INDUSTRY RELOCATION FOR CARBON FOOTPRINT REDUCTIONS OF AUSTRALIAN CITIES THROUGH RECURSIVE LINEAR PROGRAMMING BASED ON INTER-CITY INPUT-OUTPUT MODEL

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ABSTRACT

Industry structure shifts contribute to carbon footprints relocation that could be integrated into carbon-reduction action. After the theory of industry adjustment is firstly presented in America and Japan, a practical application of long-term national planning IO-LP model in Japan is a necessary complement to market-oriented economies overall. Most IO-LP models study resource allocation, waste management and micro energy decision in developed and less-developed countries. Optimal industry shifts along with decision of changes in industrial carbon intensity and technology coefficients serve as accurate guidance for cities' carbon reduction action. Yet a clear industrial scheme meeting three principles simultaneously are not made by traditional analysis that explains emissions' drive and responsibilities. Here we develop novel inter-cities IO-LP models based on 2009 Australia inter-cities input-output table (IOT) earliest transferred from inter-cities supply and using table (SUT) to address optimal industrial shifts over cities attempting both growth and emissions reduction goal and decomposition of cities' industrial carbon budgets. Our IO-LP model is novel as the first practice of industry adjustment related to reduction in emissions in developed countries and inclusive of emissions constraints that CGE model is hard to do, and also avoids the corner solution that other optimal

models may meet. To overcome the limit of infeasible solution in normal optimization, it presents a two-tier IO-LP model. A multi-dimension recursive IO-LP model. Four scenarios help cities to make crucial strategies for an average annual 1.197% national reduction - the greatest decrease in output share by 0.1% for Energy in Melbourne companying 71 million ton emissions for Agriculture in Rest of Australia at the largest reduction by 5.7%, and the highest GDP resulted from Rest of Australia's 10% drop in carbon intensity for Agriculture and that in technology coefficients for Services- rather than solely megacities' energy-related industry emissions reduction in current research. The advantage is domestic final demands no lesser than the original, for which lower exports dependency is trade-off, whereas the forth scenario avoids lower exports if Melbourne's Goods drop 10% of carbon intensity, bringing forth the largest impact on national carbon intensity decreased by 0.6179% compared with other cities' industries.

1. INTRODUCTION

The vast majority of national governments submitted Intended Nationally Determined Contributions (INDCs) agreeing to substantial reductions in greenhouse gas (GHG) emissions to reach the goal of the Paris Climate Agreement (Schurer et al., 2018). Australia pledged for a 26%–28% (including LULUCF) economy-wide reduction in GHG emissions below 2005 levels by 2030 (DFAT, 2015). Although Australia managed to halve the carbon intensity from 1990 to 2012 (Australian Government, 2014), as the largest coal exporter in the world, it emitted more CO_2 from fossil fuel combustion than any other developed country (Leal et al., 2019). In the quest for finding carbon reduction pathways that could permit going beyond the traditional sector-based approach, attention has recently been shifted to cities as major centers of economic activity (C40, 2018; C40 and Arup, 2017). This is of interest to Australia, where 60% of the nation's population reside in the major coastal cities. In this context, urban carbon transformations have been also examined through spatial unraveling (Jones and Kammen, 2013; Jones et al. 2018; Hoornweg et al., 2011).

City-scale greenhouse gas (GHG) emissions can account not only the emissions of a city's area, but also the emissions that occur outside the area which can be attributed to activities within the city (Lin, et al.; 2015, Chavez and Ramaswami, 2013, Chen et al., 2016). The carbon footprints of Australian cities have been already calculated for the five largest cities (Chen et al., 2016a, Wiedmann et al., 2016), and the carbon links between them (Chen et al., 2016a; Chen et al., 2016b) based on a Multi-Regional Input-Output (MRIO) analysis (thought consumption-based accounts) (Chen et al., 2017).

The paper builds up an Australian inter-cities industry-by-industry (ixi) input-output (ICIIIO) model using linear programming to solve endogenous output satisfying optimal structure.

