 2000).
- The damage functions specified in most widely cited IAMs have typically been highly abstracted and based on empirical research that can no longer be considered contemporary (i.e. most recent studies in FUND stem from 2009 and majority from early/mid 1990s; DICE studies stem mostly from 1990s).
- Fundamental productive elements of modern economies i.e. labour and crops may have differentiated responses to changes in climate which may not be accurately captured within top-down, GDP-level aggregate functions.

Econometric / DOSE (damage) response function literature

- More than 100 studies published since 2010 using more up-to-date econometric techniques (and increased data availability), therefore these findings can be used to improve upon the functional specifications and parameterisation of damage functions in contemporary IAMs (e.g. Hsiang 2018, Aufhammer 2018, Kjellstrom et al 2012).
- As has been observed in a number of empirical settings, damage functions, are likely to be non-linear in average temperature (damage functions within traditional IAM approaches largely inferred as linear relationships).
- These approaches face their own set of limitations, including that accurate empirical relationships using historical data may not be reflective of relationships that may be observed in the future.
- Aggregating impact/cost estimates from many different instances of micro-scale damages to obtain single macro-scale estimate for whole economy is difficult.
    - Limited studies which actually do this: some studies (Burke, Hsiang and Miguel 2015) show that inconsistencies can be reconciled if non-linearity in relationship between temperature and economic productivity is taken into account at macro scale.
    - Other studies provide summary of meta-analyses to estimate parameters but don’t necessarily calculate net aggregate effect (first-order approximations only).

D.CLIMATE specifies a set of damage functions for a bespoke integrated assessment model. These functions, unlike earlier IAMs seek to incorporate insights uncovered through more recent econometric empirical research into the relationship between climate change and economic impacts.

| DAMAGES

A starting point

The approach to damage functions in D.CLIMATE has been motivated by the work of Roson and Sartori (2016), who specify six specific damage functions, based on empirical estimates of the economic impact of climate change.

D.CLIMATE adapts and integrates 4 of the Roson and Sartori damage functions (sea level rise, crop yields, human health impacts and tourism – updated with more recent and regionalised data), the effect of rising temperatures and changing relative humidity levels on labour productivity (following an approach proposed by Kjellstrom et. al. (2017)) and an additional derived function to estimate the economic impact of climate change on capital.

Six impacts due to changes in global average temperature:

1. Sea level rise: $\%\Delta \mathrm{N_r} = \mathrm{f_r}(\Delta t)$, as percentage change in productive land stock by region (r)
2. Crop yields: $\%\Delta \mathrm{Y_{NAg_r}} = \mathrm{f_r}(\Delta \mathrm{t})$, as a percentage change in the "output" per hectare by region (r)
3. Health impacts: $\%\Delta \mathrm{A_{L_r}}$, a percentage change in labour productivity in region (r) for a given increase of +1 ℃ ($\%\Delta \mathrm{A_{L_r}}$ is not a function of Δt)
4. Tourism: $\%\Delta\, net\ inflow\ foreign\ currency_{\mathrm{r}} = \mathrm{f_r}(\Delta \mathrm{t})$, percentage change in net inflow of foreign currency in region (r) due to variations in number arrivals/departures of tourists and per capita expenditure
5. Heat stress and labour productivity: $\%\Delta \mathrm{A_{L_{ri}}} = \mathrm{f_{ri}}(\Delta \mathrm{t})$, as a percentage change in labour productivity region (r) and sector (i), where (i) includes manufacturing, services and agriculture
6. Capital damages: $\%\Delta\ of\ capital\ stock = \mathrm{f_r}(\Delta \mathrm{t})$, a percentage change in capital stock in region (r)

| DAMAGES

Sea level rise

Where we
live and work

Sea level rise erodes productive land

- D.CLIMATE estimates land area lost due to sea level rise (SLR) using a methodology proposed by Roson & Sartori (2016), who estimated the mean SLR (in metres) associated with global mean surface temperature change from a series of regressions based on data within the latest IPCC AR5 Report, while also accounting for vertical land movement:

  - SLR affects the land stock through the erosion, inundation or salt intrusion along the coastline. This phenomenon is in turn generated by (i) the thermal expansion of water bodies and (ii) glaciers' melting.

