ICES2019 March 19

Economic and Environmental impacts of carbon taxes and policy mixes of other instruments in East Asia to meet the 2050 2℃targets : An analysis using E3ME-FTT model

SOOCHEOL LEE

(Professor, Meijo University)

co-authored by

Hector Pollitt(Cambridge Econometrics)

Unnada Chewpreecha(Cambridge Econometrics),

CONTENTS

MEIJO UNIVERSITY FOUNDED 1926 NAGOYA JAPAN

cambridge econometrics

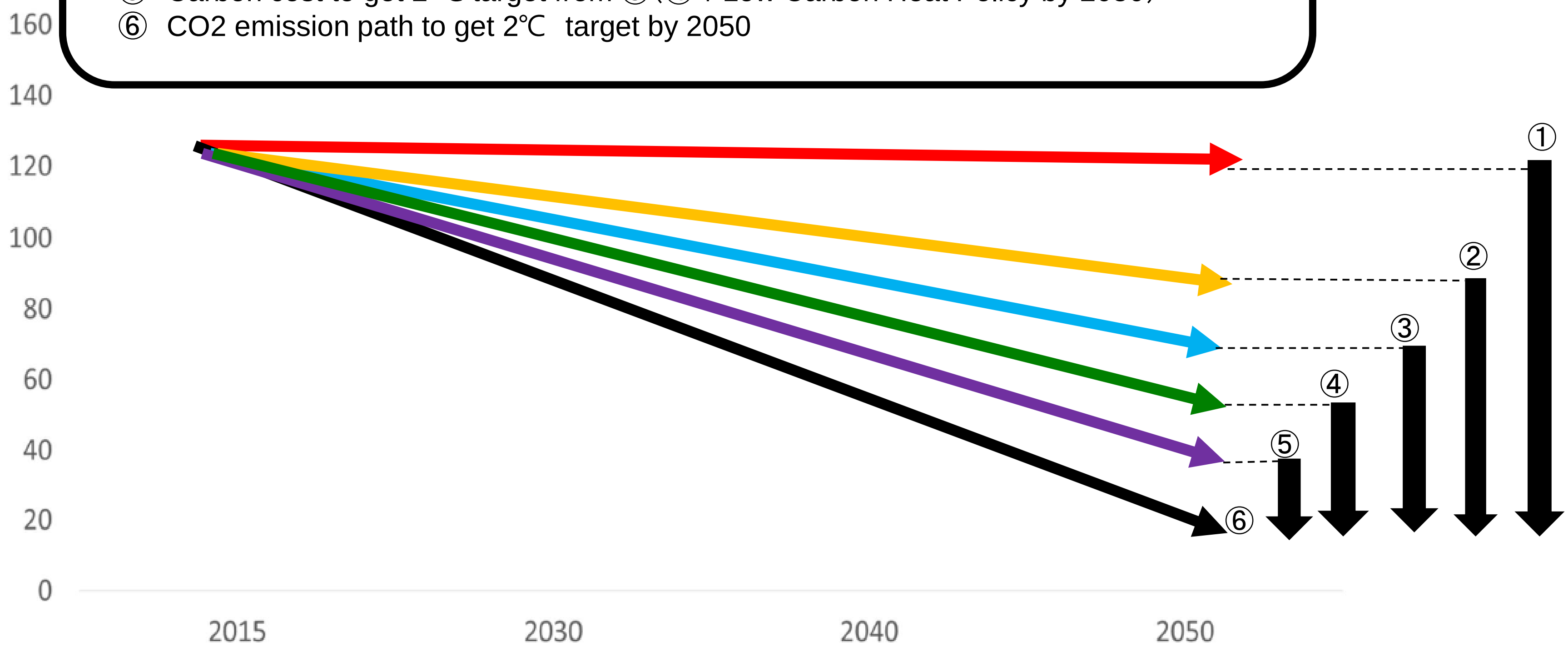
1. Research and Scenarios Overview

Research objective

Assess a range of climate policy options to achieve long-term decarbonisation targets and to show that a combination of instruments(not just carbon pricing only) is likely to produce the best results for national economies in East Asia.

Estimation of carbon cost to get 2℃ by the policy mixes target in 2050

① Carbon cost to get 2℃ target from the reference scenario by 2050
② Carbon cost to get 2 ℃ target from ②(the coal power regulation by 2050)
③ Carbon cost to get 2 ℃ target from ③(②＋Energy Efficiency Policy by 2050)
④ Carbon cost to get 2 ℃ target from ④(③＋Low Carbon Transport Policy by 2050)
⑤ Carbon cost to get 2 ℃ target from ⑤(④＋Low Carbon Heat Policy by 2050)
⑥ CO2 emission path to get 2℃ target by 2050



Long-term decarbonisation targets for 2050 in East Asia

	2050 target vs 2015 levels	BAU in 2050(IEEJ)
China	-50	8
Japan	-80	-30
Korea	-60	3
Taiwan	-70	-8

These targets are our own values as the countries in East Asia do not yet have formal targets except Japan for 2050 to be consistent with 2°C.

Policy inputs in the scenarios

	Carbon Tax	Power generation sector policies	Energy Efficiency in Industries	Transport policies	Heating policies
	✓	• feed-in-tariff • renewable subsidies • mandates to prevent new coal power plants being built	• ambitious taken from IEA's 450PPM scenario (IEA, 2016).	• fuels tax • registration tax • EV subsidies • biofuel mandate • new vehicle technologies boosted through procurement	• fuels tax • subsidies for new heating technologies • new heating systems are adopted initially in public buildings.

Role of carbon pricing in the scenarios

- Tax rate get adjusted in each scenario so the national emission reduction targets are met
- Levied on all use of fossil fuels in relation to carbon content
- Additional to rates in the baseline
- Linearly increase to 2050
- No exemptions
- No revenue recycling but part of revenues get used to fund renewable subsidies and energy efficiency investment

2. The E3ME-FTT Model

What is E3ME?

A computer-based global model for the economy, energy and environment, covering 59 regions

The model consists of collections of econometric behavioural equations and accounting identities

Based on an accounting framework and designed for projections for business and policy analysis

e3me

cambridge econometrics
clarity from complexity

www.e3me.com

E3ME: Key characteristics

- Macro-econometric model based on a post-Keynesian framework
- Optimisation not assumed
- Demand = Supply… but
- Demand <= Potential Supply
- Under the right conditions it is therefore possible to increase output and employment by demand side stimulation

What are the key dimensions & features of E3ME?

