Following the Buck: Externalities of American Households in an Evolving Trading World

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Abstract:

The growing fragmentation of production processes and expansion of international trade in the last decades have increase the scope and complexity of value added chains worldwide causing a significant rearrangement of sectoral linkages intra and interregionally. In terms of economic spillovers, this implies that a dollar entering a particular economy follows a different path than before, permeating in longer interregional feedback loops and creating additional multiplier effects outside its origin. However, it also implies that the environmental burden that such dollar embeds has changed in scale and spatial distribution. In this paper, we explore the evolution of these "paths" during 1997-2009 and highlight the main drivers of observed structural change that contribute to the surge or decline of economic spillovers and greenhouse gases emissions spatially. We specifically study the effects of an increase in income in the United States, the country with the largest trade volume in the world. We take advantage of the Extended Temporal Leontief Inverse framework, that allows tracing the evolutionary path of the American households' multiplier in a dynamic fashion, isolating the contribution of expenditure patterns, income, trade and foreign structural change to the temporal evolution. We find similar growing multiplier effects inside and outside the US due to services and manufacturing respectively, but a declining local environmental burden due to changes in interindustrial relations inside the US with declining manufacturing. We also highlight the fragmentation process with declining foreign intraregional spillovers and increasing trade spillovers. Finally, structural and trade pattern changes in the EU-15 have induced larger spillovers from US consumption to the region with lower environmental impact while disproportionally increasing pollution in developing nations.

Keywords: Temporal Leontief Inverse; Time-series Analysis; Trade; Dynamics
JEL: C67, D57, Q15, R14

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1. Introduction

The past half a century has been marked by an unprecedented expansion of international trade. In terms of volume, world trade is nearly 32 times greater now than it was in 1950, and the share of global GDP it represents rose from 5.5% in 1950 to 21% in 2007 (WTO, 2009). Combined with the effects of rapid globalization, international trade has introduced significant changes in technology, industrial organization and the spatial division of labor (Romero *et al.*, 2009). Thereby, production processes have evolved into fragmented systems worldwide that slice value-added chains into several small processes undertaken in different locations, leading to a reorganization of industrial linkages that created new channels for economic spillovers across different economies.

Concurrently, the World Bank has reported that global greenhouse gas emissions (GHG) have increased by 93% from 1970 to 2012, especially in developing countries where this fragmentation process has concentrated most of the polluted portions of value-added chains. Therefore, international trade has a significant role on the effectiveness of global climate policies such as the Kyoto Protocol and the Paris Agreement. Several recent papers have focused on the assessment of air emissions embodied in traded goods and on the geographical location of their source (Davis and Caldeira, 2010; Peters and Hertwich, 2008). However, the increasing density of transactions and linkages within and between regions and industries, due to more globalized and fragmented production systems, masks the true driving forces connecting the origin of an economic shock and its externalities worldwide.

A producer-centric approach performed at national level has traditionally dominated the literature assessing the environmental impacts of economic activity.[1] According to this view, although emissions may have been generated to provide goods or services elsewhere, pollution is assigned to their immediate producers, whereas the environmental responsibility of the other agents participating in the supply chain is usually ignored. The advantage of this framework is to determine the internal sectorial responsibility for the pollution generated locally, and how domestic structural changes are influencing these negative externalities. Consequently, many developed countries in Annex B of the Kyoto Protocol[2] have been able to report decreasing emissions, and some have officially fulfilled their mitigation commitments (Kanemoto *et al.*, 2014). This is in part because current environmental regulatory regimes allow these countries to relocate high-emission industries to low regulation countries (mostly developing countries).

Nevertheless, as all production is ultimately linked to consumption, final demand bears the actual responsibility for environmental impacts, both local and foreign, indirectly generated

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[1] The United Nations Framework Convention on Climate Change (UNFCCC, 2011) requires countries to submit annual national emission inventories accounting only for those GHG emissions produced within sovereign territories, ignoring the environmental responsibility of those consumers benefiting from international trade.

[2] At the Conference of Parties in Kyoto in 1998, emission reduction targets were set without consideration of international trade.

by the production processes in the economy (Hertwich, 2011). In this sense, households are the main contributors to externalities worldwide as they represent the major share of final consumption. Moreover, households also cause direct environmental pressure, especially for GHG emissions, through energy use for heating, cooking and displacement (driving private vehicles) (Munksgaard *et al*., 2000). Hence, the sustainability of households' spending choices must account for their environmental responsibility as consumers, and it is crucial for the design of more effective GHG abatement policies accounting for population and income growth in developed and developing countries.[3]

This discussion on consumer's environmental responsibility is the core of the consumption-based approach. It is based on the principle that all emissions throughout the supply chain of a commodity are allocated to its final consumer. In these lines, analyzing energy and environmental emissions requirements of household consumption has been one of the most well-studied aspects of the environmental and life cycle assessment (LCA) literatures for many years (Weber and Matthews, 2008). Input-output models have also long been used to analyze the attribution of environmental burdens to final demand by using the Leontief demand-pull quantity model (Leontief and Ford, 1971; Lenzen, 1998; Peters, 2008; Lenzen *et al*., 2004; Roca and Serrano, 2007; Duarte, Mainar and Sánchez Chóliz, 2017).

The difference between the production and the consumption accounting is the amount of emissions embodied in trade. From a consumer responsibility perspective, GHG emissions are related to final use of goods and services even if they are imported from other countries (Proops *et al*., 1993; Munksgaard and Pedersen, 2001). By quantifying emissions outside of the country where the consumption occurred, the consumption-based approach provides a better understanding of the spatial environmental imbalance between origin and destination responsibility in different locations (Wiedmann. 2009).

Therefore, these approaches are mutually exclusive: while the producer approach allocates the environmental burden to product's origin, the consumer approach does it to its destination. However, these are interconnected effects with structural changes in both origin and destination that ultimately affect how an additional dollar in consumption for a given country spillovers throughout the other economies inflating or mitigating its impacts. In this paper, we apply a methodology that allows distributing externalities responsibilities between consumers and producers, thus accounting for these interrelations.