  - The share of land which may be lost (in terms of economic production factor) depends on several country-specific characteristics, like: (i) the composition of the shoreline (cliffs and rocky coasts are less subject to erosion than sandy coasts and wetlands); (ii) the total length of the country coast; (iii) the share of the coast which is suitable for productive purposes (i.e. in agriculture); (iv) the vertical land movement (VLM).

$$\alpha SLR = [(\alpha + \beta \Delta t - V)(T - 2000)]$$

Where:

$$\alpha = 0.000954281;\ \beta = 0.003421296;\ V = vertical\ land\ movement\ to\ adjust\ SLR;\ T = year;\ \Delta t = average\ temperature\ change$$

  - The percentage change in the land stock by year and country, LRT, is computed by multiplying the percentage of effective land change by meter of SLR(LR) and the predicted adjusted SLR, as follows

$$L_{RT} = L_R\ [(\alpha + \beta \Delta t - V_R)(T - 2000)]$$

$$L_{RT} = \%\Delta\ land\ stock\ by\ year\ and\ region;\ L_R = \%\ of\ effective\ land\ change\ by\ meter\ of\ SLR$$

- D.CLIMATE extends the Roson & Sartori (2016) methodology to also capture urban land area lost due SLR, leveraging World Bank data describing the extent of urban area in Low Elevation Coastal Zones (LECZ) . In low lying and seacoast urban areas, residential and commercial properties may incur physical damages and require significant capital costs to repair. Economic activity that would otherwise occur in these urban areas will also need to transition to other geographies.

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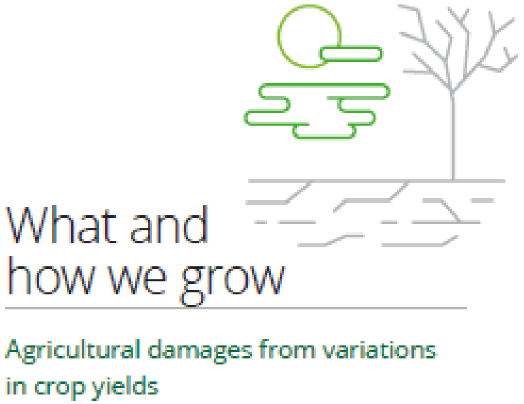
Agriculture



- Despite the many existing studies and the extensive empirical evidence produced, it is still difficult to identify some sort of “consensus” for the impacts of climate change on agricultural productivity.
- Many factors are at play:
    - the role of adaptation behaviour by farmers, firms and organisations, including variety selection, crop rotation, sowing times
    - the amount of fertilization due to higher CO2 concentration
    - the actual level of water available for irrigation, and irrigation techniques.
- D.CLIMATE adopts an approach which provides an estimate of productivity changes for the whole agricultural sector across the modelled regions. The methodology is follows Roson and Sartori (2016), which is based on the Mendelsohn and Schlesinger (1999) reduced form Agricultural Response Functions in the formulation proposed by Cline (2007), **where the variation in output per hectare (DY) is expressed as a function of temperature (T), precipitation (P) and CO2 concentration (K).**

$$DY = (115.992DT + 0.4752P + 7.884K/365)DT - 9.936DT^2$$

- One disadvantage of this approach is that adaptation is not incorporated within the function. Studies that include an agronomic adaptation do, on average, report higher yields than those that don’t; however, recent research has noted that the effects of agronomic, on-farm, within-crop adaptations (principally changes in crop variety and planting date) are found to be small and statistically insignificant.
- Additional economic adaptations such as crop switching, increasing production intensity, substituting consumption, or adjusting trade relationships are captured within the CGE model.

| DAMAGES

Human Health

How we live

Health damages
on labour productivity

- To estimate the impacts of climate change on human health, D.CLIMATE adopts an approach which is an adaption of work undertaken by Roson & Sartori (2015), which is based on Bosello et al. (2006), by considering some vector-borne diseases (malaria, dengue, schistomiasis), heat- and cold- related diseases, and diarrhoea. It does not consider other diseases and impacts mentioned in the IPCC AR5 (2014).

- The starting point of the analysis presented in Bosello et al. (2006) is a meta-analysis of the epidemiological, medical and interdisciplinary literature to achieve the best estimates for the additional number of extra cases of mortality and morbidity associated with a given increase in average temperature. The information obtained in this research has been combined with data on the structure of the working population, to infer the number of lost working days. The changes in morbidity and mortality are interpreted as changes in labour productivity.

- Roson & Sartori (2015) update the work of Bosello et al. (2006) to account for recent literature on health impacts and studies mentioned in IPCC (2014), scaling up or down the variations in labour productivity.

- The results of these studies are expressed as changes in average labour productivity for a +1°C increase in temperature (implicitly assuming that the relationship is approximately linear). To understand the relationship between human health impacts, an increase in average temperature and time, D.CLIMATE takes an approach of regressing the variables to find an equation with a satisfactory fit for the relationship.

