Estimating Mitigation Costs of Greenhouse Gas from Agricultural Production: A Combined Top-down and Bottom-up Model of Korea

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Oh Sang KWON*, Sung Won KANG**, Seongho LEE*

*Seoul National University
** Korea Environment Institute

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Contents

(1) Introduction

- **Top-down climate change economic model**
  - Mostly based on CGE models
  - Single-country vs. Global, Static vs. Recursive Dynamic
  - Almost all variables are endogenously determined inside of the model
- **Bottom-up climate change economic model**
  - Mostly optimization models
  - Static vs. Dynamic
  - Prices are either endogenous or exogenous
  - Very detailed description of technology and resource endowments is allowed
  - Industry specific: many variables are exogenously given outside of the model

(1) Introduction

- **Linking or combining two approaches may help**
  - Taking advantages of two approaches
  - Soft link: two models are built-up independently, and run recursively
  - Hard link: an integrated model containing both TD and BU models
    - Run one-shot or recursively until reaching a convergence

(1) Introduction

- **Böhringer and Rutherford (2009)**
  - A very well known linkage model used for an electricity sector
  - TD determines prices ⇒ BU determines micro-level production levels given prices

    ⇒ Supply sector of TD is replaced by the outputs provided by BU

    ⇒ New prices are found by TD ⇒ BU finds new supplies, ⋯
- **We construct a BR linkage model with 2010 Korean Data**
  - Top-down model: a single country static CGE model
  - Bottom-up model: a multi-output quadratic agricultural sector model
  - Hybridization of micro and macro data

(1) Introduction

- **Why agricultural BU model?**
  - Agriculture occupies very small proportions of output and emission
    - The joint research team of KEI and several universities is constructing linkage models for electricity and other industries as well
  - It is uncertain whether the BR algorithm will work for a multi-commodity BU model
    - There are many commodities with different prices in agricultural sector
  - A calibration issue of the BU model
    - There are many micro units of production (i.e., production unit of each product in each region)
    - Unless the BAU production of micro units are recovered by the BU model, the whole linkage model converges to a "wrong solution"
    - BR is very unclear about calibration of the BU model
    - We combine the technique of PMP (positive mathematical programming) with CGE and show that applying PMP is essential in finding the "exact solution"