By using the Extended Temporal Leontief Inverse (TLI) proposed by Avelino, Carrascal and Franco (2017), we are able to spatially distribute the economic benefits and environmental burdens of an income increase in a particular country (destination), and the local and external drivers that shape its temporal evolution (origin). The Extended TLI decomposes the intraregional and interregional structural changes that modify the channels that a shock flows through the different economies, isolating the drivers that affect the nonlinear dependence of the

[3] World population is projected to grow from 7.2 billion today to 9.7 billion in 2050 according to United Nations (UN, 2015).

inverse with its evolutionary tail. We can then isolate the effects of consumption, trade and external economic changes to spillovers' trends by region.

Given the openness and the significant trade growth experienced in the United States over the past decade, where trade rose nominally 151% from 1997 to 2015 (Figure 1)[4], we study the evolution of spillovers that end consumers (households) in America impinge in the local economy and abroad. More specifically, we analyze the multiplier changes from a one million dollar income increase in the US, in terms of economic spillovers and GHG emissions. A better understanding of the evolution of the environmental responsibilities among households and industries, both local and external, will provide a more comprehensive picture to define future climate policies.

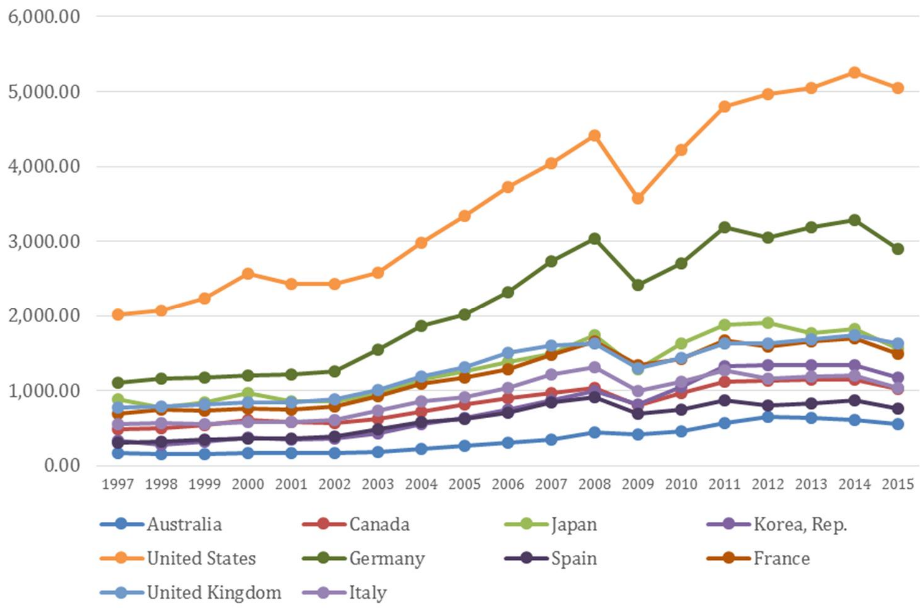

Figure 1 – Total trade of developed economies (in thousand million dollars)

The next section provides a succinct literature review of current studies in both producer and consumer approaches regarding air emissions. Section 3 describes the methodology, data and the drivers studied in this work. Section 4 explains and discusses the results and Section 5 concludes.

2. Literature Review

[IN DEVELOPMENT]

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[4] Imports rose nominally 164% while exports rose 137% from 1997-2016.

Relatively few studies have attempted to connect the household impact with the international trade studies to explore the environmental burdens associated with household consumption of goods and services (Peters and Hertwich, 2006). One way of dealing with international trade and allocating embodied CO_2 emissions to households among countries is by applying multi-regional input-output models (MRIO) (Lenzen et al. 2004; Peters and Hertwich, 2006). A review of MRIO models can be found in Wiedmann (2009). For the case of US, Weber and Matthews (2007) uses a MRIO of this country and its seven largest trading partners (Canada, China, Mexico, Japan, Germany, the UK, and Korea) to analyze the environmental effects of changes to US trade structure and volume from 1997 to 2004. The use of MRIO theoretically solves the assumption of domestic production of imports in IO analysis by using different technologies for goods and services from different regions.

By using this method, different studies (Davis and Caldeira, 2010; Druckman and Jackson, 2009; Arto and Dietzenbacher, 2014) have shown that whereas global emissions attributable to the consumer in developing countries have increased, the emissions generated within these countries have increased even more. Developing countries have thus generated emissions that have been embodied in their exports to satisfy the demand of consumers in developed countries (referred to as carbon leakage). In other words, while the net exports of emissions have increased in most of the developing countries, developed countries are net importers of emissions. Weber and Matthews (2007) already show that though the US' share of production-based CO_2 emissions shrank between 1997 and 2004, the share of consumption-based CO_2 emissions increased due to increased trade volume and to shifting toward more carbon intensive trading partners.

3. Methodology

3.1. The Extended TLI Framework

Let $\mathbf{A}_t = \left\| a_{ij,t}^{\mathrm{RR}} \right\|$ be an $(r*n)\times(r*n)$ multiregional direct input requirements matrix at time t, with n industries and r regions.[5] Also, consider $\mathbf{E}_t = \left\| e_{ij}^{\mathrm{RR}} \right\|$ a matrix of structural changes in direct input requirements between time $t-1$ and t, such that $\mathbf{A}_t = \mathbf{A}_{t-1} + \mathbf{E}_t$. Hence, we can derive the following relationships:

$$\mathbf{B}_t = (\mathbf{I} - \mathbf{A}_{t-1} - \mathbf{E}_t)^{-1} = [(\mathbf{I} - \mathbf{A}_{t-1})(\mathbf{I} - \mathbf{B}_{t-1}\mathbf{E}_t)]^{-1} = \mathbf{M}_t^{\mathrm{L}}\mathbf{B}_{t-1} \quad \textbf{(1)}$$

$$\mathbf{B}_t = (\mathbf{I} - \mathbf{A}_{t-1} - \mathbf{E}_t)^{-1} = [(\mathbf{I} - \mathbf{E}_t\mathbf{B}_{t-1})(\mathbf{I} - \mathbf{A}_{t-1})]^{-1} = \mathbf{B}_{t-1}\mathbf{M}_t^{\mathrm{R}} \quad \textbf{(2)}$$

