NBER PAPER

A Novel General Theory and Modelling Methodology of the Impacts of Trade Policies for Energy Goods and Costs of Carbon Emissions on Welfare, Distributional Impacts, and Income Inequality.

Abstract

The present study logically and scientifically constructs a novel general theory and modelling methodology for rigorously analysing the magnitudes, directions (signs), asymmetric versus symmetric dimensions, and transmission mechanisms of the long run and short run impacts of trade policies for energy goods on welfare, consumer versus producer economic surplus and income inequality in open economies. The logical deductive approach to scientific theorizing for the systematic explanation and understanding of the occurrence of an economic phenomenon is employed in the aforementioned construction of the theory of the aforementioned impacts and the corresponding modeling methodology. The "interactions among exported, import – competing, imported and non-traded renewable energy and non- renewable energy, agricultural and industrial goods and services products and factor inputs in an open economy are incorporated in the economic scientific analyses in this study. Aggregate consumer surplus is employed as an indicator of welfare in this study. Welfare distribution is indicated by the consumer surplus relative to the producer surplus in the economy under study, and income inequality in the economy under study, and income inequality in the economy as indicated by the proportion of income which accrues to the topmost (richest) twenty percent of income earners relative to that which accrues to the bottom-

most (lowest poor) forty percent of income earners in the economy under study in this study. Trade subsidies and tariffs (taxes) rates and the corresponding subsidy-equivalent and tariff-equivalent on non-tariff barriers and qualitative non-subsidy trade enhancers (inducers) on the aforementioned energy and non-energy goods and services are considered in this study.

Key words: Carbon emissions, distributional impacts, emissions costs, energy goods, modelling, optimization, trade policies, welfare.

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A Novel General Theory and Modelling Methodology of the Impacts of Trade Policies for Energy Goods and Costs of Carbon Emissions on Welfare, Distributional Impacts, and Income Inequality

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1. Introduction

The issues which have motivated the present study comprise the following: What are the likely impacts of trade policies for energy goods on the welfare distributional impacts and considering the interactions among the various sectors / subsectors in the income inequality in open economies? How can a novel general theory of the aforementioned impacts, and the corresponding modelling methodology which can be employed to quantify and scientifically validate these impacts based on real world empirical data be constructed logically? These are the research questions which this study addresses.

The objectives of this study are to construct a novel general theory of the impacts of trade policies for energy goods on welfare distributional impacts and income inequality. Specifically, this study quantifies the magnitudes and directions (signs) of these impacts and their implications. It also constructs a modelling methodology which shows how the quantification and scientific validation of these impacts can be conducted based on real world empirical data. It is general enough to be applicable to open economies globally including the United States economy.

The organization of this study is in four sections. In Section 2, this study's novel general theory of the aforementioned impacts is constructed. The theoretical results which emerge from this

theory are summarized in a number of theorems with their formal proof. The corresponding novel modelling methodology is constructed in Section 3. Concluding remarks are finally made in Section 4.

2. The significance of this study

The theme of the present study is justified by virtue of the following reasons. In the first place, the need to drastically curtail carbon emissions so as to limit inordinate increases in temperatures, which have been identified as the principal cause of global warming and adverse climate change, have in turn stimulated the need to substitute environmentally-friendly renewable energy for fossil – based energy (Masson-Delmotte 2021, Davariashtiyani, et. al., 2023, Russo and Damiesen, 2023). The renewable energy types include solar, wind, liquefied natural gas and biofuels inter alia. The non – renewable energy types comprise fossil – based energy like coal, crude oil, petrol, diesel and liquefied petroleum gas, inter alia. The present study which focuses on these energy goods is thus relevant.

Second, in order to accomplish this energy transition, economies have designed and implemented various forms of trade policies for energy goods. The current export policies for liquefied natural gas, carbon tariffs, and trade policy restrictions on solar panel components are exemplars of these in the United States. Hence, to the extent that the present study researches an important aspect goods, this study is current and important.

Third, since it is likely that goods (viz., export subsidies are taxes, export quotes, export fiscal and monetary incentives, inter alia, import tariffs, import subsidies import quotas, inter alia for energy goods will influence welfare in aggregate and distribution consumer economic surplus

relative to the producer economic surplus, and income inequality the need arises for logical scientific rigorous analyses of these impacts. However, a general theory and its corresponding modelling methodology accomplishing such impact analyses are virtually inexistent in the body of the received knowledge in the economic sciences: see for instance, Pindyck 2013, Fried et al 2018, Fernandez-Villaverde et al 20123, Fried et al 2024, Kotlikoff et al 2021b 2024). However, it needs to be emphasized that reduced-form analyses of a related problem have been undertaken (Burke et al. 2015, Carleton 2022, Tol 2023). Other approaches have also been undertaken (Dasgupta and Heal 1974, Hassler, et. al., 2016 2018, Gillingham, et. al., 2018, Egli 2018, Desmet and Rossi-Hansberg 2024, Hassler et. al., 2024). The present study which contributes significantly to narrowing these knowledge gaps is thus imperative.

By way of drawing the curtain, it is important to underscore the point that the aforementioned theory and its corresponding modelling methodology which are constructed in the present study are so general as to be applicable to economies globally including the United States economy. Moreover, the theme of the present study is firmly located on the front burners of the scientific research and policy makers and practitioners' communities. The present study is therefore significant.

3. THE NOVEL GENERAL THEORY

The logical deductive theorizing process of constructing objective, cogent, systematic, internally consistent, authentic, fruitful general scientific theory to explain and accomplish a thorough understanding of the occurrence of a phenomenon is employed to construct a novel general theory of the impacts of the trade policies for energy goods on welfare and their distributional consequences. This deductive theorizing process comprises a formal statement of the theory's axioms (viz., the maintained postulates), a formal statement of the optimization problem desired to be solved by economic agents in the economy under study, and the solution of the optimization problem which essentially comprise the set of hypotheses which direct the study and constitute the

initial answers to the questions which motivated the study. These hypotheses are those which are validated by using the relevant real-world empirical information. The hypotheses which are observed to be validated (viz., statistically significant) using the Relevant empirical information then constitute the explanation of the occurrence of the Relevant phenomenon under study.

The present study postulates the existence of a transformation function which summarises the production structure of the economy under study. It also postulates the existence of a consumer utility function. Another axiom of the present study is the existence of a welfare function. This study additionally maintains the existence of a consumer surplus function, producer surplus function, and an income inequality function which are employed in this study to quantify the distributional consequences of the trade policies for energy goods and linkage to welfare in an open economy under study. The details of these axioms are as follows.

AXIOM 1: THE NOVEL TRANSFORMATION FUNCTION

Suppose that there exists a transformation function which summarises the production structures of the economy under study. Moreover, this transformation function is an implicit mathematical function which has the physical quantities of the vector of outputs product produced in this economy and the physical quantities of the vector of factor inputs employed to produce these outputs (products) as its arguments.