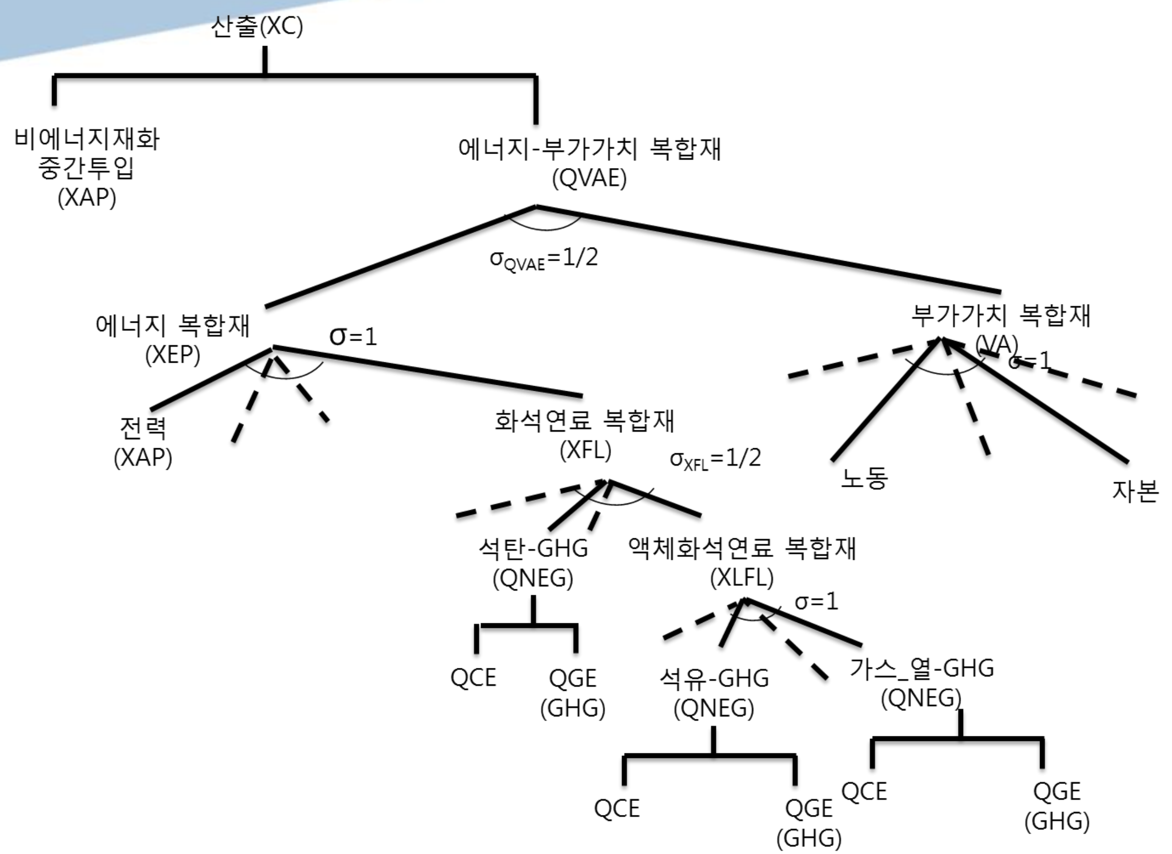
(2) Top down module

(2) Top down module

- Single country recursive dynamic CGE with trade
- 7 industry, 7 commodity, 1 household, 3 institutions
  - Calibrated share form of BR → level form
- Production: Böhringer and Rutherford (2009) industry definition and nesting structure
- Household consumption: Roy's identity from log utility function
  - Household savings : fixed share of disposable income + depreciation

(2) Top down module

- **Three institutions : Government/ Savings-Investment/ Rest of the world**
  - Government : Using tax revenue to finance government expenditure and transfer payment
    - Taxes : Production tax, tariff, income tax
    - Closure : Government saving adjusts to tax revenue
  - Rest of world : Using import revenue to finance export expenditure
    - Closure : Exchange rate adjusts to trade balance.
  - Savings-Investment: Collect savings to finance investment expenditure
    - Closure : Investment adjusts to savings level.
- **Data: 2010 basic price Input-Output table (Bank of Korea), 2010 Energy Balance (KEEI)**



(2) Top down module

Production function nesting structure

(2) Top down module

Industry

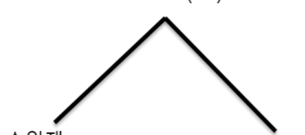
Model entry	Coverage
ELEC	Electricity
GAS-Heat	City Gas, LNG, Heat
OIL	Refinery product, Crude Oil
COAL	Coal, Coal product
ENIT*	Iron and steal, Cement, Organic chemistry, Mineral. Nonferrous metal, Transportation
NEINT	Wood and Paper, Fiber, Machinery, Electronics, Automobile, Shipbuilding, Food, Construction, Service
AGRI	Agriculture, Forestry, Fishery

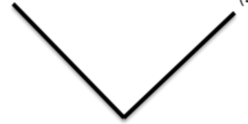
* ENIT: energy cost exceeds 5% of total cost

(2) Top down module

Trade

- **Rest of World : Revenue = import sales revenue, cost = export purchase expenditure**
  - Import- domestic demand: CES Armington composite
  - Export -domestic supply : CET transformation function
  - Foreign savings = Import sales - export purchase in domestic currency





Import-domestic demand

$$\min \quad PD_c XD_c + PMT_c XMT_c$$

$$s.t \quad XA_c = \alpha_c^q \left(\delta_c^q XD_c^{-\rho_c^q} + (1-\delta_c^q) XMT_c^{-\rho_c^q}\right)^{-\frac{1}{\rho_c^q}}$$