[5] The standard I-O notation is used in this paper. Moreover, matrices are named in bold capital letters, vectors in bold lower case letters and scalars in italic lower case letters. The matrix **I** is the identity matrix of appropriate dimensions.

where,

$$\mathbf{M}_t^{\mathrm{L}} = (\mathbf{I} - \mathbf{B}_{t-1}\mathbf{E}_t)^{-1} \tag{3}$$

$$\mathbf{M}_t^{\mathrm{R}} = (\mathbf{I} - \mathbf{E}_t\mathbf{B}_{t-1})^{-1} \tag{4}$$

$\mathbf{M}_t^{\mathrm{L}}$ and $\mathbf{M}_t^{\mathrm{R}}$ are denoted the left and right temporal multipliers (Sonis and Hewings, 1998). They convey the change in the fields of influence of the economy between periods due to the structural change $\mathbf{E}_t$ (see section 5 of Sonis and Hewings (1998) for the derivation), moving the total requirements matrix from one period to another. In fact, $\mathbf{M}_t^{\mathrm{L}}$ is a generalization of the Sherman-Morrison formula for a multi-element change in an inverse matrix (Sonis and Hewings, 1989). Therefore, the Leontief Inverse can be rewritten as:

$$\mathbf{B}_t = \mathbf{M}_t^{\mathrm{L}}\mathbf{B}_{t-1} = \mathbf{B}_{t-1} + (\mathbf{M}_t^{\mathrm{L}} - \mathbf{I})\mathbf{B}_{t-1} \tag{5}$$

$$\mathbf{B}_t = \mathbf{B}_{t-1}\mathbf{M}_t^{\mathrm{R}} = \mathbf{B}_{t-1} + \mathbf{B}_{t-1}(\mathbf{M}_t^{\mathrm{R}} - \mathbf{I}) \tag{6}$$

Notice that the second terms of Eq. 5 and 6 are the same:

$$\mathbf{D}_t = (\mathbf{M}_t^{\mathrm{L}} - \mathbf{I})\mathbf{B}_{t-1} = \mathbf{B}_{t-1}\mathbf{M}_t^{\mathrm{R}}\mathbf{E}_t\mathbf{B}_{t-1} = \mathbf{B}_{t-1}(\mathbf{M}_t^{\mathrm{R}} - \mathbf{I}) \tag{7}$$

Hence,

$$\mathbf{B}_t = \mathbf{B}_{t-1} + \mathbf{D}_t \tag{8}$$

Then, the additive temporal decomposition of the Leontief inverse can be derived as:

$$\mathbf{B}_t = \mathbf{B}_{t-1} + \mathbf{D}_t = \mathbf{B}_{t-2} + \mathbf{D}_{t-1} + \mathbf{D}_t = \cdots = \mathbf{B}_0 + \mathbf{D}_1 + \mathbf{D}_2 + \cdots + \mathbf{D}_t \tag{9}$$

From Eq. 5 and 6, a multiplicative temporal decomposition is also easily extracted:

$$\mathbf{B}_t = \mathbf{M}_t^{\mathrm{L}}\mathbf{B}_{t-1} = \mathbf{M}_t^{\mathrm{L}}\mathbf{M}_{t-1}^{\mathrm{L}}\mathbf{B}_{t-2} = \cdots = \mathbf{M}_t^{\mathrm{L}}\mathbf{M}_{t-1}^{\mathrm{L}} \ldots \mathbf{M}_2^{\mathrm{L}}\mathbf{M}_1^{\mathrm{L}}\mathbf{B}_0 \tag{10}$$

Combining both decompositions yields a formula with an intuitive interpretation:

$$\mathbf{B}_t = \mathbf{I} + (\mathbf{B}_0 - \mathbf{I}) + (\mathbf{M}_1^{\mathrm{L}} - \mathbf{I})\mathbf{B}_0 + (\mathbf{M}_2^{\mathrm{L}} - \mathbf{I})\mathbf{M}_1^{\mathrm{L}}\mathbf{B}_0 + \cdots + (\mathbf{M}_t^{\mathrm{L}} - \mathbf{I})\mathbf{M}_{t-1}^{\mathrm{L}} \ldots \mathbf{M}_2^{\mathrm{L}}\mathbf{M}_1^{\mathrm{L}}\mathbf{B}_0 \quad \textbf{(11)}$$

As asserted by Okuyama *et al.* (2006) and Sonis and Hewings (1998), Eq. 11 shows that the current steady state of the Leontief inverse is a nonlinear composition of past changes in the input structure of the economy. This represents a temporal decomposition of change, where one can trace the evolutionary path of the elements of the inverse from time 0 to time t, and the contribution of each period to the current position of the matrix.