- The analysis estimates the higher-order economic effects (or indirect costs) of human health impacts as; variations in labour productivity. It is important to note that this methodology excludes induced demand for health care.

| DAMAGES

Tourism

How we holiday

Tourism damages on the flow of global currency

- Climate is one of the main drivers of international tourism, and tourism revenue is a fundamental pillar of the economy in many countries but there is minimal tourism literature focussing on climate change effects and little climate change impact literature focussing on tourism

- To estimate tourism damages in D.CLIMATE, functions that relate visitor arrivals and departures to average temperature are employed. These functions are consistent with those employed by Roson & Satori and are derived from econometric models expressed in terms of land area, average temperature, length of coastline, per capita income and the number of countries with shared land borders

- Forecast average temperatures from MAGICC are used as inputs to these functions to determine a resulting net flow of foreign currency

- The forecast net flow of foreign currency is subsequently apportioned to the appropriate industry based on shares of direct tourism output produced by tourism data sources (such as Tourism Research Australia)

$$Net\ inflow\ of\ foreign\ currency = Expenditure_A * Variation\ in\ arrivals - Expenditure_D * Variation\ in\ departures$$

Where:

$$Expenditure_A = per\ capita\ expenditure\ of\ arrivals;\ Expenditure_D = per\ capita\ expenditure\ of\ departures$$

$$Variation\ in\ arrivals = A(T) - A_{baseyear};\ A(T) = K_A * \exp(0.22T - 0.00791T^2)$$

$$Variation\ in\ departures = D(T) - D_{baseyear};\ D(T) = K_D * \exp(-0.18T + 0.00438T^2)$$

K_A and K_D are country specific constants accounting for all other factors different from temperature i.e. average temperature, arrival and departure elasticities

| DAMAGES

Heat stress

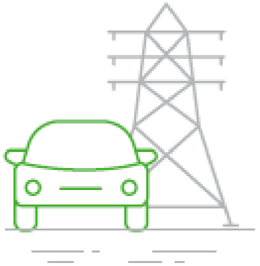
How workers work

Heat stress impacts on labour productivity

- D.CLIMATE estimates the effect of rising temperatures and changing relative humidity levels on labour productivity using wet bulb globe temperature (WBGT) as a measure of heat stress, following the methodology proposed by Kjellstrom et. al. (2017). It is assumed that changes in labour productivity (economic concept) are equal to changes in estimated work capacity (physiological concept).
- This approach utilises a series of functions describing the relationship between WBGT and labour productivity across three different work intensities:
    - 200W (equivalent to light manual labour, such as office work)
    - 300W (equivalent to moderate manual labour, such as manufacturing)
    - 400W (equivalent to high intensity manual labour, such as farming).
- Workers in each GTAP sector are assumed to perform tasks at one of the three work intensities specified above. GTAP sectors have been allocated to specific work intensities based internal advice from Deloitte subject matter experts.
- Consistent with the approach proposed by Kjellstrom et. al. (2017), it is assumed that a country or region's WBGT varies over three 4-hour intervals comprising the approximate 12 hours in a working day:
    1. Early morning and early evening: 4-hours at WBGT mean (calculated using average monthly temperature)
    2. Middle of the day: 4-hours at WBGT max (calculated using average monthly maximum temperature)
    3. Hours in between: 4-hours at WBGT half (calculated as the mid-point between WBGT mean and WBGT max)
- Labour productivity is then estimated for each country / region at monthly intervals, across each of the three 4-hour intervals assumed to comprise the working day. The mean of these three estimates is then taken to represent the average labour productivity for workers throughout the working day. Workers are assumed to maintain the same level of productivity for all days contained within each month. Monthly labour productivity estimates are then averaged to give an aggregate measure of labour productivity for each year in the modelling period.

| DAMAGES

Capital



What is built and how it is damaged

Capital damages from investing in repairs, not new infrastructure

- In general, the economic impacts of climate change on capital has been less commonly incorporated into IAM modelling. Often, reports discuss the exposure or risk of countries and regions to capital damages but do not attempt to monetise an impact.
- D.CLIMATE captures climate induced capital damages as a function of increasing global mean average temperature. Capital damages in this context, consider the impact of riverine flooding, forest fires, subsidence, high wind speeds (excluding Cyclones) and extreme heat climate events on physical capital, including dwellings, infrastructure and machinery and equipment. The methodology used in this report employs data produced by XDI modelling of climate change impacts on Australia’s physical capital stock. The XDI data provides estimates for total technical insurance premiums at the LGA level – a proxy for monetised capital damage by LGA.
- A log-log model is produced for each region drawing on data for Australian LGAs and predicted global mean average temperature increases under an RCP 6.0 emissions pathway.
- The estimated damages produced by this research can be interpreted as a percentage of annual capital investment that is diverted to repair and replace damaged assets due to an associated rise in average temperature in a region.
- Accounting for capital damages in this way represents a departure from existing economic impact modelling and integrated assessments of climate change. In some cases, capital damages are included but at a highly aggregated level that limits regional analysis.
- Global databases monetising climate induced capital damages are uncommon and those that exist are difficult to integrate into an IAM framework.

Policy

| POLICY

- How do you model a policy which doesn’t exist?
- Emissions constraints vs. carbon taxes?
- How do you set appropriate substitution parameters for decarbonisation?
- When/how to apply technological improvements?
- What do you assume about non-combustion emissions?

Next Steps

| WHERE TO NEXT?

- Combining acute and chronic damages?
- Adding more damages/refining those we have currently?
- Accounting for tail risk?
- Accounting for adaption?
- Trying to derive an optimal response?

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