Detailed Coverage

- 59 regions (33 European, 26 World)
- 70/44 economic sectors and 42/28 consumption categories
- 23 fuel users of 12 fuels

Comprehensive

- whole energy, environment and economy system
- two way feedback between each module
- covers many policy instruments

Highly Empirical

- 1970-2016 database
- 28 econometric equations
- relationships validated from data
- econometrics allows for short-medium and long term analysis

Consistent

- based on system of national accounting
- input-output tables
- bilateral trade

Forward Looking

- annual projections to 2050
- behavioural equations with effects from previous outcomes
- ex-ante scenario analysis (ex-post is also feasible)

Modular

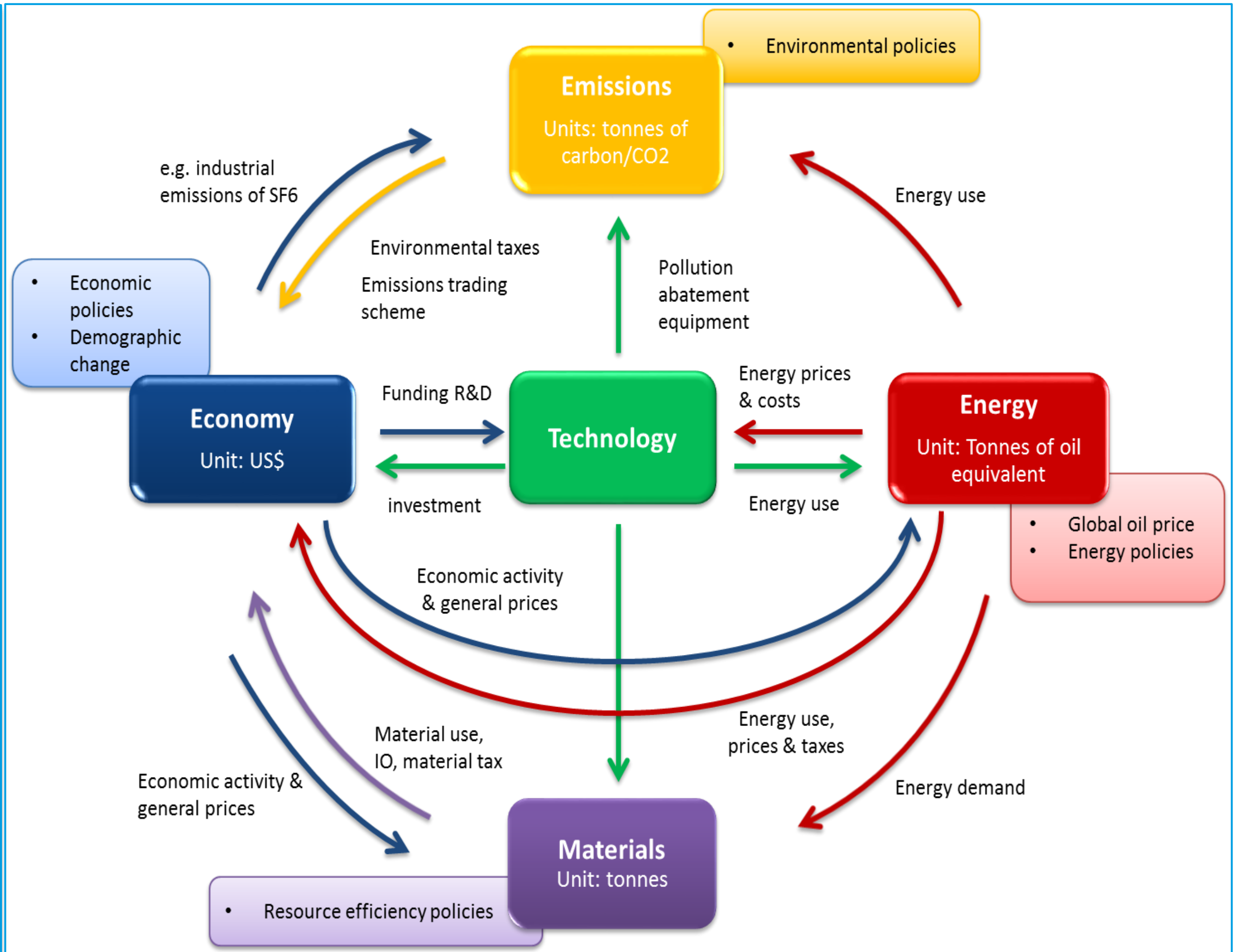
- E3: Energy, Environment, Economy and material modules
- power generation, transport and heat sub-modules
- research can be decentralised