Now, following Avelino *et al.* (2017), by splitting the matrix of structural changes into a sum of several partitions, $\mathbf{E}_t = \sum_{p=1}^{k} \mathbf{E}_t^p \mid \forall \mathbf{E}_t^p\ \exists e_{ij,t}^p \in \mathbf{E}_t^p\ s.t.\, e_{ij,t}^p \neq 0$, and using the Woodbury Matrix Identity[6] we can decompose the temporal multiplier $\mathbf{M}_t^{\mathrm{L}}$ into a linear sum of marginal effects (the derivation is also valid for the right temporal multiplier). Starting from Eq. 3 and applying the identity:

$$\mathbf{M}_t^{\mathrm{L}} = (\mathbf{I} - \mathbf{B}_{t-1}\mathbf{E}_t)^{-1} = \mathbf{I} + \mathbf{B}_{t-1}(\mathbf{I} - \mathbf{E}_t\mathbf{B}_{t-1})^{-1}\mathbf{E}_t \quad \textbf{(14)}$$

$$\mathbf{M}_t^{\mathrm{L}} = \mathbf{I} + \mathbf{B}_{t-1}\mathbf{M}_t^{\mathrm{R}}\mathbf{E}_t \quad \textbf{(15)}$$

$$\mathbf{M}_t^{\mathrm{L}} = \mathbf{I} + \mathbf{B}_t\mathbf{E}_t \quad \textbf{(16)}$$

Now, partitioning the $\mathbf{E}_t$ matrix yields:

$$\mathbf{M}_t^{\mathrm{L}} = \mathbf{I} + \mathbf{B}_t\mathbf{E}_t^1 + \mathbf{B}_t\mathbf{E}_t^2 + \cdots + \mathbf{B}_t\mathbf{E}_t^k \quad \textbf{(17)}$$

Therefore, Eq. 17 allows the decomposition of the left temporal multiplier into a sum of marginal effects of partitions of the structural change. In terms of the temporal increment (Eq. 7), notice that $\mathbf{D}_t$ can be rewritten using Eq.16:

$$\mathbf{D}_t = (\mathbf{M}_t^{\mathrm{L}} - \mathbf{I})\mathbf{B}_{t-1} = (\mathbf{I} + \mathbf{B}_t\mathbf{E}_t - \mathbf{I})\mathbf{B}_{t-1} = \mathbf{B}_t\mathbf{E}_t\mathbf{B}_{t-1} \quad \textbf{(18)}$$

Applying the structural change partition:

[6] Let $\mathbf{A}$ and $\mathbf{C}$ be invertible matrix and $\mathbf{U}$ and $\mathbf{V}$ matrices of conformable dimensions. Then, $(\mathbf{A} + \mathbf{UCV})^{-1} = \mathbf{A}^{-1} - \mathbf{A}^{-1}\mathbf{U}(\mathbf{C}^{-1} + \mathbf{VA}^{-1}\mathbf{U})^{-1}\mathbf{VA}^{-1}$. In case $\mathbf{C}$ is a unitary matrix (1×1), the identity becomes the Sherman-Morrison formula.

$$\mathbf{D}_t = \mathbf{B}_t \left(\sum_{p=1}^{k} \mathbf{E}_t^p \right) \mathbf{B}_{t-1} = \mathbf{B}_t \mathbf{E}_t^1 \mathbf{B}_{t-1} + \mathbf{B}_t \mathbf{E}_t^2 \mathbf{B}_{t-1} + \cdots + \mathbf{B}_t \mathbf{E}_t^k \mathbf{B}_{t-1} \quad \textbf{(19)}$$

$$\mathbf{D}_t = \mathbf{D}_t^1 + \mathbf{D}_t^2 + \cdots + \mathbf{D}_t^k \quad \textbf{(20)}$$

Hence, the temporal expansion can be decomposed into a sum of structural change partitions. Hence, by taking a unitary vector of final demand $\mathbf{f}_t$, one can decompose the change in current multipliers via:

$$\begin{aligned} \mathbf{x}_t = \mathbf{f}_t + (\mathbf{B}_0 - \mathbf{I})\mathbf{f}_t + \mathbf{D}_1^1\mathbf{f}_t + \mathbf{D}_2^1\mathbf{f}_t + \cdots + \mathbf{D}_t^1\mathbf{f}_t + \mathbf{D}_1^2\mathbf{f}_t + \mathbf{D}_2^2\mathbf{f}_t + \cdots + \mathbf{D}_t^2\mathbf{f}_t + \cdots \\ + \mathbf{D}_1^k\mathbf{f}_t + \mathbf{D}_2^k\mathbf{f}_t + \cdots + \mathbf{D}_t^k\mathbf{f}_t \end{aligned} \quad \textbf{(21)}$$

The series $\mathbf{D}_1^p\mathbf{f}_t + \mathbf{D}_2^p\mathbf{f}_t + \cdots + \mathbf{D}_t^p\mathbf{f}_t$ isolates the evolution of partition p's impacts on the structural change, where each element $\mathbf{D}_c^p$ is the marginal effect of partition p at period c.

Since we have not imposed any restrictions on $\mathbf{E}_t^p$, partitions may contain single elements, vectors or matrices, allowing the assessment of several drivers. By grouping these partitions in different ways, we can isolate the evolution of a particular source in a partial derivative sense, i.e., in *ceteris paribus* conditions.

3.2. Data

The World Input-Output Database (WIOD) is used as the time-series for the extended TLI framework. The WIOD is a harmonized multiregional time-series with environmental accounts for 35 sectors and 40 countries that span the period 1995-2009 (2013 Release). These tables were We combine air emissions for CO2, CH_4 and N_2O using their respective Global Warming Potentials proposed by the Intergovernmental Panel on Climate Change in its Fifth Assessment Report (2014) for a horizon of 100 years to construct an indicator of Greenhouse Gases (GHG) per industry.

The IO time-series was deflated from current prices to constant 2009 US dollars using the recommended procedure from WIOD[7], and the household portion of final demand was endogenized in each year with labor income. Using the constructed GHG data, emission coefficients by industry and year were calculated and used to estimate the required pollution input for production in each industry. This environmental burden was then allocated among local intermediate and final consumption, and exports. Hence, the final hybrid table is composed of 35

[7] http://www.wiod.org/protected3/data/update_dec14/Sources_methods_pyp_dec2014.pdf.

sectors, 1 household and 1 environmental account for each of the 40 countries and a Rest of the World (ROW) region. For clarity, the final results are aggregated into 7 industries and 8 regions (Tables 1 and 2).