Export-domestic supply

$$\max \quad PET_c ES_c + PD_c XD_c$$

$$s.t. \quad XP_c = \alpha_c^t \left(\delta_c^t ES_c^{\rho_c^t} + (1-\delta_c^t) XD_c^{\rho_c^t}\right)^{\frac{1}{\rho_c^t}}$$

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(3) Bottom up module

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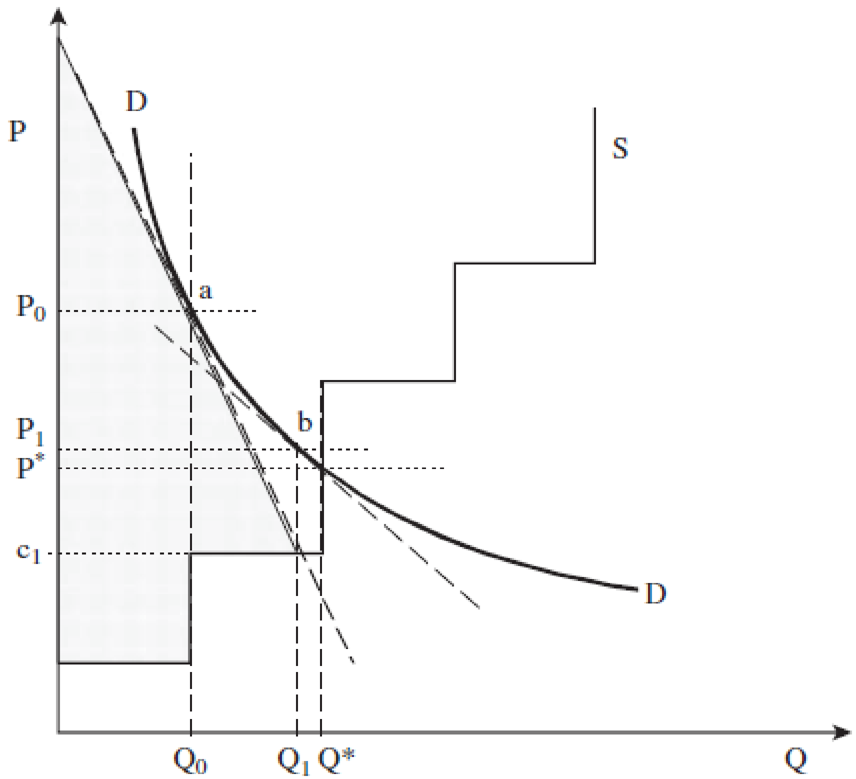
(3) Bottom up module

- **Multi product Quadratic Programing model**
  - Multi product : sum of consumer surpluses + producer surpluses of 13 agriculture products.
  - Regional choice : choice over output quantity of 13 products from 9 regions.
    - Each Ag output has 17 cost items
    - Each region has different unit costs
- **Data Construction : Input Output table (National) + Agricultural micro data (Regional)**
  - National input- output data : 2010 basic price Input-output table
  - Regional share : Agriculture, Food and Rural Affairs Statistics Yearbook (MAFRA), Regional Agriculture Income Statistics (RDA). Miscellaneous sources

(3) Bottom up module



- DD : Top down demand function (Q_0, P_0 : data)
- 1st approximation of DD at (P_0,Q_0): bottom up demand function
- Q_1 : Bottom up output
  - Q_0: lowest mc production option
  - Q_1-Q_0: Second lowest mc production option

(3) Bottom up module

Data and Equations

Data Construction

$$
\begin{aligned}
q_i^r &= S_{i,r}^q Q_i \\
x_{i,m}^r &= S_{i,m,r}^x X_{i,m} \\
v_{i,m}^r &= S_{i,m,r}^v V_{i,m} \\
\theta_{i,m}^r &= x_{i,m}^r / q_i^r \quad \text{or} \quad v_{i,m}^r / q_i^r
\end{aligned}
$$

- $Q_i, X_{i,m}, V_{i,m}$: Input-Output table
- $S_{i,r}^q, S_{i,m,r}^x, S_{i,m,r}^v$: Micro data