Denote the vector of outputs (products) quantities as qe(.)*x*, qe(.)m, qe(.)nt; q_{jx}, qjm, and q_{joot}; these are generally denoted as qe., qj.. The subscripts are given e. = (e(r)x, e(nr)m, e(nr)m, e(r)nt, e(nr)nt.), where e(r) and e(nr) denote renewable and non-renewable respectively. The subscript; respectively denote non-energy goods: j = (agricultural(a)), industrial(I) and services(s); and *x*, m, nt denote exported, imported-completing (or imported) and non-treated goods and services respectively.

Denote further, the vector of factor input quantities as **ƶ;,e. ;ƶi, j.,** where ƶi,. denote the ***i*** the factor input quantity and e. ; j. are al already indicated in the previous paragraph. Stated formally and succinctly, the aforementioned transformation function is given by (1):

$$\mathbf{T(qe., qj., ƶi,e. ƶi,j., kp) = 0 \quad (1)}$$

Where the arguments of T(.) are as already indicated. $\frac{\partial T(.)}{\partial q.} > 0 \; and \; \frac{\partial T(.)}{\partial \neq i} < 0, \; and \; \frac{\partial T(.)}{\partial K_P} < 0;$ and K_P denoted the producer-induced carbon emissions. The other generality conditions for the existence of a well-behaved transformation function are herein postulated to exist as well.

AXIOM 2: THE NOVEL CONSUMER UTILITY FUNCTION

Suppose the economy's consumer utility function is given by (2): $\cup = \cup \left(q_{j.}, q_{e.}, q_e : K_c, gK_P\right)$ (2) where q; and q_e. Respectively denote the physical quantities of the goods and services produced and consumed by the consumers in the economy under study. The subscripts ;. and e. are as already indicated. Moreover, $\frac{\partial \cup(.)}{\partial q_{j.}} > 0 \; and \; \frac{\partial \cup(.)}{\partial qe.} > 0 \; and \; \frac{\partial \cup(.)}{\partial K_C} < 0.$

K_C denotes the volume of consumer-induced carbon emissions. The other generality conditions for the existence of a well-behaved consumer utility function are postulated to exist in the economy under study in the present study.

AXIOM 3: THE TRADE POLICIES FOR ENERGY AND NON-ENERGY GOODS AND THE RELEVANT DOMESTIC PRICE

This axiom concerns the trade definitions of the policies for energy good and for non-energy goods and services. It further concerns rates on instruments of the relevant trade (export and import) policies and the tariff- (tax-) equivalents on non-tariff (non-tax) trade enhancers as well as the subsidy-equivalents on non-subsidy rated enhancers (induce) of trade. Exported and imported goods and services are considered here. The relevant domestic prices are given by (3d') – (3d``):

$$P_{e(.)x} = P_{e(-)xf} \; E \begin{pmatrix} 1 + S_{e(.)x} \\ 1 - Tex \end{pmatrix} \qquad \begin{matrix} (3d') \\ (3d'') \end{matrix}$$

$$P_{e(.)m} = P_{e(-)mf} \; E \begin{pmatrix} 1 + T_{e(.)m} \\ 1 - Se(.)m \end{pmatrix} \qquad \begin{matrix} (3b') \\ (3b'') \end{matrix}$$

$$P_{jx} = P_{jxf} \; E \begin{pmatrix} 1 + S_{jx} \\ 1 - T_{jx} \end{pmatrix} \qquad \begin{matrix} (3c') \\ (3c'') \end{matrix}$$

$$P_{jm} = P_{jmf} \; E \begin{pmatrix} 1 + T_{jm} \\ 1 - S_{jm} \end{pmatrix} \qquad \begin{matrix} (3d') \\ (3d'') \end{matrix}$$

$P_{e(-)x}, P_{e(-)m}$ denote the Respective domestic prices of exported, imported, and import-completing energy goods; $e(.)x = e(r)x, e(nr)x;\ \ e(.)m = e(r)m, e(nr)m; e(r), e(nr)$. denote Renewable and non-Renewable energy. P_{jx}, P_{jm} denote the Respective domestic prices of exported, imported or imported-competing non-energy goods; j = agricultural (a), industrial (J), and services (SS). $P_{e(.)xf} s P_{e(.)mf}, P_{jxf}, P_{jmf}$ are corresponding foreign (global) prices. $S^{sj.}_{e(.).}, T^{tj}_{e(.).x}$ are the Respective subsidy Rate and the tariff (tax) rate, and subsidy equivalent and tariff-equivalent Rates on non-tariff trade barriers and enhancers (inducers) on energy goods and non-energy goods. Denote the analogues of (3d') – (3d'') for factor inputs as $r_{i,.}, S_{i,e(.).}, T_{i,e(.).},, S_{i,j.}, T_{i,j.}$, where ***i*** denotes the ***i*** th factor input.

AXIOM 4: THE CONSUMER BUDGET EQUATION

The consumer budge equation is given by ( ):

$$Y = \sum_{e(.).} P_{e(-).}\, q_{e(.).} + \sum_{j.} P_{j.} q_{j.} \ + \sum_{e(-)nt} P_{e(.)nt} q_{e(.)nt} + \sum_{jnt} P_{jnt} q_{jnt} \ + K_C K_C + K_P K_P \quad (4)$$

$(e(.) = e(r).,e(nr).\ ; e(.).= e(.)x, e(.)in) - (j.= jx, jm\ ; j =$ agricultural(a), industrial (J) and services (SS). Where Y denotes consumer income; K_C denotes the unit costs of consumer – induced carbon emissions and producer-induced carbon emissions, K. denote the perspective volumes of carbon emissions; and all the other variables are as already indicated (K. = K_C .K_P).

AXIOM 5: THE NET BENEFITS FUNCTION

This study further postulates that there exists on net benefits function for the economy under study. Denote this net benefits functions as B = B(.). Conceptually, this function is given by (5):

$$B = B(.) = \sum_{e(.).} P_{e(.).} q_{e(.).}$$

$$+ \sum_{j.} P_{j.} q_{j.} + \sum_{e(.)nt} P_{e(.)nt} q_{e(.)nt}$$

$$+ \sum_{jnt} P_{jnt} q_{jnt} - wl$$

$$- \sum_{i,e(.).} r_{i,e(.).} \bar{Z}_{i,e(-).} - \sum_{i,j.} r_{i,j.} \bar{Z}_{i,j-}$$

$$- \sum_{i,jnt} r_{i,jnt} \bar{Z}_{i,e(.)nt}$$

$$- \sum_{i,jnt} r_{i,jnt} \bar{Z}_{i,jnt}$$

$-K_C K_C - K_P K_P$ (5)

Where **w** denotes the wage Rate, **L** denotes the volume of labour demands, $\mathbf{r_{ij}}$ denotes the **ith** factor input price; all the other variables are as already indicated. The net benefits B is the algebraic difference between gross benefits and gross costs, where the gross costs comprise gross costs of factor inputs and gross costs of consumer-induced carbon emissions and producer-induced carbon emissions.