om

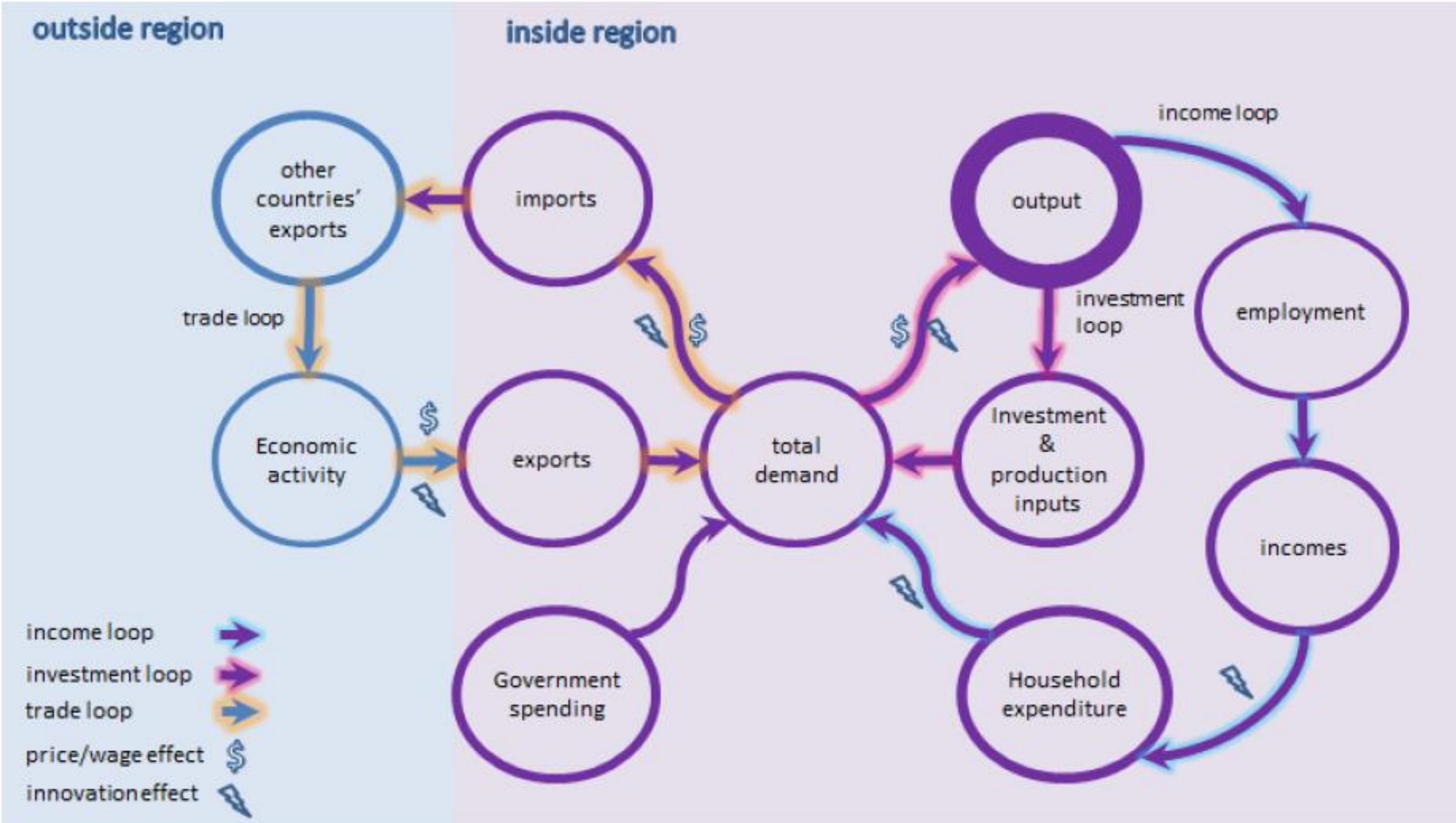
cambridge econometrics

E3ME as an E3 model

- Each component of the model is shown in its own box
- Exogenous factors are shown on the outside edge for each component
- The linkages between the components are shown by arrows that indicate which values are transmitted

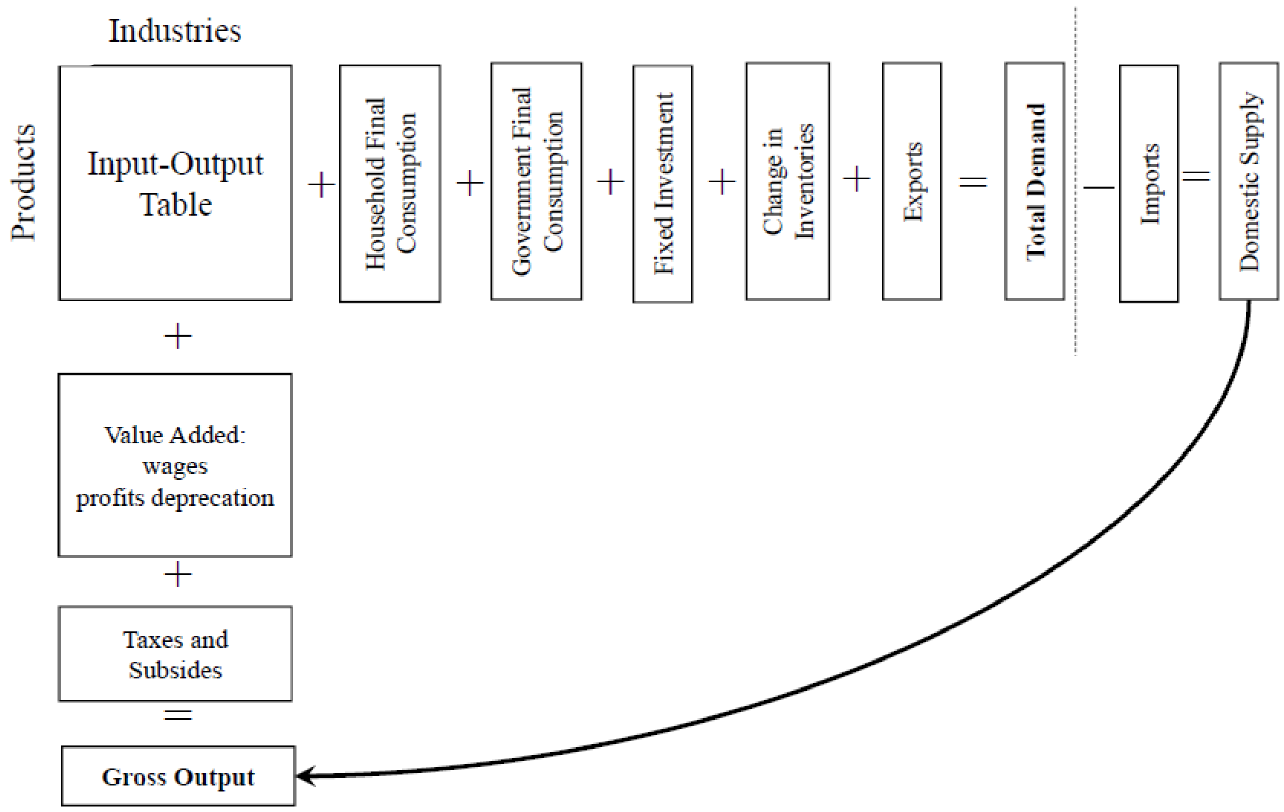


GDP determination in E3ME



cambridge econometrics

Linkage with I-O table in E3ME



Which macroeconomic models to use?

