Applying Climate Change Damage Functions to the Sub-National Regions in a Global CGE Model *

Ken Itakura† Akira Hibiki‡

IMCOMPLETE DRAFT

Climate change is a global issue affecting countries and regions with rising temperatures resulting from emissions of greenhouse gases. Economic activities demand energy, primarily fossil fuels emitting carbon dioxide, accelerating global warming. Policies to mitigate the emissions and to adopt the climate change have been extensively studied in interrelated areas of energy, the environment, and the economy. The interrelatedness calls for applied models to encompass the linkages between them. Computable general equilibrium (CGE) models play a crucial role in addressing the linkages for economic modeling. Dixon and Jorgenson (2013) offers an extensive collection of CGE models, and among them are specific CGE models designed to study energy, the environment, and economic nexus. Since the Global Trade Analysis Project (GTAP) have been providing publicly available CGE models and database, an energy-environmental version of the GTAP model and database (GTAP-E) was developed by Burniaux and Truong (2002) and McDougall and Golub (2007), and there have been many studies utilizing the GTAP-E.

This study extends the GTAP-E model and database (Aguiar et al., 2019) by incorporating the sub-national regions, prefectures, of Japan to explore the linkage between them and the global economy. To capture all prefectures' economic structure in data, we utilize forty seven input-output (IO) tables corresponding to each prefecture (Table A1). Since the domestic transactions within a country are not covered in the GTAP database, we introduced them to the database. These introduction of prefectures and their domestic

*We are grateful for helpful comments from Roberto Roson and Martina Sartori. We acknowledge funding from the JSPS KAKENHI Grant No.JP22K01464, and the Environment Research and Technology Development Fund (JPMEERF20S11821) of the Environmental Restoration and Conservation Agency of Japan.

†Graduate School of Economics, Nagoya City University, (e-mail: itakura@econ.nagoya-cu.ac.jp)

‡Graduate School of Economics and Management, Tohoku University

transactions also need to be reflected in the GTAP-E model which retains most of the core features in the standard GTAP model (Hertel, 1997; McDougall, 2003; Corong et al., 2017).

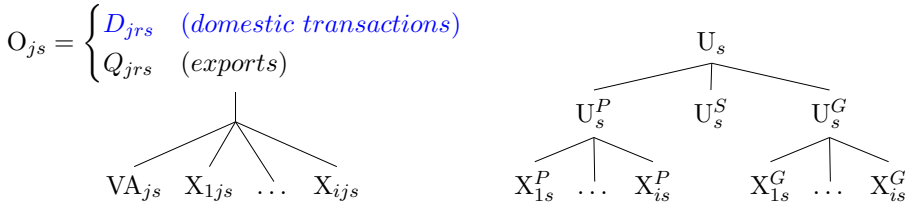


Figure 1: Structure of Production and Consumption

In Figure 1, the left hand side illustrates the production structure of the model while the right hand side depicts the consumption structure. O_{js} is output of industry j in prefecture s, VA_{js} is value-added composite used by j in s, X_{ijs} is composite good i used by j in s. Domestic transaction of j between prefecture r and prefecture s is D_{jrs}. Note that the data on domestic transactions are only available for Japan. For representative regional household's consumption structure, U_s is per capita utility from aggregate household expenditure in s, U_s^P, U_s^S, U_s^G correspond to sub-utility from private consumption, savings, gov't expenditure, respectively, where X_{is}^P is composite good i for private household's consumption and X_{is}^G is composite good i for government.

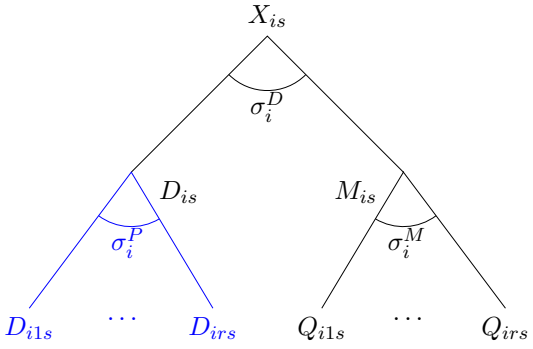


Figure 2: CES Aggregator for Composite Goods (X_{is})

Figure 2 illustrates the composite goods (X_{is}) demanded by producers, the private household and the government in prefecture s. D_{is} is domestic composite good i, D_{irs} is good i from prefecture r, M_{is} is composite import i from country r, Q_{irs}. Constant

elasticities of substitution are σ_i^D, σ_i^M, and σ_i^P.