AXIOM 6: THE WELFARE FUNCTION

Another axiom of the present study is that there exists a welfare function W = w(.) in the economy under study. It is further postulated in the present study that the existence of this welfare function is premised on the prevalence of the Rawlinson general equilibrium condition in the economy under study. It is additionally postulated that unversed demand and inverse supply functions $q_{l,d}^{-1}\ (P_l, T_d)\ and\ q_{l,s}^{-1}\ (P_l, T_s)$ respectively for the l th good or service exists in such a Rawlinson economy, and that the corresponding equilibrium quantity exchanged q_l also exists in this economy.

Notably, $\boldsymbol{p}$ denotes the own price of $\boldsymbol{q}$, whereas $\mathbf{T_d}$ denotes the vector $\boldsymbol{l}$ of shift factors of this inverse demand function and $\boldsymbol{T_s}$ denotes the vector of shift factors of this inverse supply function. denote the existing corresponding equilibrium price as $\boldsymbol{T_l}$. The present study formally conceptualisers welfare $\boldsymbol{w}$ as the algebraic sum of the excess of the amount which the producers of goods and services in the community under study are willing to pay for these goods and services over and above the amount which then vendors of these of goods and are willing to received, given the equilibrium price and quantity $\left(\tilde{P}_l, \tilde{q}_l\right)$ and the existence of the aforementioned maintained postulates. The strength of this concept of welfare is amendable to logical opertionalisation. The study further argues that upon fruitful operationalization, the operationalized components can be linked to appropriate real-world referents to facilitate the relevant objective scientific measurements in an innovative novel manner. Based on the present study's conceptualization of welfare, this study's welfare function is postulated as formally given by (6):

$$w = w(.) = \sum_l \int_0^{\tilde{q}_l} q_{l,d}^{-1}\ (P_l, T_d) dq_{l,d}$$

$$-\sum_l \int_0^{\tilde{q}_l} q_{l,s}^{-1}\ (P_l, T_s) dq_{l,s}$$

$$l = e(r)x, e(nr)x, e(r)m, e(nr)m, e(r)nt, e(nr)nt; jx, jm, jnt$$

Where all the variables and symbols are as already indicated; note also that the subscripts (l,d) and (l, s) denote the demand for and supply of the **lth** good or service respectively.

It is important to indicate that the present study also utilizes two principal indicators of distribution, viz., the relative contributions (shares) of procurers and vendors in aggregate welfare and income inequality in the economy under study. The relative shares are conceptualized in Axiom 7, whereas income inequality is conceptualized in Axiom 8.

AXIOM 7: THE RELATIVE WELFARE SHARE FUNCTIONS

It is postulated in the present study that these exists relative welfare share functions for procurers and vendors of goods and services in the economy under study. Denote these welfare share functions as $R_{NC} = R_{WO}$ and $R_{WP} = R_{WP(.)}$ respectively. More formally, these are given by (7a) and (7b) respectively:

$$R_{WC} = R_{WC}(.) = \left(1 - \frac{\sum_l \int_O^{\tilde{q}_{l,}} q_{l,s}^{-1}(.) dq_{l,s}}{\sum_l \int_O^{\tilde{q}_{l,}} q_{l,d}^{-1}(-) dq_{l,d}}\right)^{-1} \qquad (7a)$$

$$R_{WC} = R_{WC}(.) = \left(1 - \frac{\sum_l \int_O^{\tilde{q}_{l,}} q_{l,d}^{-1}(.) dq_{l,d}}{\sum_l \int_O^{\tilde{q}_{l,}} q_{l,d}^{-1}(.) dq_{l,s}}\right)^{-1} \qquad (7b)$$

AXIOM 8: THE INCOME INEQUALITY FUNCTION

The present study conceptualizes income inequality as the proportion of income which accrues to the topmost l, percent highest income earners relative to the corresponding proportion of aggregate income which accrues to the bottom-most/ lowers) β percent income earners in the economy under study. Denote income inequality as ψ, and the income inequality function as ψ(.). The novel income inequality function conceptualized in this study is postulated to exist in the economy under study and formally given by (8):

$$Y^{-1} Ne^{+} \int_{Y_{e+}}^{Y_{max}} Y.f(Y, \theta) dY$$

$$\psi = \psi(.) = \qquad (8)$$

$$Y^{-1}N_{\beta-}\int_{Ymin}^{Y_{\beta-}} Y.f(Y,\theta)dY$$

Where G denotes the Gth percentile of the distribution of Y; ß denotes the ßth where Y denotes income; N_e+ and $N_ß$- respectively denote the respective populations in the aforementioned income earners in the aforementioned conceptualization of income inequality; $f(Y,\theta)$ denotes the probability density function of her statistical distribution of income and Θ denotes the vector of the parameters of this statistical distribution. $Y \in \mathbb{R}\,\phi,\ Y_{min} \leq Y \leq Y_{max};\ Y_{min} = \min(Y), Y_{max} = \max(Y),\ \theta_{min} \leq \theta \leq \theta_{max,}\ \ominus \subset \mathbb{R}\phi, f(.) > 0, \int_Y f(.)dY = 1, \int_{\tilde{Y}} = prob\ (\tilde{Y}_{min} \leq \tilde{Y} \leq \tilde{Y}_{max})$: $\mathbb{R}^{\phi}$ denotes the ϕ-dimensional Euclidean spare.

AXIOM 9: THE OPTIMISATION PROBLEM

The additional postulate of the present study is that the economic agents in the economy desire to solve the multi-objective- multi-constraints, constrained optimization problem in (9a) – (9d):

Max B = B (.) (9a)

Max ∪=∪ (.) (9b)

s.t. T(.) = 0 (9c)

$Y - \tilde{E}(.) = 0$ (9d)

Where all the variables and functions are as already indicated; $\tilde{E}(.)$ denotes the expenditure function as already specified in (4). The Lagrangean-equivalent specification of (9a) – (9d) is given by (10):

Max $\mathbb{L}('') = B(.) + \cup(.)$

$-\lambda_T T(.) - \lambda_Y(Y - \tilde{E}(.)$ (10)

Where ʎ. Are the relevant Lagrangean multipliers.

Lemma 1

Given the postulates in Axioms 1-9, the first order (necessary) conditions and the second order (sufficient) 1 condition for solving the optimization problem in (9a) – (9d) OR the Lagrangean-equivalent in (10) are given respectively by (11a) – (11d) and (12):

$$\frac{\partial B(.)}{\partial q_l} + \frac{\partial \cup (.)}{\partial q_l} = \lambda_T \frac{\partial \tilde{E}(.)}{\partial q_l} \qquad (11a)$$

$$\frac{\partial B(.)}{\partial Z_{i,l}} + \frac{\partial \cup (.)}{\partial Z_{i,l}} = \lambda_T \frac{\partial T(.)}{\partial Z_{i,l}} - \lambda_Y \frac{\partial \tilde{E}(.)}{\partial Z_{i,l}} \qquad (11b)$$

$$(-1)^8 H_8^* \left(q_l^*, Z_{\bar{L}}^*, '\lambda_T^* , \lambda_Y^*\right) > 0, 8$$

Where $H_8^*(.)$ denotes the relevant bordered Hessian determinant of the optimization problem in (9a) – (9d) OR its Lagrangean equivalents (10) which has been evaluated at the stationary point $\left(q_R^*, Z_{i,l}^*, \lambda_T^*, \lambda_Y^*\right)$ obtained from the solution of the first order conditions (11a) – (11d). Recall the definition of the subscript l in (6) in Axiom 6.