Quadratic Programming

$$
\begin{aligned}
\max_{q_i^r} \quad & \Sigma_i \bar{P}_i Q_i \left[1 - \frac{Q_i - 2\bar{Q}_i}{2\varepsilon_i \bar{Q}_i} \right] - \Sigma_i C_i(Q_i) \\
s.t. \quad Q_i &= \Sigma_r q_i^r, \quad q_i^r \geq 0, r = 1, 2, \cdots, R \\
C_i(Q_i) &= \Sigma_r c_i^r q_i^r \\
c_i^r &= \Sigma_m P_m \theta_{i,m}^r \quad m = 1, 2, \cdots, M \\
\Sigma_i \alpha_{ij}^r q_i^r &\leq \beta_j^r, \quad j = 1, 2, \cdots, J
\end{aligned}
$$

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(3) Bottom up module

Output, Cost, Region

	Model entry
Output (i)	Rice, Barley, Bean, Potato, Vegi, Fruit, Flower, MissCrop, (Crops) Dairy, Meat, Pork, Poultry, MissLstock (Livestocks)
Cost (m)	SEED, FERT, PEST, FEED, CUB, MED, ENERGY, WATER, SMACH, LMACH, FACIL,OINPUT, OSERV, (Intermediate Inputs) KCOST, LCOST, SUR, (Value Added) TW(Taxes and Residue)
Region (r)	GG(Gyunggi), GW(Gangwon), CB (Chungbook), CN(Chungnam), JB(Junbook), JN(Junnam),KB(KyungBook), KN(Kyungnam) JJ(Jeju)

(4) Hybridization

① Industry definition

② Top down module adjustment

③ Bottom up module adjustment

④ Linking module

(4)-① Industry definition

- **Top down module AGRI industry disaggregation:13 Agriculture industry**
  - Single price for AGRI doesn't make sense; Significant heterogeneity
    - Ex) Same price for Rice, Meat, Flower ?

- **Match Top down Agri industry = Bottom up Agri output**
  - Forestry and Fishery : relocate from Agri to EINT (energy intensive industry)
  - Threshing (Input Output entry): relocate from NIENT to rice (97.5%) and Barley (2.5%)

(4)-① Industry definition

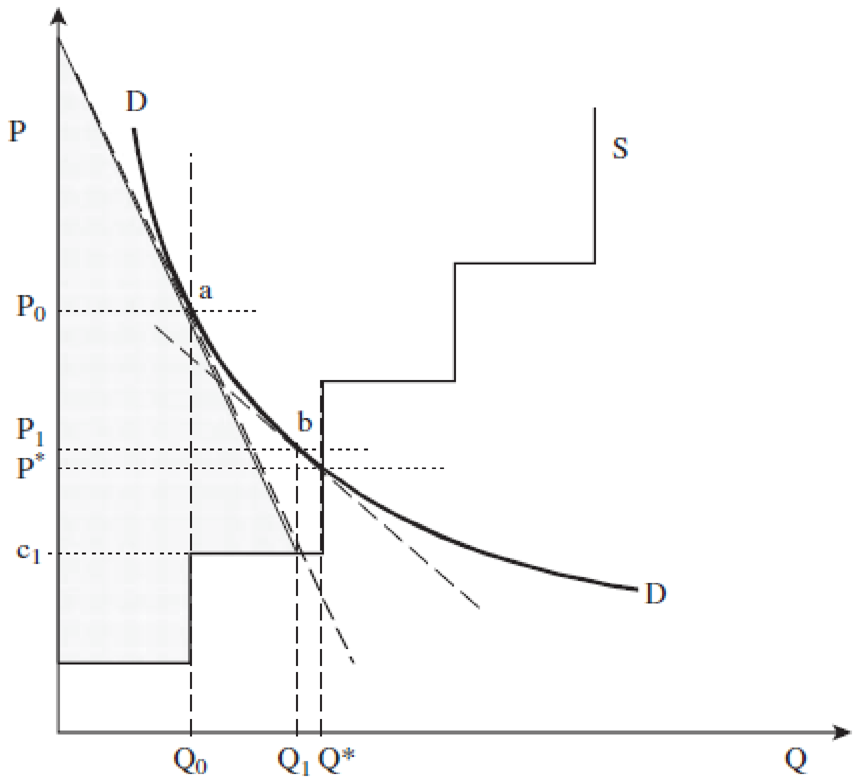
Input-Output		Hybrid model	Input-Output table		Hybrid model
1	Rice	Rice	14	Dairy	Dairy
2	Barley/other grain	Barley	15	Meat	Meat
3	Bean	Bean	16	Pork	Pork
4	Potato	Potato	17	Poultry	Poultry
5	Vegetables	Vegi	18	Other Livestock	MissLstock
6	Fruit	Fruit	19	Forestry	EINT
7	Medicinal crops	MissCrop	20	Wood	EINT
8	Other food crops	MissCrop	21	food forest product	EINT
9	Tabaco	MissCrop	22	Other forest product	EINT
10	Flower	Flower	23	Fishing	EINT
11	Rubber	MissCrop	24	marine farming	EINT
12	seed/ seedling	MissCrop	25	Agriculture service	NIENT
13	Other nonfood crops	MissCrop	42	Thrashing	Rice, Barley