Table 1 – Sectoral Aggregation

	Sectors	**Aggregation**
c1	Agriculture, Hunting, Forestry and Fishing	Primary
c2	Mining and Quarrying	
c3	Food, Beverages and Tobacco	Manufacturing
c4	Textiles and Textile Products	
c5	Leather, Leather and Footwear	
c6	Wood and Products of Wood and Cork	
c7	Pulp, Paper, Paper , Printing and Publishing	
c8	Coke, Refined Petroleum and Nuclear Fuel	
c9	Chemicals and Chemical Products	
c10	Rubber and Plastics	
c11	Other Non-Metallic Mineral	
c12	Basic Metals and Fabricated Metal	
c13	Machinery, NEC	
c14	Electrical and Optical Equipment	
c15	Transport Equipment	
c16	Manufacturing, NEC; Recycling	
c17	Electricity, Gas and Water Supply	
c18	Construction	Construction
c19	Sale, Maintenance and Repair of Motor Vehicles; Retail Sale of Fuel	Trade
c20	Wholesale Trade and Commission Trade	
c21	Retail Trade	
c23	Inland Transport	Transportation
c24	Water Transport	
c25	Air Transport	
c26	Other Supporting and Auxiliary Transport Activities	
c22	Hotels and Restaurants	Services
c27	Post and Telecommunications	
c28	Financial Intermediation	
c29	Real Estate Activities	
c30	Renting of M & Eq. and Other Business Activities	
c31	Public Admin and Defense; Compulsory Social Security	
c32	Education	
c33	Health and Social Work	
c34	Other Community, Social and Personal Services	
c35	Private Households with Employed Persons	
	Households	Households

Table 2 – Regional Aggregation

Countries	Regions	Acronym
AUT, BEL, DNK, FIN, FRA, DEU, GRC, IRL, ITA, LUX, NLD, PRT, ESP, SWE, GBR	Europe 15	EU15
BGR, CYP, CZE, EST, HUN, LTU, LVA, MLT, POL, ROU, SVK, SVN	Rest of Europe	Rest-EU
CAN, MEX, USA	NAFTA	NAFTA
CHN	China	CHN
IND	India	IND
AUS, JPN, KOR	Rest of Developed Nations	Rest-Dev
BRA, IDN, RUS, TUR, TWN	Rest of Developing Nations	Rest-NDev
ROW	Rest of the World	ROW

3.3. Partitions

Since we adopt a consumer-centric approach, we analyze the evolution of the multiplier of American households by introducing a unitary shock in this sector, i.e., by increasing income in the US in one million dollars. The Extended TLI allows decomposing such evolutionary path into the marginal influence of several structural change drivers, conveying a more detail picture of what is influencing its dynamics. The isolation of particular drivers is accomplished by partitioning the intertemporal change in the direct input requirement table ($\mathbf{E}_t$) in different ways (see Figure 2).

Our basic decomposition (Level 1) is composed of six partitions. First, by isolating the column of the sector being shocked, we obtain the industry's "own effect". This is the impact on the multiplier if only the sector's technology or direct input requirements were changing *ceteris paribus*. It highlights the only part of the structural change that is under control of the sector. Since we are shocking households, the "own effect" is in fact an "expenditure effect", and reflects how changes in consumption shares influence direct, indirect and induced effects. In a multiregional context, by splitting this partition into "local own (expenditure) effects" (changes in local consumption) and "external own (expenditure) effects" (changes in households' imports) we are able to study spillovers.

By isolating the row of the sector being shocked in a partition, we measure the marginal "substitution effect" of the structural change.[8] The partition shows, *ceteris paribus*, how the change in the sector's sales structure affects its multiplier via forward linkages. In our context, it reflects shifts in labor demand composition and wages (i.e., changes in value added shares of

[8] This partition does not include purchases from the sector itself (E_{hh}) since they are accounted for in the own effect. As this element influences both backward and forward linkages, it could potentially be removed from the own effect and studied separately in its own partition (similar to the idea of self-generated changes used by Sonis *et al*. (1996)).

labor). Since there are no income transfers between countries in the WIOD, we only analyze the local substitution effect.

A fourth basic partition is the one that only includes changes in interindustrial relationships among American sectors, i.e., changes in row and column $n+1$ are ignored. This partition measures marginal "interrelational effects": the effects of changes in industrial linkages to the household multiplier. This procedure reveals the evolution of the indirect effects keeping induced effects constant. These are called "local interrelational effects".

We can also estimate the influence of trade on the American households' multiplier by isolating the off-diagonal block matrices (the interregional trade matrices) of $\mathbf{E}_t$ in another partition. "Trade effects" reveal the impact of changes in trade patterns to local and external spillovers. They can increase / decrease the multiplicative effect of the income shock in US households in different nations depending on the new channels of interindustrial circulation.

The sixth partition isolate intraregional structural changes in all nations except the US and represent "external interrelational effects". These are the impact of domestic linkages rearrangements in foreign nations to the multiplier of American households.

Further decompositions of the basic trade partition can be performed (Level 2) to disentangle the impact of particular regions. This implies creating subpartitions of the original trade partition in which changes in import patterns of a block of countries are isolated from the rest. Then, these subpartitions show the marginal impact that changes in trade pattern from the block affect the spillover effects of an increase in household income in the US. The same type of decomposition is done for external own effects and external interrelational effects.