Simulations (econometrics)

- Facing with real world policy options
- Lack of perfect knowledge or foresight
- People don't always behave rationally!
- Responses to policy based on real world behaviours
- Post-Keynesian school of economic thinking

Optimisation (computable general equilibrium)

- Starting from already optimal outcome
- Known-end point
- Finding the least cost way of getting there
- Useful for resource allocations
- Neoclassical school of economic thinking

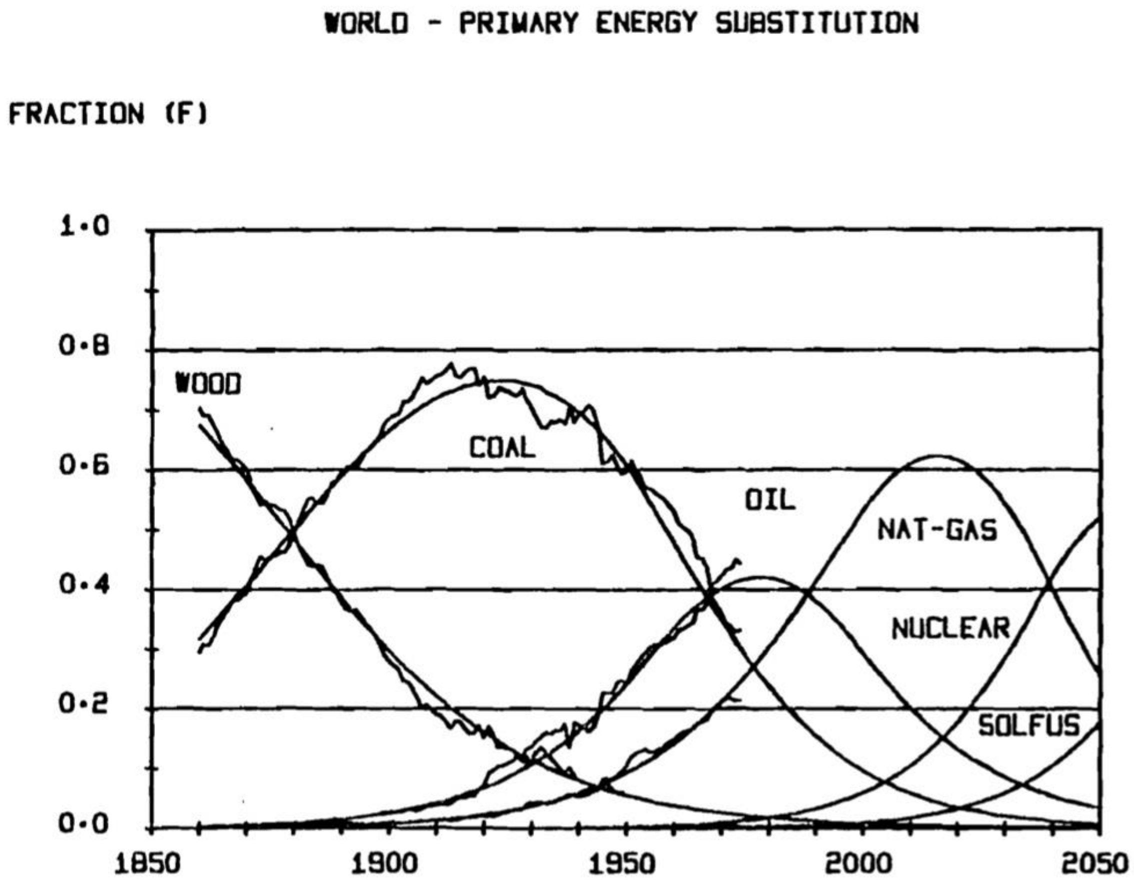
Linking E3ME to technology sub-modules

- Bottom-up model; econometric equations no appropriate for power generation because there is typically a small number of large plants and the econometric approach is not well suited for the development of new renewable technologies
- Current standard in energy systems modelling is by cost-optimisation/linear programming
  e.g. TIMES/MARKAL, MESSAGE, AIM, etc
- Are optimal scenarios the answer to the question asked?
- Is optimisation always what policy-makers find useful?

FTT Theory

- FTT:Power uses a decision-making core for investors wanting to build new electrical capacity, facing several options.
- The decision-making core takes place by pairwise levelised cost (LCOE) comparisons, conceptually equivalent to a binary logit model, parameterised by measured technology cost distributions.

The FTT models of technology diffusion



Marchetti & Nakicenovic *Tech. Rep. IIASA* (1978)
See also Technology and Global Change by Grubler

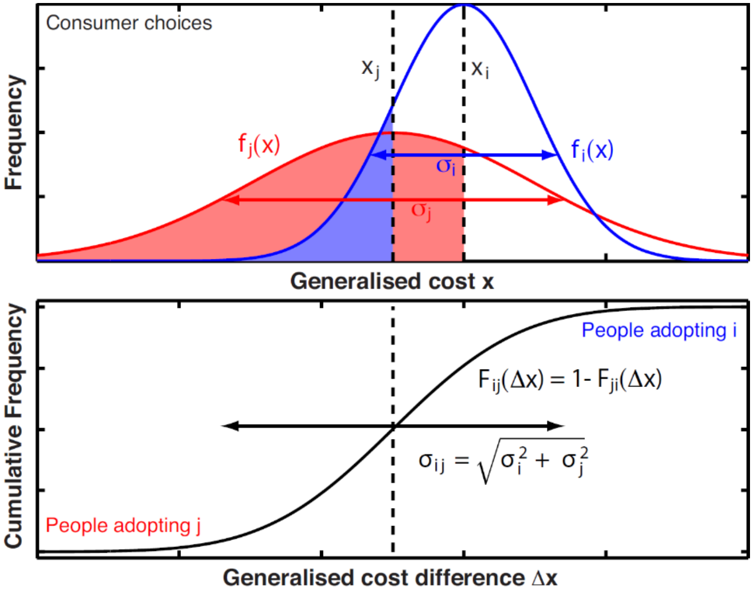
FTT Theory (cont)

- Costs include reductions originating from learning curves, as well as increasing marginal costs of renewable natural resources (for renewable technologies) using cost-supply curves.

- Due to learning-by-doing and increasing returns to adoption, it results in path-dependent technology scenarios that arise from electricity sector policies.