(4)-② Top down adjustment

- Production quantity of 13 ag. Sectors are provide by the BU model
- Intermediate input demand of those 13 sectors are also provided by the BU model
- Value-added demands of the 13 sectors are also provided by the BU model
- There are no zero-profit conditions for those 13 sectors
  - Profits are determined by the BU model
  - Profits given by the BU model is distributed to the household

(4)- ③ Bottom up adjustment

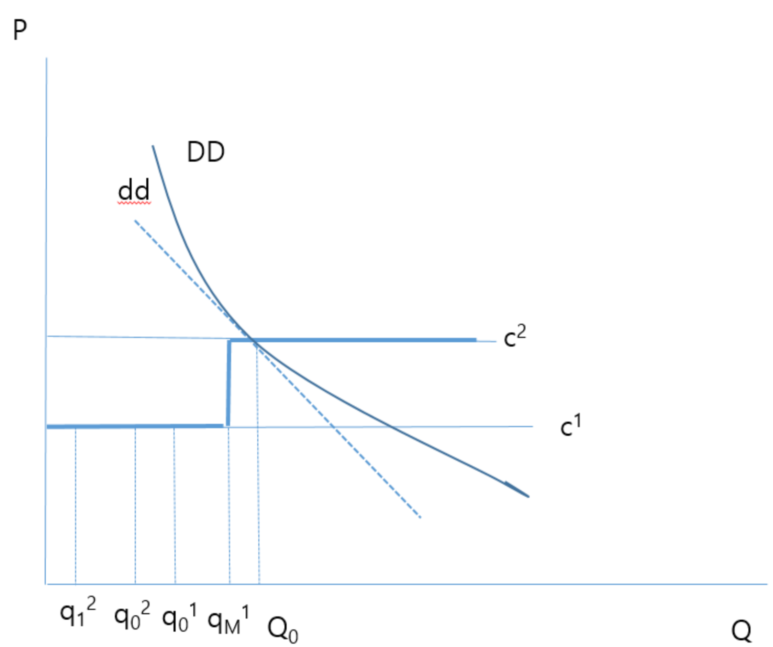
Bottom up in Hybrid model



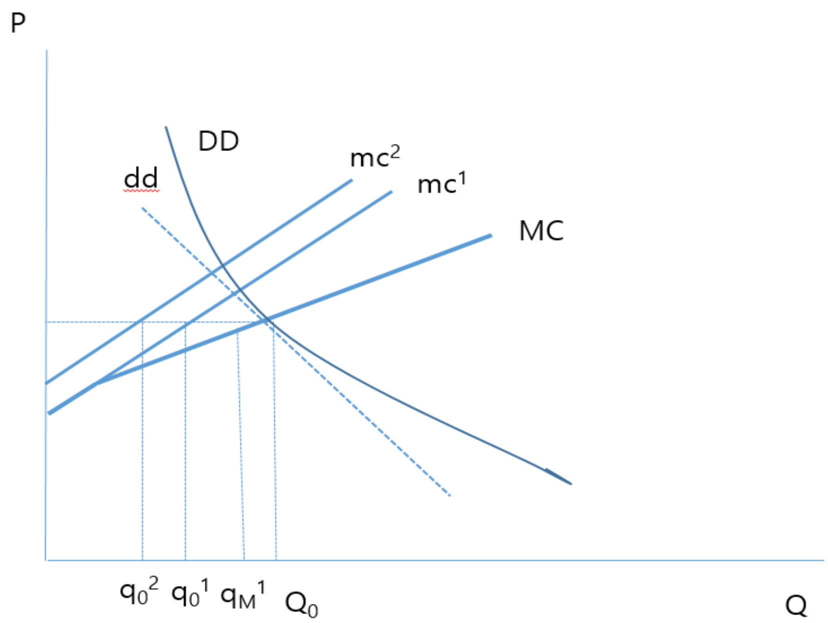
- DD : Top down demand function (Q_0, P_0 : data)
- 1st approximation of DD at (P_0,Q_0): bottom up demand function
- Q_1 : Bottom up output
  - Q_0: lowest mc production option
  - Q_1-Q_0: Second lowest mc production option
- In reality, each micro production unit does not produce up to its capacity limit (intro. PMP)

(4)- ③ Bottom up adjustment

As long as the MCs are constant, there is no way to recover the observed choice of each production unit.



q_0^1, q_0^2 : data ≠ q_M^1, q_1^2: Q. P. BAU solution



q_0^1, q_0^2 : data = Q. P. BAU solution

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(4)- ③ Bottom up adjustment

PMP in Action (1)

Model 1: Calibration constraints