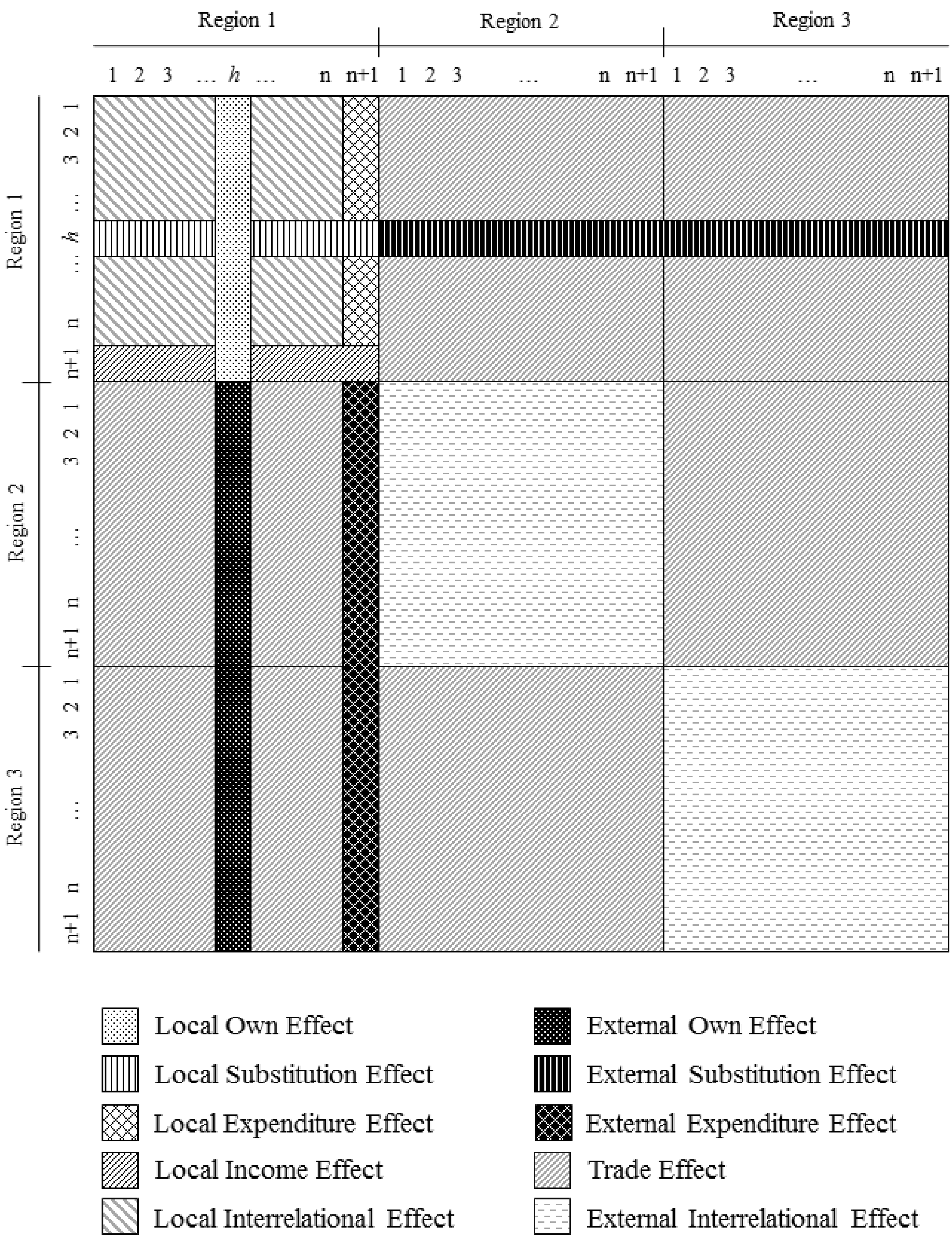

Figure 2 – Basic partitions in a multiregional IO table

4. Results and Discussion

Overall, there is a growing trend in the US households' multiplier, comprised of increasing local and external effects (the former higher than the latter) (Figure 3). In terms of economic spillovers, China is the primary beneficiary from income shocks followed by Canada and Mexico (NAFTA), European Union and India. The sector that concentrate most of spillovers is service, although there is a moderate increase in induced effects and leakages to manufacturing and trade. Spatially, most of these trends repeat in the local US economy, with exception of manufacturing that is declining, the opposite effect that happens externally where the latter and services grow their multiplier effects.

Pollution-wise, nonetheless, the picture is quite different from economic benefits. The overall emissions multiplier due to American households' income shocks increased 10% from 1997, exclusively driven by a 60% surge in external emissions, especially after 2001 while local emissions decline 10% over the same period. The major sources of such indirect emissions were developing nations, particularly China, India and Mexico.