PROOF

Lemma 1 is proved by taking the first order partial derivative of the Lagrangean function (10) with respect to the endogenous variables in (10) and equating each partial derivative result in zero, and rearranging the relevant terms to obtain (11a) – (11d) in Lemma 1 as required. Notably; $\frac{2L(.)}{27}, = -T(.) = 0 \; and \; \frac{2L(.)}{\partial \lambda_Y} = -\left(Y - \tilde{E}(.)\right) = 0$ and rearranging terms give (11c) – (11d) in Lemma 1 as required.

Q.E.D

THEOREM 1

Given the aforementioned postulates in Axioms 1 – 9 and Lemma 1, the system of optimal producer supply of the vector products of (denoted as $q_{l,s}^* = q_{l,s}^*(.)$) , producer demand for factor inputs (denoted as $Z_{i,l,d}^*(.)$, optimal consumer demand (denoted as $q_{l,d}^* = q_{l,d}^*(.)$) are respectively given by (13a) – (13c)

$$q_{l,s}^* = q_{l,s}^*(.) \qquad (13a)$$

$$q^*_{l,d} = q^*_{l,d}(.) \qquad (13b)$$

$$Z^*_{i,l,d} = q^*_{i,l,d}(.) \qquad (13c)$$

Where $l = e(r)x, e(nr)x, e(r)m, e(nr)m, e(r)nt, e(nr)nt, jx, jm, jnt$; $\boldsymbol{j}$ = agricultural(a), Industrial (I), Services (SS) and e(r), e(nr) respectively denote renewable energy and non-renewable energy; $\boldsymbol{x}$ denotes exported, $\boldsymbol{m}$ denotes import-competing or imported and $\boldsymbol{nt}$ denotes non-traded. The arguments of the functions (13a), (13c) are product prices (viz., own prices, prices of complementary products, prices of substitutable products), factor input prices, (viz., own prices, complementary and substitutable factor input prices). The arguments of the function (13b) are the aforementioned product prices and income. The rest of the arguments of (13a) and (13c) and (13b) are the costs of producer-induced carbon emissions.

In the product supply function (13a), the own price impact is positive ceteris paribus. The cross-price marginal impacts are respectively positive and negative for complementary and substitutable products. The marginal impacts of the factor input prices are negative ceteris paribus.

In the producer factor inputs demand function (13c), product prices exert positive marginal impacts, and factor input prices exert negative marginal impacts. The marginal impacts of complementary factor prices and factor prices of substitutable factor inputs are negative and positive respectively. The own factor input price in this factor input demand function (13c).

In the consumer product demand function (13b), the own price marginal impact is negative ceteris paribus. The cross-price marginal impacts are negative for complementary products and positive for substitutable products. The marginal impact of income is positive in this function.

In (13a) – (13c), the cost of producer-induced carbon emissions, and consumer-induced carbon emissions exert negative marginal impacts ceteris paribus.

PROOF

Theorem 1 is proved as follows. This entails the proof of (13a) – (13c) in Theorem 1. Given that the aforementioned postulates in Axioms 1 – 9 hold and that Lemma 1 also holds, invoking the principle in the mathematical optimization theorem that the first order partial derivative of the value function in an optimization problem with respect to the relevant prices give the system of optimal demand and supply functions, in the context of the present study give (13a) – (13b) as

required. Notably, the value functions here are $B^* = B^*(.)$ and $\cup^* = \cup^*(.)$ obtained from substitution of the stationary point $\left(q_l^*, \not{Z}_{i,l}^*, \not{\Lambda}_T^*, \not{\Lambda}_Y^*\right)$ into B(.) and ∪(.).

Q.E.D

Remarks

Among other things, the optimal system of product supply and demand and factor inputs' demand functions (13a) – (13c) reflects the relationships between renewable energy exported, imported import-competing, non-traded goods and non-renewable energy exported, imported, import-competing and non-traded goods, as well as non-energy exported, imported, import-competing, non-traded goods and services (agricultural, industrial and services). The substitutable and complementary relationships among all these types of energy and non-energy goods and services all hold for (13a) – (13c). These interactions constitute novel theoretical results obtained in the present study.

Consider now, the marginal impacts of trade policies for energy goods and the present study's concept of welfare. These trade policy instruments comprise subsidy and rates tariff and renewable and non-renewable energy goods exported and imported denoted respectively as; $S_{e(r)x}, S_{e(nr)x,}\ S_{e(r)m}, S_{e(nr)m}, T_{e(r)x}, T_{e(nr)x}, T_{e(nr)m}$. The marginal impacts of these subsidy and tariffs (taxes) in welfare $\boldsymbol{w}$ are summarized in Theorem 2 with its formal proof.

THEOREM 2

Given that Axioms 1 – 9 hold, then the marginal impacts of the trade policy for energy goods (viz., the subsidy and tariff of tax rates $S_{e(.)x}, T_{e(.)x}, S_{e(.)m}, T_{e(.)m}$) on welfare w are given by (14a) – (14d):

$$\frac{\partial W}{\partial S_{e(.)s}} = \sum_l \int_0^{\tilde{q}_l} \frac{\partial q_{l,d}^{-1}(.)}{\partial P_l} \left(\frac{\partial q_{e(.)x}}{\partial P_l}\right)^{-1} \frac{\partial q_{e(.)x}}{\partial P_{e(.)x}}\ P_{e(.)xf}\ Edq_{l,d}$$

$$-\sum_l \int_0^{\tilde{q}_l} \frac{\partial q_{l,s}^{-1}(.)}{\partial P_l} \left(\frac{\partial q_{e(.)x}}{\partial P_l}\right)^{-1} \frac{\partial q_{e(.)x}}{\partial P_{e(.)x}}\ P_{e(.)xf}\ Edq_{l,s} \lessgtr 0 \qquad (14d)$$

$$\frac{\partial W}{\partial T_{e(.)x}} = -\sum_l \int_0^{\tilde{q}_l} \frac{\partial q_{l,d}^{-1}(.)}{\partial P_l} \left(\frac{\partial q_{e(.)x}}{\partial P_l}\right)^{-1} \frac{\partial q_{e(.)x}}{\partial P_{e(.)x}}\ P_{e(.)xf}\ Edq_{l,d}$$