2. METHODOLOGY

It is the novel practice of inter-cities industry adjustment related to reduction in emissions in developed countries via inclusion of emissions constraints in the IO-LP model while the CGE model is hard to include the factor endowment and emissions constraints (López-Morales & Faye Duchin (2015), and the objective format of our model avoids the corner solution encountered by the optimal models that aim at maximum value-added (Liu, 2006) or final demands (Rose, 1996). To overcome the infeasibility of a solution in normal optimization, it presents a two-tier IO-LP model and a multi-dimensional recursive IO-LP model, which not only reflects the market-oriented economy as the CGE model, but also jumps to a more efficient economic system.

In the 1st tier IO-LP model, the optimal model (1) assures the feasible solution enables national carbon emission to be reduced by 1.197% per year but attains endogenous industrial output more or less than the base-year output. Despite strict constraints on production and carbon emissions in the 2nd tier IO-LP model, the optimal model (2) attains optimized output by inputting the updated export dependency rate deduced from model (1).

3 DATA

2009 Australia Environmental ixi ICIOT reflects the symmetric association between one industry and the next among various cities and embodied carbon during inter-city transactions – the earliest trial – transferred from Australian inter-city supply and use tables (IC SUT) and an matrix approach improved from Rueda-Cantuche (2011); Miller and Blair (2009); Rueda-Cantuche and Raa, (2009) in spite that those researches merely convey national SUT to national IOT. The IC SUT and IC IOT allow for the integration of multiple city scales. Australian IC SUT is close and supra-regional, representing Australia's national accounting commodity-by-industry (cxi) inter-industry transactions tables - the inter-cities cxi supply/making matrix and industry-by-commodity (ixc) using matrix (Chen, et al., 2018). It interprets the linkage of supply with commodity by industry among different Australian cities' area from making matrix or the network demand of industry for commodity over cities from the using matrix according to the Australian Industrial Ecology Virtual Laboratory (2016) (Wiedmann, et al. 2015, Bachmann et al. 2014). The inter-city transaction in the using table represent deliveries of 9 products to other industries in 5 different cites (e.g. Melbourne, Sydney, Brisbane, Adelaide, Perth), Rest of Australia and Rest of the World, or to final demand. The last two column-wise categories depict the products used in certain cities are produced by the industries in the rest of Australia and the rest of the world. It is equivalent to the imported products in these cities from the rest of Australia and those from the rest of the world in an open table. The total industry output is the sum of products input the industries, complementary imports and value added (broken in to Compensation of employees, Gross operating surplus & mixed income, Taxes less subsidies on products, Other taxes less subsidies on production for Australian cities and regions, into Consumption of fixed capital for Rest of the World). The last two row-wise categories depict the industries in certain cities who generate products for the rest of Australia and the rest of the world. It is equal to the exported products by the industry in the cities to the rest of Australia and those from the rest of the world in an open matrix.

The IC SUT suits consumed-based carbon footprint accounting (Arunima Malik, 2018), but the ixi IOT obtains increasing interest since it has merits on analyzing technology, inter-industry relations by the new System of National Accounts-SNA08 (UN, 2009). In light of this, the IO-LP models only use a symmetric ixi IC IOT to structure an optimal model towards a low-carbon economy. The initial transformed Inter-Cities IOTs is so-called close system which no export is from and import enter. In this table, the rest of the world is regarded as a region in intermediate part and final demand. Further it derives the open table in which the rest of the world is out of system of Australia， because the intermediate and final demand of rest of world is regarded as export, and the intermediate input of rest of world is regarded as part of value-added. The hybrid Australian Environmental ixi IC IOT table (table 2) accounts for the cities' carbon emissions in physical terms (transformed from energy consumed by energy resource discharging CO_2 equivalent) because cities attract the attention of many environmental economists. This enables the computation of the intensity of carbon emissions by industry. The table connects the value of the economic system to the quantity of consumed energy, which in turn relates directly to carbon emissions. The export is regarded as an item of final demand, and the import is excluded from the intermediate but enters value-added (including five cities and rest of Australia and the world). No studies transform from the IC SUT to the symmetric IC IOT. Our method is similar to the application of supra-country transformation (Erik Dietzenbacher et al., 2013), but more focus on the transformation from the cxi IC SUT to the symmetric IC IOT, supra-city transformation. Contrarily to the ixi SIOTs, the ixi table is closer to statistical databases and based on pragmatic assumption. But it is hard to identify the homogenous cost structure for energy industries which are usually composed of more secondary activities.