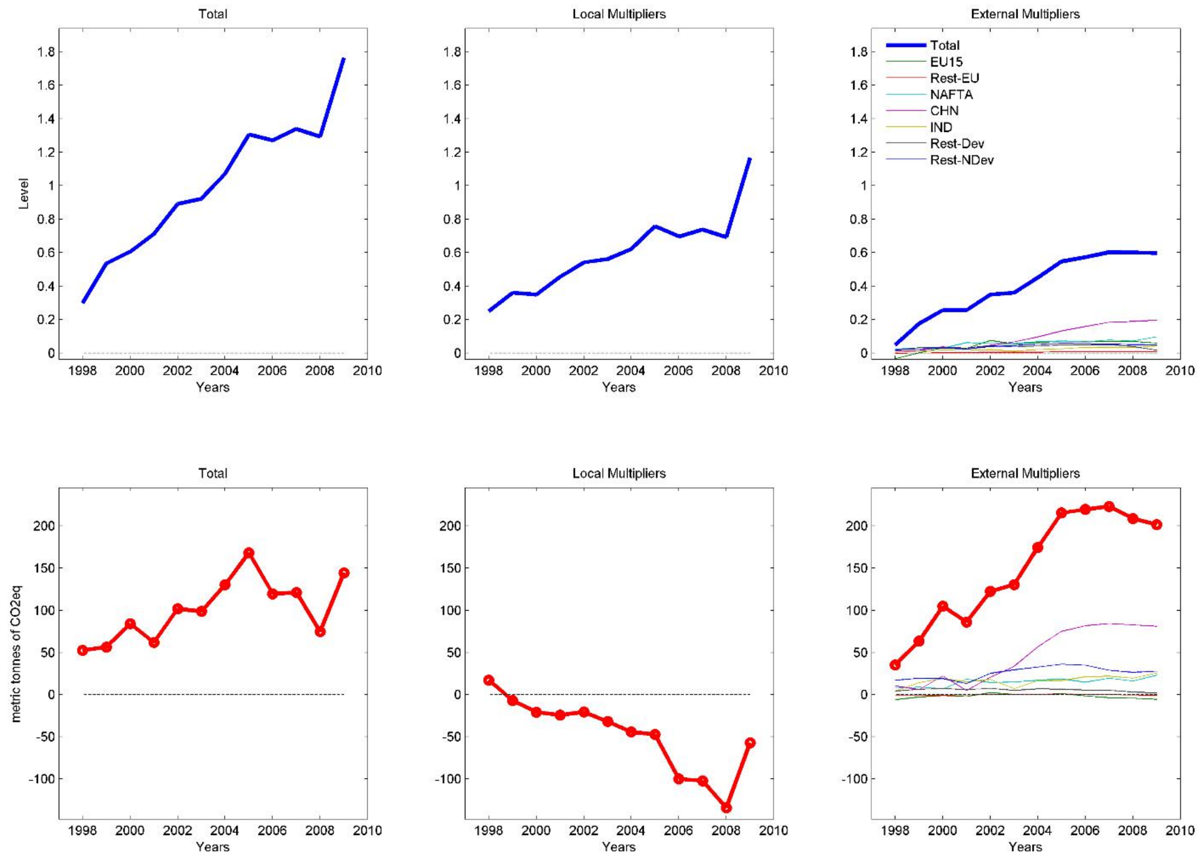

Figure 3 - Trends in accumulated temporal impacts of an income increase in the US

We apply the Level 1 decomposition to isolate the effects of each partition in explaining the multiplier paths described in Figure 3. Changes in households' expenditure pattern have a growing positive influence in both local and external spillovers as well as emissions, especially after 2001 (see columns LO and EO in Figures 4 and 5). The overall picture highlights growing local multipliers for services, households and trade fueled by both increasing consumption of domestic services and expanding linkages of these sectors with the rest of the US economy (LO top). Local consumption shifts towards domestic service sectors creates indirect spillover effects in foreign manufacturing and service industries (LO bottom). GHG emissions follow these trends, but they are generated via different channels. Locally, the increasing spillovers of labor intensive service industries leads to higher induced effects, introducing increasing emissions from households. Externally, manufacturing industries are responsible for most of the pollution. The EU-15 benefits the most from these LO leakages even though China and other developing countries bear most of it pollution costs.

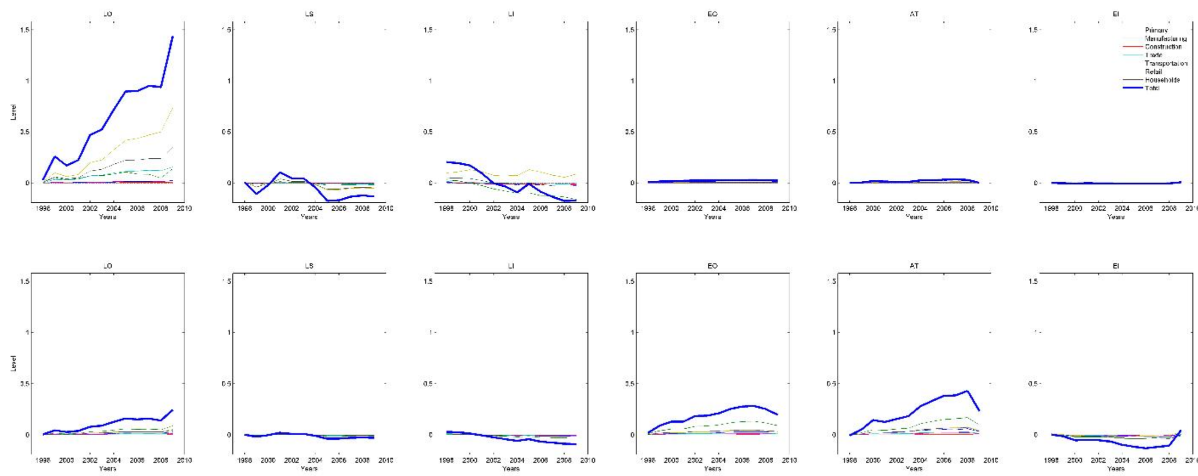

Figure 4 – Trends in decomposed accumulated temporal impacts, multipliers (local effects top, external effects bottom)

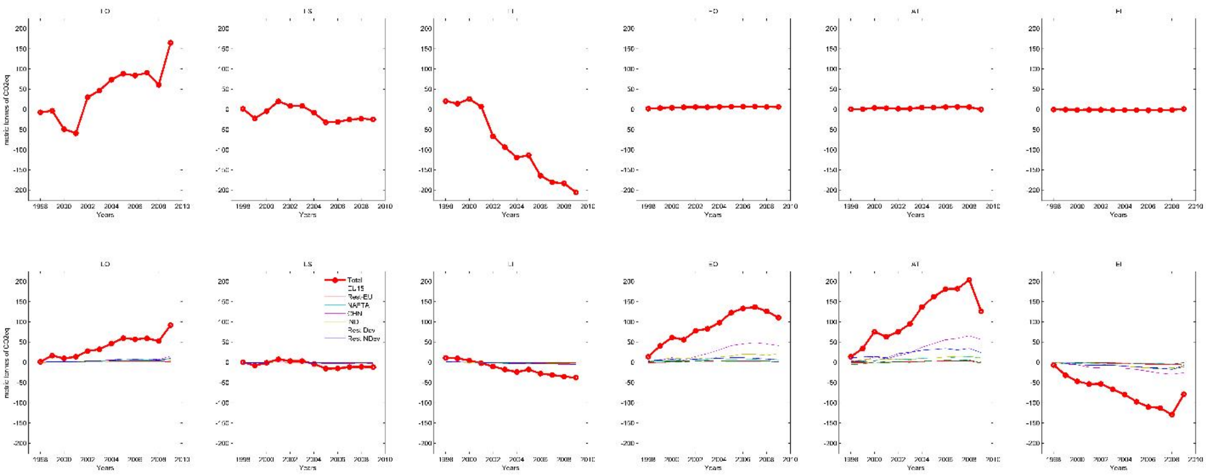

Figure 5 – Trends in decomposed accumulated temporal impacts, emissions (local effects top, external effects bottom)

Figure 4 also shows growing external multipliers for manufacturing (EO bottom), reflecting a spatial substitution effect from local to external manufacturing consumption. Pollution follow suit, impacting particularly China and India.