Value-added composite in the GTAP-E model is drawn in Figure 3

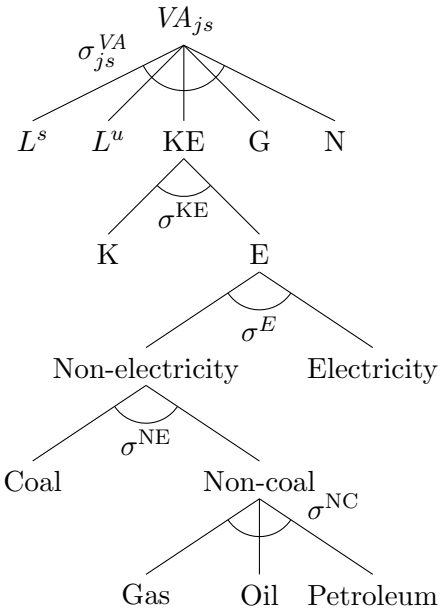


Figure 3: Value-Added Nest in GTAP-E

We implement experimental simulations of climate damage functions over the baseline simulation. Constructing the baseline for 2011–2100 takes long-term projections of the total and working-age population published by United Nations (2022) for countries, and National Institute of Population and Social Security Research (2018) for prefectures. Long-term GDP projections are obtained from OECD (2018), and gross regional product (GRP) from Economic and Social Research Institute (2022). We use the GEMPACK economic modelling software (Harrison and Pearson, 1996) for the simulations as well as the modification of database and model.

We adopt the climate change damage functions identified by Roson and Sartori (2016), and they are classified into six categories as follows for our experimental simulations;

S1 heat effects on labor productivity

S2 human health

S3 agricultural productivity

S4 sea level rise

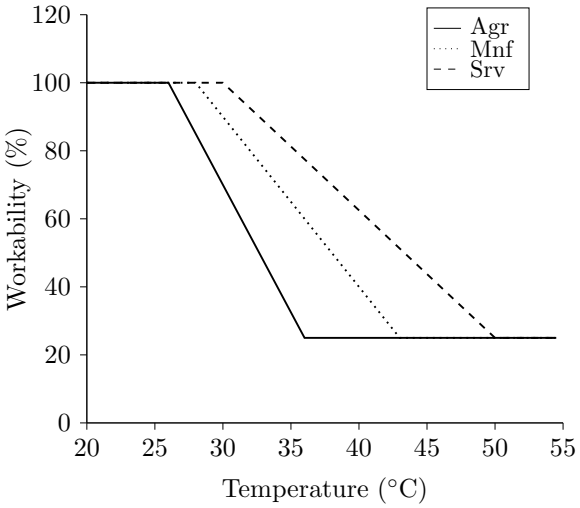
S5 households' energy demand

S6 tourism flows

S7 all damage functions combined (S1–S6)

We impose the six damage functions over the baseline for 2011–2100, assuming a 3°C of global warming.

For the heat effects on labor productivity (S1), as hours working outside is shortened by heat stress, measured in the Web Bulb Globe Temperature (WBGT), the relation between workability and temperature are summarized in Figure 4, following Roson and Sartori (2016). As temperature surpasses a certain level, workability begins to drop. The level of threshold differs by industry such as agriculture (Agr), manufacturing (Mnf), and services (Srv). For our experimental simulation, we impose these drops on labor productivity.



Source: Redraw from Roson and Sartori (2016)