Technology shares determined by Aggregating every choices

$$\Delta S_i = \sum_j S_i S_j \left(A_{ij} F_{ij} - A_{ji} F_{ji} \right) \Delta t$$



J.-F. Mercure, Energy Policy 48, 799-811 (2012)

Si : Share of technology i

Aij : Life time of technology i and lead time of technology j

Fij : Probability that technology i would be chosen between i and j

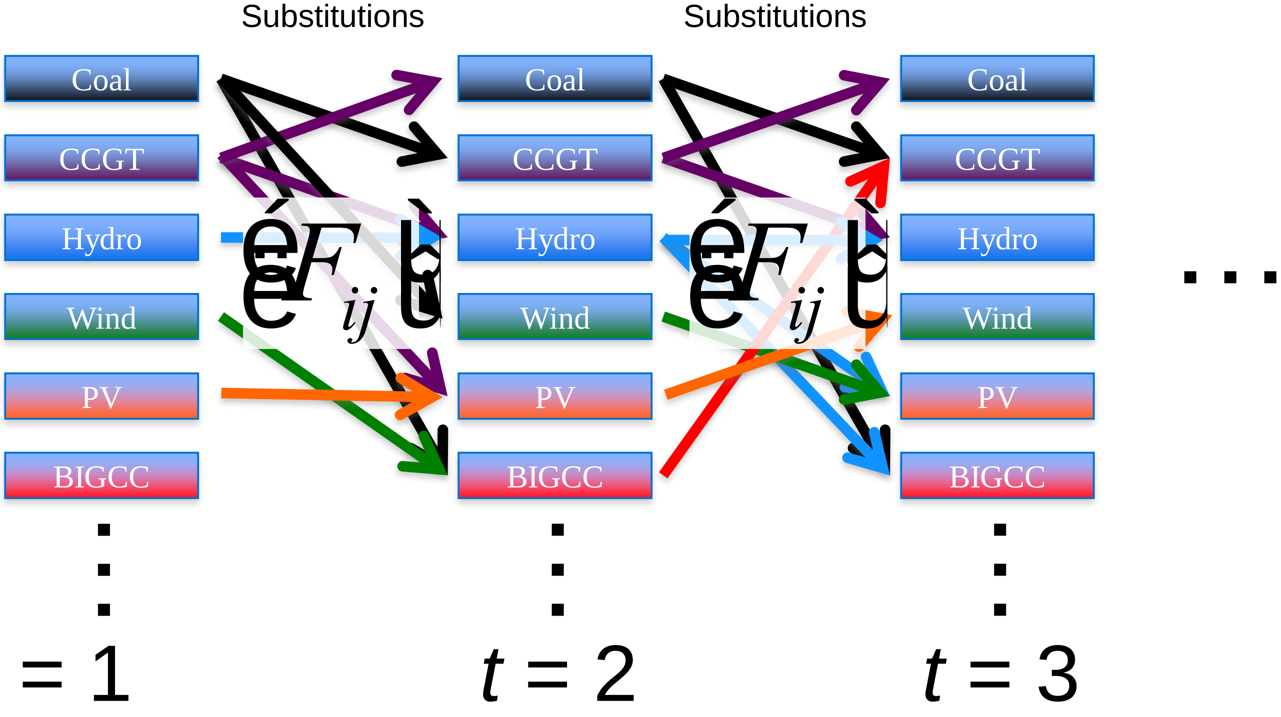
t : time

cambridge econometrics

Modeling technology substitution in FTT;Power

Simulates:

- The future replacement and diffusion
- Of power technologies
- By power generation sectors worldwide (59 world regions)
- Based on dynamical shares equations (the FTT method – no optimisation)
- Useful energy demand by country as an exogenous driver (depending on future levels of construction/gereration)



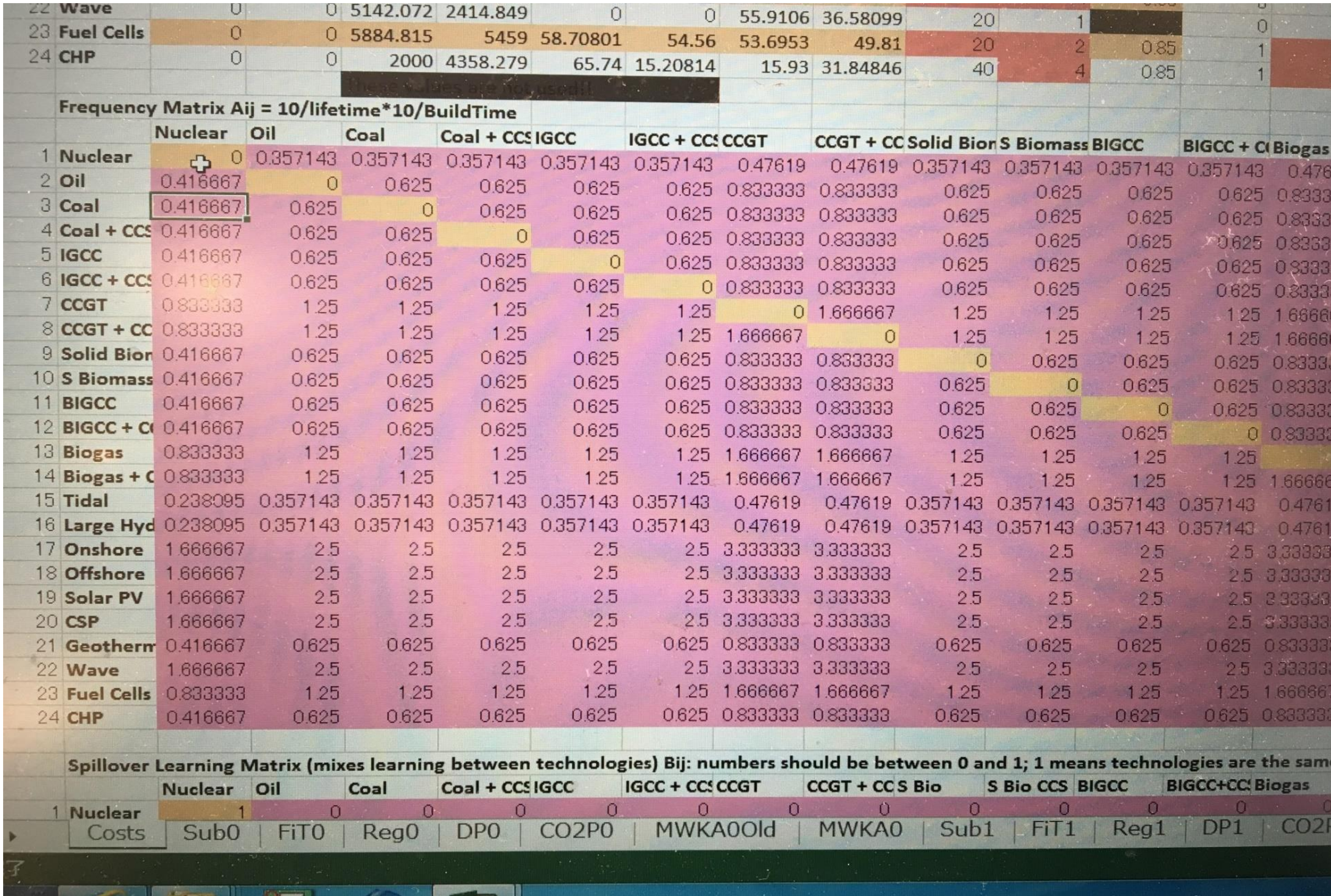
J.-F. Mercure, Energy Policy 48, 799-811 (2012)

cambridge econometrics

FTT-Power (LCOE – IEA 2016)