The ixi ICIO Table follows the simplest possible way deriving an ixi matrix, with the final demand in the Using Table remaining unchanged. According to the SUT in the simplest way, the key issue is reallocating items between rows rather than between columns. Two approaches can be derived from combining the information on input structures depicted by the use table at basic prices with the supply table so that all the secondary production (including the inputs used to produce them) are re-allocated either to the industry for which the product is a primary output (product technology, Model C) or to the main product of the industry that actually produces it (industry technology, Model D). Let us define ${}^{rl}\mathbf{U}=({}^{rl}u_{ij})$ $i, j = 1, . . ., n$ and $r, l=1,..., m$ as the use matrix of products i in region r consumed by industry j in region l, in dimensions of commodities (rows) by industries (columns), accounted as ${}^{1}\mathbf{q}={}^{1r}\mathbf{U}\mathbf{i}+{}^{1}\mathbf{f}$ and ${}^{r}\mathbf{x}'=\mathbf{i}'\,{}^{rl}\mathbf{U}+{}^{r}\mathbf{v}'$, where ${}^{1}\mathbf{x}$ is denoted as the column vector of industry output in region l; ${}^{1}\mathbf{q}$ as the column vector of product output in region l. ${}^{1r}\mathbf{V}$ is Make or supply matrix in a complete picture of the economy. Its row sums comprise the vector of total industry output, ${}^{1}\mathbf{x} = {}^{1r}\mathbf{V}\mathbf{i}$, and its column sums comprise total commodity output, ${}^{r}\mathbf{q}' = \mathbf{i}'\,{}^{rl}\mathbf{V}$. Its transposition is ${}^{rl}\mathbf{V}' = ({}^{lr}v_{ij})$ $i, j = 1, . . ., n$ and $r, l=1,...,m$ where product i in region l is produced by industry j in region r. In the making table, the last two column-wise categories depict the industries in certain cities produced products for the rest of Australia and the rest of the world. It is equivalent to the exported products in these cities from the rest of Australia and those from the rest of the world in the open table. The last two row-wise categories depict the industries in certain cities who purchase the products from the rest of Australia and the rest of the world. It is equal to the imported products by the industry in the cities to the rest of Australia and those from the rest of the world in the open matrix. Matrix ${}^{1r}\mathbf{D} = {}^{1r}\mathbf{V}\,{}^{1}\hat{\mathbf{q}}^{-1}$

is the market shares of each industry in region *r* to the product output in region *l* (supply table); and ${}^{rl}\mathbf{Z} = {}^{rl}\mathbf{U}^{r}\hat{\mathbf{x}}^{-1}$ as the input requirements for products in region *l* per unit of output of an industry in region *r* (use table). A sales structure approach is dependent on the producing industry. As the level of the product output becomes that of the industry output, the pattern of sales will however remain the same. Model D (fixed product sales structure) instead is clearly preferred for the transformation of SUT into IOT, thus an ICIIIO Matrix in the intermediate part is structured as

$$\mathbf{A_D}(\mathbf{U},\mathbf{V}) = {}^{lr}\mathbf{D}\,{}^{rl}\mathbf{Z} = {}^{lr}\mathbf{V}\,{}^{l}\hat{\mathbf{q}}^{-1}\,{}^{rl}\mathbf{U}^{r}\hat{\mathbf{x}}^{-1}$$

Final uses will have to change thus indicating now the intermediate and final demand associated with the industry supplying the products rather than with the commodities themselves, so they are equal to the gap between total industry output and intermediate output. Concerning the value added components, they remain unchanged because the level of the industry outputs will not be altered by the methods used for the construction of the SIOT. In a close IO system, the import and export are shown respectively as the row term of intermediate supply and the column term of intermediate demand. It is transformed from the structure of MR SUT including the rest of the world and, unlike most SUTs, reflects one country's transaction, and the export shown in column-wise final demand, and import shown as row-wise input.