Figure 4: Workability and Temperature

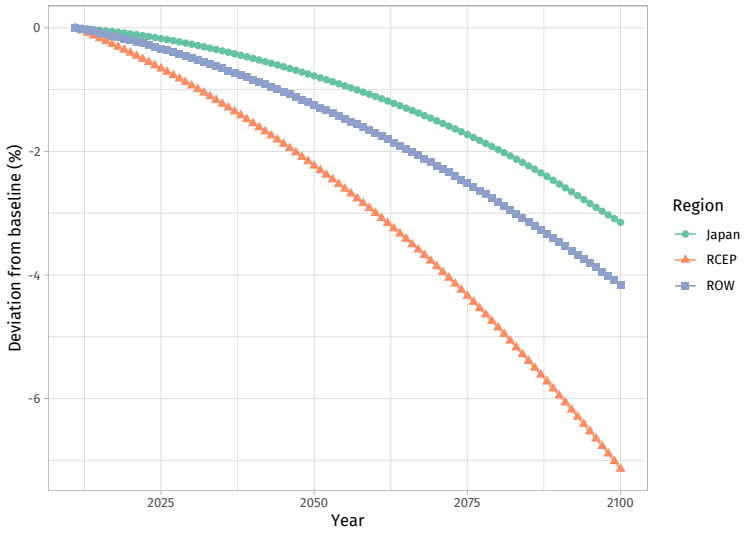
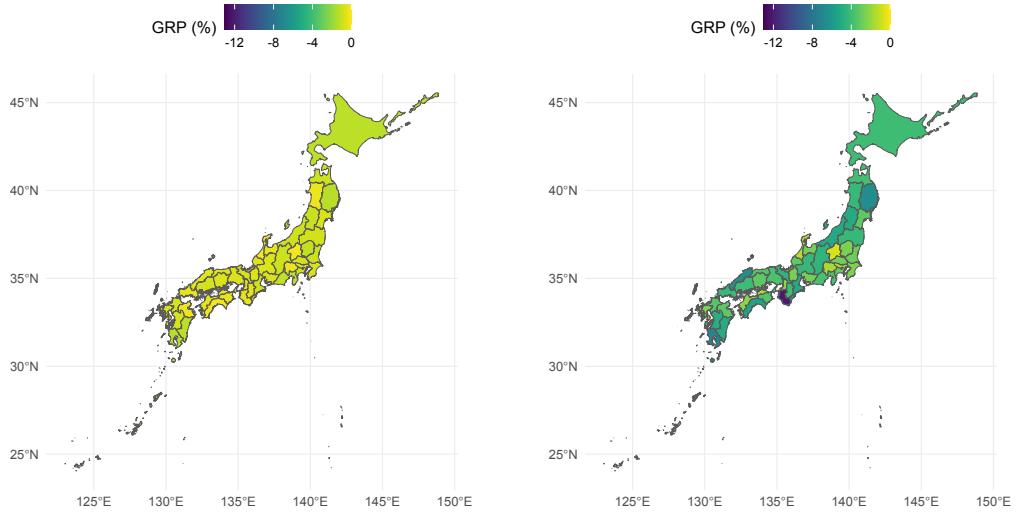


Figure 5: Climate change impact on real GDP



(a) Agricultural productivity impact

(b) All climate damage functions combined

Figure 6: Impact on Real Gross Regional Product in Japan
(percent changes relative to the baseline)

References

Aguiar, Angel, Maksym Chepeliev, Erwin Corong, Robert McDougall, and Dominique van der Mensbrugghe (2019), "The GTAP Data Base: Version 10," *Journal of Global Economic Analysis*, **4**(1), 1–27, `https://jgea.org/ojs/index.php/jgea/article/view/77`.

Burniaux, Jean-Marc and Truong P. Truong (2002), "GTAP-E: An Energy-Environmental Version of the GTAP Model," *GTAP Technical Paper, Purdue University*, **16**.

Corong, Erwin, Thomas Hertel, Robert McDougall, Marinos Tsigas, and Dominique van der Mensbrugghe (2017), "The Standard GTAP Model, Version 7," *Journal of Global Economic Analysis*, **2**(1), 1–119, `https://jgea.org/ojs/index.php/jgea/article/view/47`.

Dixon, Peter B. and Dale W. Jorgenson, eds. (2013), *Handbook of Computable General Equilibrium Modeling*, North Holland, Amsterdam.

Harrison, W. Jill. and Ken R. Pearson (1996), "Computing Solutions for Large General Equilibrium Modeling Using GEMPACK," *Computational Economics*, **9**, 83–127.

Hertel, Thomas W., ed. (1997), *Global Trade Analysis: Modeling and Applications*, Cambridge University Press, New York.

McDougall, Robert (2003), "A New Regional Household Demand System for GTAP," *GTAP Technical Paper, Purdue University*, **20**, 1–57.

McDougall, Robert and Alla Golub (2007), "GTAP-E: A Revised Energy-Environmental Version of the GTAP Model," *GTAP Research Memorandum, Purdue University*, **15**.