0	From: IEA Projected costs of generating electricity																	
	p.103	p. 62-63							p.43									
	Discount rate	10%	Rate increase price of carbon	1%	Starting price of carbon ($/t)				22.10	dD/D	15%	Es/D:		1%	Upeak/Utot	30%	Us/Utot	1% Negative all
	Carbon Costs	std	Overnight	std	Fuel	std	O&M	std	Lifetime	Lead Time	Load Facto	Type	LCOE	std	Fuel CO2	Efficiency	Emissions	Learning rat
	$/MWh	$/MWh	$/kW	$/MWh	$/MWh	$/MWh	$/MWh	$/MWh	years	years		0,1,2,3	$/MWh	$/MWh	kgCO2/GJ	%	tCO2/GWh	b
luclear	0	0	4896.00	1525.05	9.60	2.33	11.00	6.15	60	7	85%	1	109.95	34.41	0.0	100%	0.0	-0.086
)il	0	0	1227.84	1033.63	223.66	239.52	22.13	5.69	40	4	85%	1	265.34	256.04	73.3	45%	586.4	-0.014
'oal	0	0	2292.95	775.01	25.62	11.23	7.41	6.02	40	4	85%	1	69.54	25.08	99.4	43%	832.2	-0.044
'oal + CCS	0	0	4224.69	1172.55	22.43	10.23	15.02	4.55	40	4	85%	1	104.72	29.87	99.4	37%	96.7	-0.074
GCC	0	0	3829.06	1705.94	20.05	1.57	10.09	1.51	40	4	85%	1	91.11	29.34	99.4	42%	852.0	-0.044
GCC + CCS	0	0	4521.14	1523.05	19.96	7.50	12.87	0.52	40	4	85%	1	104.83	31.77	99.4	37%	96.7	-0.074
'CGT	0	0	1067.00	336.75	66.46	16.52	5.82	2.80	30	2	85%	1	88.23	21.79	56.1	57%	354.3	-0.059
'CGT + CCS	0	0	2446.53	520.63	71.20	1.47	6.42	0.40	30	2	85%	1	114.19	9.31	56.1	47%	43.0	-0.074
olid Biomass	0	0	4007.00	2587.47	93.24	72.94	18.55	26.53	40	4	85%	2	175.59	118.82	0.0	43%	0.0	-0.074
Biomass CCS	0	0	5938.74	2985.00	93.24	72.94	18.55	26.53	40	4	85%	2	206.35	125.15	-112.0	37%	-980.8	-0.105
IGCC	0	0	3829.06	1705.94	93.24	72.94	10.09	1.51	40	4	85%	2	164.30	100.12	0.0	42%	0.0	-0.074
IGCC + CCS	0	0	4521.14	1523.05	93.24	72.94	12.87	0.52	40	4	85%	2	178.10	97.19	-112.0	37%	-980.8	-0.105
iiogas	0	0	3733.00	3519.63	0.00	36.62	60.52	5.84	30	2	85%	2	116.32	89.69	0.0	57%	0.0	-0.074
iiogas + CCS	0	0	5112.53	3703.50	0.00	36.62	60.52	5.84	30	2	85%	2	136.94	92.44	-54.6	47%	-376.4	-0.105
mall Hydro	0	0	2782.50	3538.98	0.00	0.00	38.40	6.45	80	7	85%	3	89.04	70.86	0.0	100%	0.0	-0.020
arge Hydro	0	0	2492.50	2499.96	0.00	0.00	9.86	10.43	80	7	85%	3	55.21	55.92	0.0	100%	0.0	-0.020
)nshore	0	0	1841.00	443.49	0.00	0.00	21.38	8.67	25	1	30%	0	98.50	27.25	0.0	100%	0.0	-0.105
)ffshore	0	0	5000.00	579.58	0.00	0.00	40.71	19.82	25	1	42%	0	190.32	37.17	0.0	100%	0.0	-0.136
olar PV	0	0	1833.50	552.90	0.00	0.00	22.80	15.57	25	1	14%	0	187.39	65.20	0.0	100%	0.0	-0.269
'SP	0	0	4901.00	1859.10	0.00	0.00	17.38	22.10	25	1	55%	0	129.37	64.58	0.0	100%	0.0	-0.152
ieothermal	0	0	5822.50	2036.63	0.00	0.00	17.28	34.10	40	4	85%	3	109.99	66.53	0.0	100%	0.0	-0.074
Vave	0	0	5142.07	2414.85	0.00	0.00	55.91	36.58	20	1	46%	0	207.34	107.70	0.0	100%	0.0	-0.218
uel Cells	0	0	5884.82	5459.00	58.71	54.56	53.70	49.81	20	2	85%	1	205.17	159.93	15.3	80%	68.9	-0.234
'HP	0	0	2000.00	4358.28	65.74	15.21	15.93	31.85	40	2	85%	1	76.82	124.79	15.3	80%	68.9	-0.044
																	1 GWh = 3600 GJ	
requency Matrix Aij = 10/lifetime*10/BuildTime																		
	Nuclear	Oil	Coal	Coal + CCS	IGCC	IGCC + CCS	CCGT	CCGT + CCS	Solid Biom	S Biomass (	BIGCC	BIGCC + CCS	Biogas	Biogas + CCS	Small Hydro	Large Hydro	Onshore	Offshore