$$
\begin{aligned}
\max_{q_i^r} \quad & \Sigma_i \bar{P}_i Q_i \left[1 - \frac{Q_i - 2\bar{Q}_i}{2\varepsilon_i \bar{Q}_i}\right] \\
& -\Sigma_i C_i(Q_i) \\
s.t. \quad Q_i &= \Sigma_r q_i^r, \quad q_i^r \geq 0, r = 1, 2, \cdots, R \\
C_i(Q_i) &= \Sigma_r c_i^r q_i^r \\
c_i^r &= \Sigma_m P_m \theta_{i,m}^r \quad m = 1, 2, \cdots, M \\
\Sigma_i \alpha_{ij}^r q_i^r &\leq \beta_j^r, \quad j = 1, 2, \cdots, J \qquad (\mu_j^r) \\
q_i^r &\leq q_{i,0}^r \qquad (\lambda_i^r)
\end{aligned}
$$

Model 2: quadratic cost function

$$
\begin{aligned}
\max_{q_i^r} \quad & \Sigma_i \bar{P}_i Q_i \left[1 - \frac{Q_i - 2\bar{Q}_i}{2\varepsilon_i \bar{Q}_i}\right] \\
& -\Sigma_i C_i(Q_i) \\
s.t. \quad Q_i &= \Sigma_r q_i^r, \quad q_i^r \geq 0, r = 1, 2, \cdots, R \\
C_i(Q_i) &= \Sigma_r \left(d_i^r + 0.5 e_i^r q_i^r\right) q_i^r \\
\Sigma_i \alpha_{ij}^r q_i^r &\leq \beta_j^r, \quad j = 1, 2, \cdots, J \qquad (\mu_j^r)
\end{aligned}
$$

(4)- ③ Bottom up adjustment

PMP in Action (2)

FOC of model 1 $MB_i^r(q) - c_i^r - \Sigma_j \mu_j^r \alpha_{i,j}^r - \lambda_i^r = 0, \mu_j^r \geq 0, \lambda_i^r \geq 0$

FOC of model 2 $MB_i^r(q) - d_i^r - e_i^r q_i^r - \Sigma_j \mu_j^r \alpha_{i,j}^r = 0, \mu_j^r \geq 0, \lambda_i^r \geq 0$