$$+\sum_l \int_0^{\tilde{q}_l} \frac{\partial q_{l,s}^{-1}(.)}{\partial P_l} \left(\frac{\partial q_{e(.)x}}{\partial P_l}\right)^{-1} \frac{\partial q_{e(.)x}}{\partial P_{e(.)x}} P_{e(.)xf}\, Edq_{l,s} \lessgtr 0 \qquad (14b)$$

$$\frac{\partial W}{\partial S_{e(.)m}} = -\sum_l \int_0^{\tilde{q}_l} \frac{\partial q_{l,d}^{-1}(.)}{\partial P_l}$$

$$\times \left(\frac{\partial q_{e(.)m}}{\partial P_l}\right)^{-1} \frac{\partial q_{e(.)m}}{\partial P_{e(.)m}} P_{e(.)mf}\, Edq_{l,d}$$

$$+ \sum_l \int_0^{\tilde{q}_l} \frac{\partial q_{l,s}^{-1}(.)}{\partial P_l} \left(\frac{\partial q_{e(.)m}}{\partial P_l}\right)^{-1} \frac{\partial q_{e(.)m}}{\partial P_{e(.)m}} \times P_{e(.)mf}\, Edq_{l,s} \gtrless 0 \qquad (14c)$$

$$\frac{\partial W}{\partial T_{e(.)m}} = \sum_l \int_0^{\tilde{q}_l} \frac{\partial q_{l,d}^{-1}(.)}{\partial P_l} \left(\frac{\partial q_{e(.)m}}{\partial P_l}\right)^{-1} \times \frac{\partial q_{e(.)m}}{\partial P_{e(.)m}} . P_{e(.)mf}\, Edq_{l,d}$$

$$- \sum_l \int_0^{\tilde{q}_l} \frac{\partial q_{l,s}^{-1}(.)}{\partial P_l} \left(\frac{\partial q_{e(.)m}}{\partial P_l}\right)^{-1} \frac{\partial q_{e(.)m}}{\partial P_{e(.)m}} \times P_{e(.)mf}\, Edq_{l,s} \lessgtr 0 \qquad (14d)$$

Where $l = e(r)x, e(nr)x, e(r)m, e(nr)m, e(r)nt, e(nr)nt; j, jm, jnt,$ j = agricultural (a), industrial (I), services (SS); $e(.)x = e(r)x, e(nr)x$; $e(.)m = e(r)m, e(nr)m$ and all the variables are as already indicated.

PROOF

The proof of Theorem 2 entails the formal proof of (14a) – (14d) in Theorem 2. Suppose Axioms 1 – 9 hold. From (6) in Axiom 6 where the present study's concept of welfare w and its functions w(.) are formally specified, invoking the Leibnitz Theorem for taking the partial derivative of a multi-argument integral function, while invoking the composite function rate, the inverse function rule, product function rule, in the context of (6) in Axiom (6) and (3a') – (3d'') in Axiom 3 give (14a) – (14d) in Theorem 2 as required.

Q.E.D.

The impacts of trade policies $S_{e(.)x}, T_{e(.)x}, S_{e(.)m}, T_{e(.)m}$ on the share of procurers' welfare R_{WC} and the relative share of vendors' welfare R_{WP} are summarized in Theorem 3 with the formal proof.

THEOREM 3

The impact trade policies of $S_{e(.)x}, T_{e(.)x}, S_{e(.)m}, T_{e(.)m}$ on the relative shares of procurers' and vendors' welfare R_{WC} and R_{WP} are given by (15a) – (15d):

$$\frac{\partial R_{WC}}{\partial S_{e(.)x}} = -\left(1 - \frac{\sum_l \int_0^{\tilde{q}_l} q_{l,s}^{-1}(.)dq_{l,s}}{\sum_l \int_0^{\tilde{q}_l} q_{l,d}^{-1}(.)dq_{l,d}}\right)^{-2}$$

$$\times \left(\sum_l \int_0^{\tilde{q}_l} q_{l,d}^{-1}(.)dq_{l,d}\right)^{-2}$$

$$\times \left[-\sum_l \int_0^{\tilde{q}_l} q_{l,d}^{-1}(.)dq_{l,d} \cdot \sum_l \int_0^{\tilde{q}_l} \frac{\partial}{\partial S_{e(.)x}} q_{l,s}^{-1}(.)dq_{l,s} + \sum_l \int_0^{\tilde{q}_l} q_{l,d}^{-1}(.)dq_{l,s} \cdot \sum_l \int_0^{\tilde{q}_l} \frac{\partial}{\partial S_{e(.)x}} q_{l,s}^{-1}(.)dq_{l,d}\right]$$

$$\gtrless 0 \qquad (15a)$$

$$\frac{\partial R_{WC}}{\partial T_{e(.)x}} = \frac{\partial R_{WC}}{\partial S_{e(.)x}} \gtrless 0 \qquad (15b)$$

$$S_{e(.)x} = T_{e(.)x} \frac{\partial P_{e(.)x}}{\partial T_{e(.)x}} = -P_{e(.)xf} E$$

$$\frac{\partial R_{WP}}{\partial S_{e(.)m}} = -\left(\frac{\sum_l \int_0^{\tilde{q}_l} q_{l,d}^{-1}(.)dq_{l,d}}{\sum_l \int_0^{\tilde{q}_l} q_{l,s}^{-1}(.)dq_{l,s}}\right)^{-2}$$

$$\times \left(\sum_l \int_0^{\tilde{q}_l} q_{l,s}^{-1}(.)dq_{l,s}\right)^{-2}$$

$$\times \left[-\sum_l \int_0^{\tilde{q}_l} q_{l,s}^{-1}(.)dq_{l,s} \cdot \sum_l \int_0^{\tilde{q}_l} \frac{\partial}{\partial S_{e(.)m}} q_{l,d}^{-1}(.)dq_{l,d} - \sum_l \int_0^{\tilde{q}_l} q_{l,d}^{-1}(.)dq_{l,d} \cdot \sum_l \int_0^{\tilde{q}_l} \frac{\partial}{\partial S_{e(.)m}} q_{l,s}^{-1}(.)dq_{l,s}\right]$$

$$\gtrless 0 \qquad (15c)$$

$$\frac{\partial R_{WP}}{\partial T_{e(.)m}} = \frac{\partial R_{WP}}{\partial S_{e(.)x}} \gtrless 0 \qquad (15d)$$

$$S_{e(.)m} = T_{e(.)m} \frac{\partial P_{e(.)m}}{\partial T_{e(.)m}} = -P_{e(.)mf} E$$

Where all the variables are as already indicated. Recall from (3b'') in Axiom 3 that $\frac{\partial P_{e(.)m}}{\partial S_{e(.)m}} = -P_{e(.)mf}.E < 0.$

PROOF

Theorem 3 is proved as follows. This entails the proof of (15a) – (15d) in Theorem 3. Given that the postulates in Axiom 1 – 9 hold. Taking the first order partial derivatives of the welfare function w = w(.) in (6) of Axiom 6 and the relative welfare shares of procurers and vendors R_{WC} and R_{WP} in (7a) and (7b) in Axiom 7 with respect to subsidy rates and tariff (tax) rates on renewable and non-renewable energy export and energy import $S_{e(.)x}, T_{e(.)x}, S_{e(.)m}, T_{e(.)m}$ by utilizing the Leibnitz Theorem on the partial derivative of integral functions jointly with the composite function rule of differential calculus, the inverse function rule, the product rule in the case of (6), and the inverse function rule, the quotient function rule, the product rule of differential calculus in the case of (7a) – (7b). these respectively yield (15a) – (15d) in Theorem 3 as required.