FTT Power   Frequency Matrix Aij = 10/lifetime*10/Build Time



22	Wave	0	0	5142.072	2414.849	0	0	55.9106	36.58099	20	1		0
23	Fuel Cells	0	0	5884.815	5459	58.70801	54.56	53.6953	49.81	20	2	0.85	1
24	CHP	0	0	2000	4358.279	65.74	15.20814	15.93	31.84846	40	4	0.85	1

[redacted]

Frequency Matrix Aij = 10/lifetime*10/BuildTime

		Nuclear	Oil	Coal	Coal + CCS	IGCC	IGCC + CCS	CCGT	CCGT + CC	Solid Bior	S Biomass	BIGCC	BIGCC + C	Biogas
1	Nuclear	0	0.357143	0.357143	0.357143	0.357143	0.357143	0.47619	0.47619	0.357143	0.357143	0.357143	0.357143	0.4761
2	Oil	0.416667	0	0.625	0.625	0.625	0.625	0.833333	0.833333	0.625	0.625	0.625	0.625	0.83333
3	Coal	0.416667	0.625	0	0.625	0.625	0.625	0.833333	0.833333	0.625	0.625	0.625	0.625	0.83333
4	Coal + CCS	0.416667	0.625	0.625	0	0.625	0.625	0.833333	0.833333	0.625	0.625	0.625	0.625	0.83333
5	IGCC	0.416667	0.625	0.625	0.625	0	0.625	0.833333	0.833333	0.625	0.625	0.625	0.625	0.83333
6	IGCC + CCS	0.416667	0.625	0.625	0.625	0.625	0	0.833333	0.833333	0.625	0.625	0.625	0.625	0.83333
7	CCGT	0.833333	1.25	1.25	1.25	1.25	1.25	0	1.666667	1.25	1.25	1.25	1.25	1.66666
8	CCGT + CC	0.833333	1.25	1.25	1.25	1.25	1.25	1.666667	0	1.25	1.25	1.25	1.25	1.66666
9	Solid Bior	0.416667	0.625	0.625	0.625	0.625	0.625	0.833333	0.833333	0	0.625	0.625	0.625	0.83333
10	S Biomass	0.416667	0.625	0.625	0.625	0.625	0.625	0.833333	0.833333	0.625	0	0.625	0.625	0.83333
11	BIGCC	0.416667	0.625	0.625	0.625	0.625	0.625	0.833333	0.833333	0.625	0.625	0	0.625	0.83333
12	BIGCC + C	0.416667	0.625	0.625	0.625	0.625	0.625	0.833333	0.833333	0.625	0.625	0.625	0	0.83333
13	Biogas	0.833333	1.25	1.25	1.25	1.25	1.25	1.666667	1.666667	1.25	1.25	1.25	1.25	0
14	Biogas + C	0.833333	1.25	1.25	1.25	1.25	1.25	1.666667	1.666667	1.25	1.25	1.25	1.25	1.666667
15	Tidal	0.238095	0.357143	0.357143	0.357143	0.357143	0.357143	0.47619	0.47619	0.357143	0.357143	0.357143	0.357143	0.47619
16	Large Hyd	0.238095	0.357143	0.357143	0.357143	0.357143	0.357143	0.47619	0.47619	0.357143	0.357143	0.357143	0.357143	0.47619
17	Onshore	1.666667	2.5	2.5	2.5	2.5	2.5	3.333333	3.333333	2.5	2.5	2.5	2.5	3.333333
18	Offshore	1.666667	2.5	2.5	2.5	2.5	2.5	3.333333	3.333333	2.5	2.5	2.5	2.5	3.333333
19	Solar PV	1.666667	2.5	2.5	2.5	2.5	2.5	3.333333	3.333333	2.5	2.5	2.5	2.5	3.333333
20	CSP	1.666667	2.5	2.5	2.5	2.5	2.5	3.333333	3.333333	2.5	2.5	2.5	2.5	3.333333
21	Geotherm	0.416667	0.625	0.625	0.625	0.625	0.625	0.833333	0.833333	0.625	0.625	0.625	0.625	0.833333
22	Wave	1.666667	2.5	2.5	2.5	2.5	2.5	3.333333	3.333333	2.5	2.5	2.5	2.5	3.333333
23	Fuel Cells	0.833333	1.25	1.25	1.25	1.25	1.25	1.666667	1.666667	1.25	1.25	1.25	1.25	1.666667
24	CHP	0.416667	0.625	0.625	0.625	0.625	0.625	0.833333	0.833333	0.625	0.625	0.625	0.625	0.833333

Spillover Learning Matrix (mixes learning between technologies) Bij: numbers should be between 0 and 1; 1 means technologies are the same;

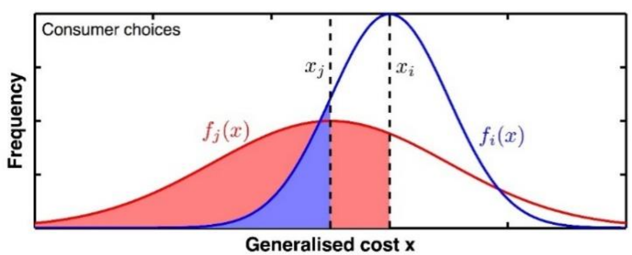
		Nuclear	Oil	Coal	Coal + CCS	IGCC	IGCC + CCS	CCGT	CCGT + CC	S Bio	S Bio CCS	BIGCC	BIGCC+CCS	Biogas
1	Nuclear	1	0	0	0	0	0	0	0	0	0	0	0	0

Costs | Sub0 | FiT0 | Reg0 | DP0 | CO2P0 | MWKA0Old | MWKA0 | Sub1 | FiT1 | Reg1 | DP1 | CO2P