4 RESULTS and DISCUSSION

It finds that reduction in share of Agriculture in Rest of Australia and Energy in Melbourne is crucial more than change in share of normal industries in other cities. Such structure shifts enable average annual 1.197% reduction in carbon emissions for national goal in the basic scenario, simultaneously each city's final consumer obtain more product of each type after adjustment. These will be satisfied at the same time only if a significant decrease in exports of Agriculture and Electricity. The 2nd and 3rd scenarios simulate changes in industrial carbon intensity and technology coefficients, resulting in that Agriculture in Rest of Australia and Goods in Melbourne and Rest of World are more deserved to renewable energy, but Food in Rest of Australia and Melbourne are considered to be advanced in high technology. It complements the mainstream comment about renewable electricity in Australia (Wolfram et al., 2016), the Australian electricity sector's transition to renewable energy (Howard et.al., 2018) and electrifying Australian transport (Wolfram and Wiedmann, 2017). It identify the key industry urgent for technological advance by comparing the updated solution to optimal structure and corresponding national carbon intensity with a 5%-20% decline of all input in a certain industry due to the adoption of advanced technologies, repeatedly, the model can capture the industry which advances its key technology when capital is limited.

In contrast with two tier IO-LP model, the recursive multi-dimension IO-LP model regards the beneficial of foreigner demand equal to that of the domestic user, and it examines with recursive search algorithm to what extent a 10% reduction in industrial carbon intensity in a city (i.e. Goods in Melbourne and Food in Rest of Australia) bring forth a decrease (by 0.618% and 0.618% respectively) in national carbon emissions within strict constraints at original export dependency rate, which help to build up an accurate plan of carbon reduction goal when Agriculture and Electricity is also import to Rest of World.

Two-tier model results in figure 4 suggest reducing Agriculture of Rest Australia and moving the energy out of Megacity like Melbourne and Adelaide to other less developed regions (such as Rest of Australia) and regions (Rest of Australia) and significant increase of service output and its share of Adelaide would help immensely. The model consider the carbon emissions annual reduction by 1.197%, there are an application of multi-cities input-output table in 2009. Electricity and Energy represent the highest and second highest carbon intensity industries the highest and third value-added rate to output. The output share of energy in Melbourne decrease by 0.12% (equivalent to 10% drop in output value), while the rest of Australia increase their output share of energy by 0.03% but a drop of 0.14% in output value for the rest of Australia. To counteract the GDP losses associated with this production decline as well as to decrease the carbon emissions, Australia should increase in the output share for service with the lowest carbon intensity and the second highest value-added rate, for example, in Rest of Australia by about 12% and at Melbourne by 0.06%, corresponding to a 22% and 0.06% drop in output value in above two regions. Agriculture’s share and value share of output need a 0.29% drop (namely a 5.72%

fall in output value) in the rest of Australia and by a 0.46% drop (corresponding to a 1.84% rise in output value) in Adelaide.

The result reveals that individual carbon budget at cities' industrial level in Australia. As separately industries among various regions, agriculture reduce CO_2 emissions to the largest extent by 5.7% (with 4.3 million ton) to 70.5 million ton in Rest of Australia, where Electricity has the largest emissions (85.9 million ton) with a 0.46% reduction (i.e. 0.39 million ton emissions), followed by Transport with the 0.35% decrease (namely 66.4 thousand to). With regard to cities, Melbourne as the largest energy-based emissions city decrease emissions of Electricity and Energy to the highest degree by 0.32% and 10% (at 30.5 million ton and 1.1 million ton) to 30.4 million ton and 9.6 million ton. However, Adelaide increase emissions of all industries, with the largest increase in CO2 emissions by 1.97% for Electricity (at 95.5 thousand ton).

Apart from the view of transition to renewable energy in Electricity and Transport (Wolfram and Wiedmann, 2017, Wolfram, et al., 2016), the multi-recursive model on the forth scenario with assumption of the international trade continuous finds that the largest decrease at 0.62%. in national carbon intensity is caused by a 10% reduction in carbon intensity for Electricity in Melbourne or Goods of Rest of Australia. So they should be decarbonized in prior to others industries of other regions, which is different from the result of two-tier model that decarbonization of Agriculture in Rest of Australia is super to that of others industries in other areas supposed the lower export rate. According to table 5, the industrial carbon intensity reduction in the two industries both by 10%, the total national intensity reduction that is called as synergy effects would be 1.24%. This combination should be the largest compared with the synergy effects of any other two industries over cities. Therefore, it is the most effective way to reduce national carbon intensity by choosing the industries from the list of comparative high percentage of reduced national CO2 intensity in the case of the same 10% decrease in the industrial CO2 intensity.