Q.E.D

The impacts of renewable and non-renewable energy export subsidy rates and tariff (tax) rates $S_{e(.)x}, T_{e(.)x}, S_{e(.)m}, T_{e(.)m}$ on income inequality Ψ in (8) in Axiom 8 are summarized in Theorem 4 with its formal proof.

THEOREM 4

Given the postulates of Axioms 1 -9, the impacts of energy trade subsidy and tariff (tax) rates (export and imports) $S_{e(.)x}, T_{e(.)x}, S_{e(.)m}, T_{e(.)m}$ on income inequality Ψ are given by (16a) – (16

$$\frac{\partial \Psi}{\partial T_{e(.)m}} = \left(N_\beta - \int_0^{Y_{\beta-}} Y.f(Y, \ominus)dY\right)^{-2}$$

$$\times \left[N_\beta - \int_0^{Y_{\beta-}} Y.f(Y, \ominus)dY \times N_\varrho \int_{Y_{\varrho+}}^{Y_{100}} Y.f(Y, \ominus)dY - N_{\varrho+}N_\varrho \int_{Y_{\varrho+}}^{Y_{100}} Y.f(Y, \ominus)dY\right.$$

$$\times N_{\beta} - \int_{0}^{Y_{\beta-}} \frac{\partial}{\partial Y} Y.f(Y, \ominus) dY]$$

$$\times \left[\left(\frac{\partial q_{e(.)m,d}}{\partial Y} \right)^{-1} \frac{\partial q_{e(.)m,d}}{\partial P_{e(.)m}} . P_{e(.)mf} E \right] \begin{matrix} < \\ > \end{matrix} 0 \qquad (16a)$$

$$\frac{\partial \Psi}{\partial S_{e(.)m}} = \frac{\partial \Psi}{\partial T_{e(.)m}} \begin{matrix} < \\ > \end{matrix} 0 \qquad (16b)$$

$$T_{e(.)m} = S_{e(.)m} \frac{\partial P_{e(.)m}}{\partial S_{e(.)m}} = -P_{e(.)mf}.E$$

$$\frac{\partial \Psi}{\partial S_{e(.)x}} = \frac{\partial \Psi}{\partial S_{e(.)m}} \begin{matrix} < \\ > \end{matrix} 0 \qquad (16c)$$

$$S_{e(.)m} = S_{e(.)x} \frac{\partial P_{e(.)x}}{\partial S_{e(.)x}} = -P_{e(.)xf}.E$$

$$\frac{\partial \Psi}{\partial T_{e(.)x}} = \frac{\partial \Psi}{\partial S_{e(.)m}} \begin{matrix} < \\ > \end{matrix} 0 \qquad (16d)$$

$$S_{e(.)m} = T_{e(.)x} \frac{\partial P_{e(.)x}}{\partial T_{e(.)x}} = -P_{e(.)xf}\ E$$

PROOF

The proof of Theorem 4 entails the proof of (16a) – (16d). In each case, taking the first order partial derivative of the income inequality function Ψ, in (8) in Axiom 8 with respect to the instruments of energy trade policies $S_{e(.)x}, T_{e(.)x}, S_{e(.)m}, T_{e(.)m}$ in turn by utilizing the Leibnitz Theorem on partial derivative of a multi-argument integral function, the composite function rule, the quotient rule, the product rule, the sum rule, all of differential calculus, and simplifying the results given (16a) – (16d) in Theorem 4 as required.

Q.E.D

4. THE MODELLING METHODOLOGY

The aforementioned postulates in the novel general theory and the resulting system of optimal product supply functions, factor input demand functions, and product demand functions of the procurers of the products are all essentially equilibrium long run function. Additionally, recall the aforementioned postulate of the prevalence or operation of the Rawlinson general equilibrium economy under study in the present research. However, in the short run, the operations of various frictions in the firm of various economic trammels prevent the exchange of goods and services including energy goods in the economy from adjusting instantaneous to the aforementioned equilibrium long run bath. Exemplars of such frictions or economic trammels include the inability of products and factor inputs procurers and vendors to perceive changes in the levels of the arguments of the aforementioned supply and demand functions. This tends to limit instantaneous adjustments in the short run. As these frictions (economic trammels) become weaker due to improvements in the ability of these economic agents to perceive the aforementioned changes over time economic behaviour tends to correct itself and move back to the aforementioned equilibrium long run bath.

Depending upon the magnitude of the strength of this adjustment process, not all the aforementioned disequilibrium is removed; additionally, the removal of this disequilibrium may be slow or fast.

The Cleve Granger Representation Theorem is herein invoked (Engle and Granger 1987). This theorem inter alia suggests that if there exist a long run relationship between a given economic phenomenon and its determinants, then there automatically exists a corresponding equilibrium correction relationship between them.

This equilibrium correction function yields, jointly, the short run impacts and the long run impacts, of these determinants, and the proportion of disequilibrium in the economic phenomenon which is automatically corrected per unit time over time. The converse of …….

The impacts of producer-induced carbon emissions, and procurer-induced carbon emissions on welfare, the relative shares of producer welfare and product procurers welfare, and income inequality are summarized in Theorem 5 and Theorem 6 with their formal proofs.

THEOREM 5

Given that Axioms 1 – 9 hold, then the respective marginal impacts of the unit costs of producer-induced carbon emissions K_P and product procurer-induced carbon emissions K_C on welfare $\boldsymbol{w}$, the relative shares of producer welfare R_{WP}, product procurers' welfare R_{WC} and income inequality Ψ are given by (17a) – (17):

$$\frac{\partial W}{\partial K_P} = \sum_l \int_0^{\tilde{q}_l} \frac{\partial}{\partial K_P}\, q_{l,d}^{-1}(.)dq_{l,d}$$

$$-\sum_l \int_0^{\tilde{q}_l} \frac{\partial}{\partial K_P}\, q_{l,s}^{-1}(.)dq_{l,s} \lessgtr 0 \qquad (17a)$$

$$\frac{\partial W}{\partial K_C} = \sum_l \int_0^{\tilde{q}_l} \frac{\partial}{\partial K_C}\, q_{l,d}^{-1}(.)dq_{l,d} \lessgtr 0 \qquad (17b)$$

$$\frac{\partial R_{WP}}{\partial K_P} = \left(\frac{\sum_l \int_0^{\tilde{q}_l}\, q_{l,d}^{-1}(.)dq_{l,d}}{\sum_l \int_0^{\tilde{q}_l}\, q_{l,s}^{-1}(.)dq_{l,s}} - 1\right)^{-2}$$