National Institute of Population and Social Security Research (2018), *Regional Population Projections for Japan: 2015-2045*, IPSS, Tokyo.

OECD (2018), *GDP Long-term Forecast*, OECD, Paris.

Roson, Roberto and Martina Sartori (2016), "Estimation of Climate Change Damage Functions for 140 Regions in the GTAP 9 Database," *Journal of Global Economic Analysis*, **1**(2), 78–115.

United Nations (2022), *World Population Prospects: The 2022 Revision*, U.N., New York.

Appendix A: Input Output Tables, 2011

Table A1: Source of Input Output Table of Prefectures

No.	Prefecture	Sectors	Source Institution
1	Hokkaido	104	Hokkaido Regional Development Bureau
2	Aomori	108	Department of Planning and Policies, Aomori Prefectural Government
3	Iwate	189	Survey Statistics Division, Hometown Promotion Department
4	Miyagi	110	Planning Department Statistics Division
5	Akita	108	Survey Statistics Division, Planning Promotion Department
6	Yamagata	108	Statistics Planning Division, Mirai Planning and Creation Department
7	Fukushima	107	Statistics Division, Planning and Coordination Department
8	Ibaraki	190	Statistics Division, Department of Policy Planning, Ibaraki Prefectural Government
9	Tochigi	103	Statistical department, Inhabitant of Prefecture Living Part
10	Gunma	108	Statistics Division, General Affairs Department
11	Saitama	190	Statistics Division, Department of General Affairs
12	Chiba	191	Statistics Division, Policy and Planning Department
13	Tokyo	190	Management and Coordination Section, Statistics Division, Bureau of General Affairs
14	Kanagawa	190	Statistics Center, Policy Bureau
15	Nigata	178	Statistics Division, General Affairs Management Department
16	Toyama	187	Statistical Survey Division, Business Administration Department
17	Ishikawa	190	Statistics Information Office, Prefectural Culture and Sports Department
18	Fukui	104	Statistics Information Department, Area Strategy Part
19	Yamanashi	190	Statistics and Survey Division, Resident Affairs Department
20	Nagano	190	Statistical Room, Overall Policy Planning and Evaluation Division, Plan Promotion Part
21	Gifu	190	Statistics Division, Gifu Prefectural Government
22	Shizuoka	190	Data Utilization Promotion Division, Digital Strategy Bureau
23	Aichi	188	Statistics Division, Community Affairs Department, Bureau of Community and Cultural Affairs
24	Mie	188	Mie Prefecture Department of Strategic Planning
25	Shiga	108	Statistics Division, General Planning Department
26	Kyoto	105	Planning and Statistics Division
27	Osaka	190	Statistics Division, Department of General Affairs
28	Hyogo	188	Data & Analysis Division, Hyogo Vision Planning Bureau, Government Civil Policy Planning & Administration Department
29	Nara	108	Statistical Analysis Division, Governor's Office of General Affairs Department
30	Wakayama	190	Research and Statistics Division, Policy Plan Bureau , Wakayama Planning Department
31	Tottori	108	Statistics Division, Reiwa Era Development Office
32	Shimane	98	Statistical Survey Division, Policy Planning Bureau
33	Okayama	108	Statistical Analysis Division, General Policy Bureau
34	Hiroshima	108	Statistics Division, General Affairs Bureau
35	Yamaguchi	108	Statistical Analysis Division, General Planning Department
36	Tokushima	108	Statistical Data Division, Policy Studies Department
37	Kagawa	108	Statistical Survey Division
38	Ehime	178	Statistical Analysis Section, Planning and Statistics Division, Planning and Development Department
39	Kochi	108	Statistical Analysis Division, General Affairs Department
40	Fukuoka	107	Policy Planning and Regional Development Department
41	Saga	108	Statistical Analysis Division, Policy Department
42	Nagasaki	108	Statistics Division, Civil Life & Environmental Affairs Department
43	Kumamoto	104	Statistics and Research Division, Department of Planning and Development
44	Oita	104	Statistical Survey Division, Planning Promotion Department
45	Miyazaki	108	Statistics and Research Division, General Policy Planning Department
46	Kagoshima	106	Statistical Department
47	Okinawa	401×343	Statistics Devision, Department of Planning