For FOC's to be equivalent at $q_{i,0}^r$

$$
\begin{aligned}
c_i^r + \lambda_i^r &= d_i^r + e_i^r q_{i,0}^r \\
d_i^r &= c_i^r \\
e_i^r &= \lambda_i^r / q_{i,0}^r
\end{aligned}
$$

(4)-④ Linking module

Export module

- Adjusted CGE + PMP BU model
- BAU linking model achieves BAU solution at the 1st iteration
- Both TD and BU solutions converge mostly within 20 iterations when a policy shock is introduced
- PMP procedure has another advantage of generating smoother responses to policy shocks

(5) A Policy Simulation

(5) A Policy Simulation

Overview

- Investigates mitigation costs of specific technological measures in agricultural production in Korea (non-energy source GHGs)
- Considers producer's response to the measure by using a BU agricultural sector model
- Make prices endogenous by linking the TD model with the BU model
- GHGs emission sources in agriculture (IPCC, 1996)
  - Rice cultivation: flooded rice fields
  - Domestic livestock enteric fermentation
  - Domestic livestock manure management
  - Agricultural soils
  - Field burning of agricultural residues

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(5) A Policy Simulation

Overview

- **Intermittently flooded irrigation**
  - In rice production
  - Reduces the scaling factor for water management
  - Reduces the emission coefficient by converting continuously flooded paddy fields (single aeration) into intermittently flooded faddy fields (multiple aeration), installing irrigation facilities
    - 1 and 0.83 → 0.66 (IPCC, 1997)
  - An increases in irrigation cost is necessary and incorporated into c_i^r in the BU model
    - Irrigation facilities cost + labor and operating costs per ha (RDA, Cho 2014), 630,000 Won/ha

(5) A Policy Simulation

Overview

- **Enteric Fermentation**
  - Reduces methane emission from digestion process, improving the quality of roughage
  - Applied to dairy and meat cows
  - Cost increase is calculated from the cost data
  - Meat cow methane reduces by 9kg per head a year
  - Dairy cow methane reduces by 24kg per head a year (RDA)

(5) A Policy Simulation

Overview

- **Manure Management**
  - Reduces emission coefficients of N2O by constructing and operating improved manure management facilities: purification, energy-conversion, …, but the exact instruments are unknown yet.
  - It is difficult to find construction cost data of manure management facilities, which are mostly supported by the government
  - Liquefying has the smallest emission coefficient (0.02 or 0.005 vs. 0.001) with additional costs (IPCC, 1996)
  - Each animal may need different liquefying cost, but we applied per unit cost of swine to all animals (cows, swine, and poultries) (2,000 Won/ton)
  - The policy assumed is increasing the share of liquefying by 100%

(5) A Policy Simulation

Overview

- Results

	Change in Amount	%
GDP	-9.0 (B. Won)	-0.001
Total CO2 eq	-2,078 (1,000 ton)	-0.374
Ag. CO2 eq	-2,080 (1,000 ton)	-12.306
Irrigation	-999 (1,000 ton)	-13.652
Enteric Fermentation	-773 (1,000 ton)	-18.142
Manure Management	-309 (1,000 ton)	-5.795

(5) A Policy Simulation

Overview

- **Results**
  - Only with 3 mitigation measures, a substantial amount of agricultural emission can be reduced
  - Marginal abatement cost is about 4,313 Won/ton, which is less than the anticipated CO2 permit price
  - Non-energy mitigation costs occupy relatively small shares in total cost
  - But there are some caveats because fixed facility costs often funded by the government are not completely incorporated into the simulation
  - Marginal abatement costs are smaller than the estimates from a stand-alone BU model (Kwon et al., 2015)

(6) Summary

- What we found
  - Decomposition technique can be applied to multiple output case
  - Both TD and BU module needs significant modification for hybrid model construction
  - PMP technique in BU module is quite helpful
  - Decomposition allows more production options in production
  - Marginal abatement costs of GHGs reduction in agricultural sector does not seem to be large

Thank you!

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