$$\times \left(\sum_l \int_0^{\tilde{q}_l}\, q_{l,s}^{-1}(.)dq_{l,s}\right)^{-2}$$

$$\times\, \sum_l \int_0^{\tilde{q}_l}\, q_{l,s}^{-1}(.)dq_{l,s}\, .\sum_l \int_0^{\tilde{q}_l} \frac{\partial}{\partial K_P}\, q_{l,d}^{-1}(.)dq_{l,d}$$

$$-\sum_l \int_0^{\tilde{q}_l}\, q_{l,d}^{-1}(.)dq_{l,d}\, .\sum_l \int_0^{\tilde{q}_l} \frac{\partial}{\partial K_P}\, q_{l,s}^{-1}(.)dq_{l,s} \lessgtr 0 \qquad (17c)$$

$$\frac{\partial R_{WC}}{\partial K_P} = -\left(\frac{\sum_l \int_0^{\tilde{q}_l}\, q_{l,s}^{-1}(.)dq_{l,s}}{\sum_l \int_0^{\tilde{q}_l}\, q_{l,d}^{-1}(.)dq_{l,d}}\right)^{-2}$$

$$\times \left(\sum_l \int_0^{\tilde{q}_l}\, q_{l,d}^{-1}(.)dq_{l,d}\right)^{-2}$$

$$\times \left[-\sum_l \int_0^{\tilde{q}_l}\, q_{l,d}^{-1}(.)dq_{l,d}\, .\sum_l \int_0^{\tilde{q}_l} \frac{\partial}{\partial K_P}\, q_{l,d}^{-1}(.)dq_{l,d}\right]$$

$$+\left[\sum_l \int_0^{\tilde{q}_l}\, q_{l,s}^{-1}(.)dq_{l,s}\, .\sum \int_0^{\tilde{q}_l} \frac{\partial}{\partial K_P}\, q_{l,d}^{-1}(.)dq_{l,sd}\right] \lessgtr 0 \qquad (17d)$$

$$\frac{\partial R_{WP}}{\partial K_C} = -\left(\frac{\sum_l \int_0^{\tilde{q}_l} q_{l,d}^{-1}(.)dq_{l,d}}{\sum_l \int_0^{\tilde{q}_l} q_{l,s}^{-1}(.)dq_{l,s}}\right)^{-2}$$

$$\times \left(\sum_l \int_0^{\tilde{q}_l} q_{l,s}^{-1}(.)dq_{l,s}\right)^{-2}$$

$$\times \left[-\sum_l \int_0^{\tilde{q}_l} q_{l,s}^{-1}(.)dq_{l,s} \; . \sum_l \int_0^{\tilde{q}_l} \frac{\partial}{\partial K_C} q_{l,d}^{-1}(.)dq_{l,d}\right] \begin{matrix} < \\ > \end{matrix} 0 \qquad (17e)$$

$$\frac{\partial R_{WC}}{\partial K_C} = -\left(1 - \frac{\sum_l \int_0^{\tilde{q}_l} q_{l,s}^{-1}(.)dq_{l,s}}{\sum_l \int_0^{\tilde{q}_l} q_{l,d}^{-1}(.)dq_{l,d}}\right)^{-2}$$

$$\times \left(\sum_l \int_0^{\tilde{q}_l} q_{l,d}^{-1}(.)dq_{l,d}\right)^{-2}$$

$$\times \left[-\sum_l \int_0^{\tilde{q}_l} q_{l,s}^{-1}(.)dq_{l,s} \; . \sum_l \int_0^{\tilde{q}_l} \frac{\partial}{\partial K_C} q_{l,d}^{-1}(.)dq_{l,d}\right] \begin{matrix} < \\ > \end{matrix} 0 \qquad (17f)$$

PROOF

Proving (17a) – (17f) in Theorem 5 proves Theorem. The respective first order partial derivative utilizing the aforementioned Leibnitz Theorem and aforementioned rules of differential calculus (17a) – (17f) in Theorem.

Q.E.D

THEOREM 6

Suppose Axioms 1 – 9 hold, then the marginal impacts of emissions KC, KP on income inequality Ψ are by (17g') – (17g''):

$$\frac{\partial \Psi}{\partial K_C} = \sum_l = \frac{\partial \Psi}{\partial Y} . \left(\frac{\partial q_{l,d}(.)}{\partial Y}\right)^{-1} \frac{\partial q_{l,d}(.)}{\partial K_C}$$

$$= \sum_l \left(N_{\beta-} \int_{Y_{min}}^{Y_{\beta-}} Y . f(Y, \ominus) dY\right)^{-2}$$

$$\times [N_{\beta} - \int_{Y_{min}}^{Y_{\beta-}} Y.f(.)dY \,.\, N_{\varrho+} \int_{Y_{\varrho+}}^{Y_{max}} \frac{\partial}{\partial Y} Y.f(.)dY$$

$$-N_{\varrho+} \int_{Y_{\varrho+}}^{Y_{max}} Y.f(.)dY \,.\, N_{\beta-} \int_{Y_{min}}^{Y_{\beta-}} \frac{\partial}{\partial Y} Y.f(.)dY$$

$$\times \left[\left(\frac{\partial q_{l,d}(.)}{\partial Y}\right)^{-1} \frac{\partial q_{l,d}(.)}{\partial K_C}\right] \begin{matrix} < \\ > \end{matrix} 0 \qquad (17g')$$

$$\frac{\partial \Psi}{\partial K_P} = \sum_l = \frac{\partial \Psi}{\partial Y} . \left(\frac{\partial q_{l,d}(.)}{\partial Y}\right)^{-1} \frac{\partial q_{l,d}(.)}{\partial K_P}$$

$$= \sum_l \left(N_{\beta-} \int_{Y_{min}}^{Y_{\beta-}} Y.f(.)dY\right)^{-2}$$

$$\times [N_{\beta} - \int_{Y_{min}}^{Y_{\beta-}} Y.f(.)dY \,.\, N_{\varrho+} \int_{Y_{\varrho+}}^{Y_{max}} \frac{\partial}{\partial Y} Y.f(.)dY$$

$$-N_{\varrho+} \int_{Y_{\varrho+}}^{Y_{max}} Y.f(.)dY \,.\, N_{\beta-} \int_{Y_{min}}^{Y_{\beta-}} \frac{\partial}{\partial Y} Y.f(.)dY$$

$$\times \left[\left(\frac{\partial q_{l,d}(.)}{\partial Y}\right)^{-1} \frac{\partial q_{l,d}(.)}{\partial K_P}\right] \begin{matrix} < \\ > \end{matrix} 0 \qquad (17g'')$$

PROOF

The proof of Theorem 6 entails proving (17g') and (17g'') in Theorem 6 formally. Evaluating the partial derivatives of the composite functions in (17g') – (17g'') by utilizing the Leibnitz Theorem concerning the partial derivatives of multi-argument integral functions, and the aforementioned rules of differential calculus give (17g') – (17g'') in Theorem 6 as required.