Modeling technology substitution in FTT;Transport

新技術の導入：イノベーション – 選択 – 拡散

FCV (Fuel Cell Vehicle)
||
燃料電池自動車

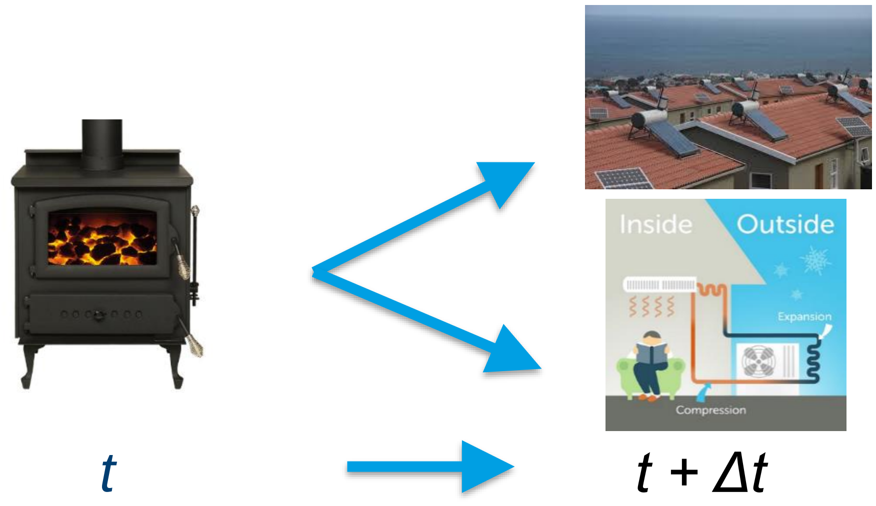


$$t \longrightarrow t + \Delta t$$

J.-F. Mercure, Energy Policy 48, 799-811 (2012)

cambridge econometrics

Modeling technology substitution in FTT;Heat



- Households replace their heating systems in time intervals related to technical lifetimes
- Choices are based on **Levelised Costs of Heating (LCOH):** combined measure of investment costs, fuel costs, and maintenance costs
- Calibration of these costs to observed preferences and trends: accounts for different comfort levels, local variations, existing policies etc.
- Behavioural assumptions: no switching back to less comfortable technologies

cambridge econometrics

FTT linkage with E3ME

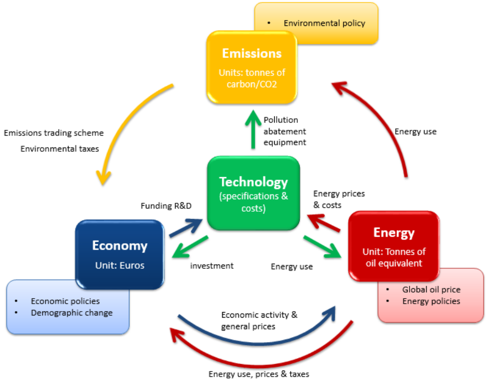
Post-Schumpeterian (evolutionary) — **FTT**

- product demand
- Fuel/Material demand

(FTT ↑ / ↓ E3ME)

- Fuel/Material consumption
- Investment in new production technology
- product price

Post-Keynesian — **E3ME** =



3. Modelling Results

REMINDER:
Policy inputs in the scenarios

	Carbon Tax	Power generation sector policies	Energy Efficiency in Industries	Transport policies	Heating policies
1	✓	×	×	×	×
A	✓	• feed-in-tariff	• low	• fuels tax	• fuels tax
B	✓	• feed-in-tariff • renewable subsidies	• moderate	• fuels tax • New vehicle efficiencies • EV subsidies	• fuels tax • subsidies for new heating technologies
C	✓	• feed-in-tariff • renewable subsidies • mandates to prevent new coal power plants being built	• ambitious taken from IEA's 450PPM scenario (IEA, 2016).	• fuels tax • registration tax • EV subsidies • biofuel mandate • new vehicle technologies boosted through procurement	• fuels tax • subsidies for new heating technologies • new heating systems are adopted initially in public buildings.

CO_2 reduction from 2015

	China	Japan	Korea	Taiwan
Target	-50	-80	-60	-70
Baseline(IEEJ) (2050, MCO2t)	8 (9706)	-30 (802)	3 (621)	-8 (239)

Max carbon tax rate = $1,500/t$CO_2$

CO_2 prices in each scenario, 2050

(2018 prices, $/t$CO_2$, additional to baseline)

	China	Japan	Korea	Taiwan
Baseline	0	0	0	0
S1 (C Tax)	1,500	1,500	1,500	1,500
S2 (+ Power)	717	1,200	1,100	1,000
S3 (+ En Eff)	300	850	500	750
S4 (+ Trans)	143	521	390	525
S5 (+ Hhold)	21	293	218	220

Impacts on GDP, % from baseline in 2050

	China	Japan	Korea	Taiwan
S1 (C Tax)	-0.7	-4.3	-1.6	-3.9
S2 (+ Power)	-0.6	-4.1	-1.2	-1.8
S3 (+ En Eff)	-0.1	-3.2	-0.8	-1.5
S4 (+Trans)	0.3	0.8	0.8	-1.2
S5 (+ Hhold)	0.3	1.0	1.0	-1.0

MEIJO UNIVERSITY FOUNDED 1926 NAGOYA JAPAN

cambridge econometrics

Impacts on sectoral output, % from baseline in 2050 (East Asia)

	S1	S2	S3	S4	S5
Agriculture	-2.0	-1.6	-1.4	-0.5	-0.3
Basic manufacture	-1.1	-0.9	-0.1	0.5	0.5
Advanced manufacture	-1.0	-0.8	0.2	0.9	1.0
Utilities	-6.3	-3.8	-11.2	-10.3	-10.0
Construction	0.5	-0.1	2.1	2.6	2.6
Services	-1.6	-1.3	-0.9	-0.1	0.1

MEIJO UNIVERSITY FOUNDED 1926 NAGOYA JAPAN

cambridge econometrics

4. Conclusions

- Each East Asian faces different challenges to decarbonize but can meet their long-term decarbonisation targets by carbon pricing only.
- But a broad range of policies, across all sectors is required
- Carbon pricing is a key element of the package but is not sufficient (at feasible prices)
- All of the other policies interact with carbon pricing, allowing emissions to be cut effectively
- GDP impacts will improve if other policies are implemented – or carbon tax revenues are recycled

List of FTT References

- FTT:Power: J-F Mercure, Energy Policy, **48** 799-811 (2012)
- FTT:Heat: Knobloch et al Energy Efficiency, https://link.springer.com/article/10.1007/s12053-018-9710-0 (2018)
- FTT:Transport: Mercure et al https://arxiv.org/abs/1702.04133 (2017)
- Energy resources database: Mercure & Salas, Energy, **46** 322-336 (2012)
- Consumption of non-renewable resources: Energy Policy, 63, 469-483 (2013)
- Economic impacts of decarbonisation: http://arxiv.org/abs/1310.4403
- Macroeconomic impact of stranded fossil fuel assets: Mercure et al, Nature Climate Change, Volume 8, pp 588–593 (2018).