Q.E.D

…… of this statement also holds true. This Clive Grange Representation Theorem has been formally proved (Engle and Granger 1987). In the context of the optimal equilibrium long run functions of demand and supply in (13a) – (13c), the corresponding equilibrium correction functions are given by (17):

$$\Delta Q_{l,t} = \omega + \sum_{w=1}^{w*} \propto_{\omega} \Delta Q_{l,t-w}$$

$$+ \sum_{\cup=0}^{\cup*} \sum_{v=0}^{v*} \phi_u \, v \Delta \Lambda u, v \, (t-w)$$

$$+\rho\left(Q_{l,t-1} - \hat{Q}_{l,t-1}\right) \qquad (18d)$$

$$Q_{l,t} = \left[q_{l.dt}, q_{l,st}, \not{Z}_{i,l,dt}\right] \qquad (18b')$$

$$\Lambda = [P_l, P_l, Y \; K_P, K_C] \qquad (18b'')$$

$$l = e(r)x, e(nr)x, e(r)m, e(nr)m, e(r)nt, e(nr)nt, jx, jm, jnt$$

$Q_{l,t}$ denotes the observed levels of Q_l in period t;

$\hat{Q}_{l,t}$ denote the estimated equilibrium long run levels of Q_l in period t;

P_l denotes the own price of product whereas

P_l' denote the corresponding prices of complementary and substitutable products to product ***l***;

Y denotes income which is an argument in the procurers' product and demand function;

ρ denotes the proportion of the disequilibrium in $Q_{l,t}$ which is corrected (removed) per unit timer over time to get $Q_{l,t}$ to operate on the long run equilibrium path $\hat{Q}_{l,t}$: $\left(Q_{l,t} - Q_{l,t}\right)$ denotes the disequilibrium in $Q_{l,t}$ (viz.,) the equilibrium correction term.

ω is the intercept parameter, $\propto \omega, \phi_{u,v}$ are slope parameters; $\phi_{u,v}$ give the relevant short run impacts of the determinants of the supply and demand functions in (13a) – (13c). the parameters of the estimated equilibrium long run $\hat{Q}_{(.)}$ functions corresponding to (13a) – (13b) give the long run impacts of the determinants of $Q_{l,t}$ in (13a) – (13c). All the variables are as already indicated. K_P, K_C are the respective unit costs of producer-induced carbon emissions and procurers'-induced carbon emissions. The relevant short run impacts can be computed by combining the parameters $Q_{u,v}$ in (17) with (14a) – (14d) in Theorem 2, and with (15a) – (15d) in Theorem 3, and with (16a) – (16d) in Theorem 4.

The asymmetric versus symmetric dimensions of the long rum impacts of the determinant Δ_x say and the short run impacts of Λ_l say are derived by defining an asymmetry indicator D_l given by (19) for the long run impacts and (20) for the short run impacts;

$$Q_{l,t} = \cdots \ldots + \vee_l \Lambda_{l,t} + \eta_{l,LR} D_{l,LR} \Lambda_{l,t} \ldots \ldots \ldots \ldots \qquad (19a)$$

Where

$$D_{lLR} = \begin{cases} -1 \; if \; \Delta\Lambda_l < 0 & (19b) \\ 0, if \; \Delta\Lambda_l = 0 & (19b'') \\ +1, if \; \Delta\Lambda_l > 0 & (19b''') \end{cases}$$

And $\vee_l, \eta_{lLR}$ are parameters;

Whereas

$$\Delta Q_{l,t} = \cdots + \phi_l \Delta \Lambda \quad _l + \eta_{lSR} D_{l,SR} \Delta\Lambda_{l,} + \cdots \qquad (20a)$$

Where $\phi, \eta_{l_{SR}}$ are parameters; and where

$$D_{l_{SR}} = \begin{cases} -1 \; if \; \Delta(\Delta\Lambda_l) < 0 & (20b') \\ 0, if \; \Delta(\Delta\Lambda_l) = 0 & (20b'') \\ +1, if \; \Delta(\Delta\Lambda_l) > 0 & (20b''') \end{cases}$$

Where $\eta_{l_{LR}} = 0$ then the relevant long run impact is symmetric. When $\eta_{l_{LR}} \neq 0$ then the relevant impact is symmetric short run whereas $\eta_{l_{SR}} \neq 0$ implies asymmetric short run impact. When $\eta_{.} > 0_S$ then increasing (decreasing) levels of the determinant Δ_l say yields impacts of Larger (smaller) magnitudes in the case of response variable Q_l. When $\eta_{.} = 0$ then these two types of impacts are of the same magnitudes for increasing and decreasing levels of the determinant Λ_l variable Q_l, implying the prevalence of a symmetric impact, ceteris paribus.

On the empirical, conventional econometric estimation and hypotheses testing and the PROEV-related hypotheses testing procedures can be employed see for instance, (Judge, et al 1985, Fomby, Hill, and Johnson 2009, Yerfi Fosu 1992).

5. Concluding Remarks

The present study has logically and scientifically constructed a novel general theory and modelling methodology for rigorously analyzing the magnitudes, directions (signs), asymmetric versus symmetric dimensions, and transmission mechanisms of the long run and short run impacts of trade policies for energy goods on welfare, distributional impacts (viz., the relative shares in welfare of the consumer versus producer economic surplus) and income inequality in open economies. The logical deductive approach to scientific theorizing for the systematic explanation and understanding of the occurrence of an economic phenomenon is employed in the aforementioned construction of the novel general theory of the aforementioned impacts and the corresponding modeling methodology. The inextricable interactions among exported, import–competing and imported renewable energy, non-renewable energy, agricultural and industrial goods, and services products and factor inputs and carbon emissions in an open economy, are incorporated in the economic scientific analyses in this study. Aggregate joint consumer and producer surplus is employed as an indicator of welfare in this study. Welfare distribution is indicated by the consumer surplus relative to the producer surplus in the economy under study, and income inequality in the economy under study. Income inequality is indicated by the proportion of total income which accrues to the topmost (richest) twenty percent of income earners relative to that which accrues to the bottom-most (lowest poor) forty percent of income earners in the economy under study in this study. Trade subsidies and tariffs (taxes) rates (and the corresponding subsidy-equivalent and tariff-equivalent rates on non-tariff trade barriers and non-subsidy trade enhancers (inducers) on the aforementioned energy and non-energy goods and services and the costs of carbon emissions are considered in this study. The results of this study suggest that the magnitudes, directions (signs), asymmetric versus symmetric dimensions, and the

transmission mechanisms of the aforementioned long run and short run impacts can be employed innovatively to augment the levels of aggregate welfare, consumer welfare and producer welfare, and to reduce the level of inequality in an open economy globally. The potential sources of the relevant real world empirical data for validating the hypotheses emerging from the aforementioned novel general theory of the aforementioned impacts and the corresponding novel modelling methodology have been explicitly indicated in this study.

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