Notice that changes in interindustrial relationships in the US exhibit an overall negative trend, i.e., internal structural changes are diminishing spillover effects from income. Such downward trend is stronger in manufacturing due to outsourcing, although it benefits service industries, whose spillovers increase. The negative effect in the former is the main factor leading to a decline in local emissions from interrelational effects. These weaker multipliers in manufacturing also spillover to external linkages that decline together with pollution.

The dynamics observed in local income effects (LI) is due to labor market variations during the period (Figure 6). The declining trend observed post-2001 is driven by short recession period following the dot-com bubble and 9/11 with increasing unemployment rate and unemployment duration, leading to a spike in part-time jobs due to losses in permanent positions. These led to a significant decline in household income during the period, corroding induced effects and local multipliers.

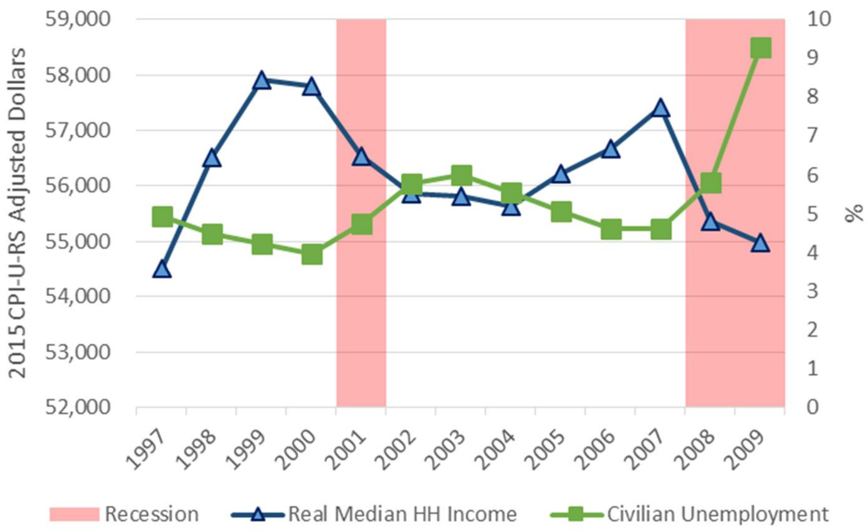

Figure 6 – Income and Employment Indicators for the US, 1997-2009 (Source: FRED, BLS, NBER)

In the external side, changes in import composition and trade patterns worldwide are the main drivers of the external emission multiplier increase. Interestingly, trade effects (AT bottom) and external interrelational effects (EI bottom) shed light into the fragmentation process discussed in Jones and Kierzkowski (1990, 2005) and Romero *et al*. (2009). They indicate that most linkages (and consequently spillovers) are shifting from intra to interregional feedbacks, a clear reflection of longer production chains where production fragmentation induces shorter manufacturing in more locations, introducing smaller intra-regional spillovers and larger inter-regional ones.

Given the importance of both external own effects, trade effects and external interrelational effects, we further decompose these partitions by regions to explore their role in these externalities.

The Level 2 decomposition for external own effects is presented in Figures 7 and 8. Decomposing the effects of changes in the import structure of American households, one clearly notices that the largest portion of the aggregated positive spillovers are driven by import changes from China that significantly grow after 2001 until the 2008 crisis. External manufacturing sectors concentrate most of these spillovers, but primary and service sectors, as well as foreign income also share the increase. Changes in American consumption of commodities from NAFTA also led to positive local and external spillovers that stabilized after 2001, a similar trend to EU-15 and other developed countries import effects. Pollution patterns follow the overall spillover effects, concentrating emissions in the countries where products originate.

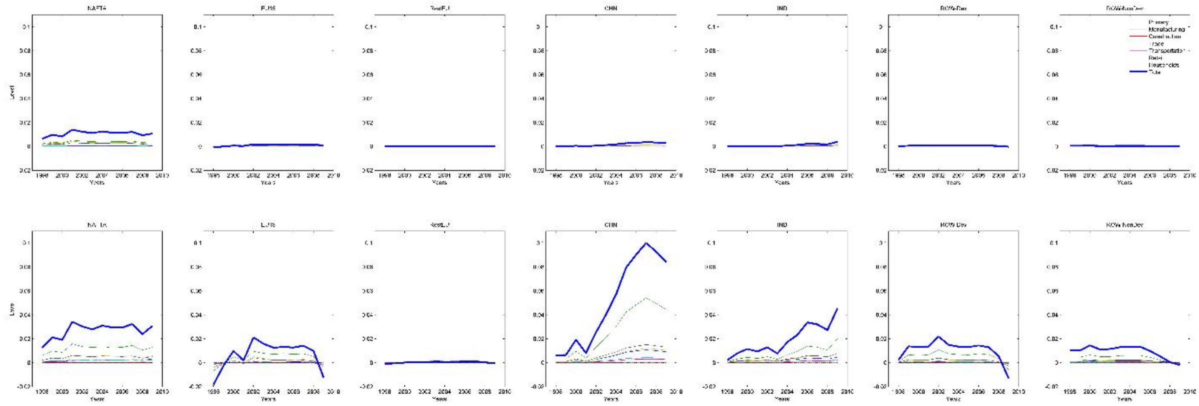

Figure 7 – Trends in decomposed accumulated temporal impacts of external own effect, multipliers (local effects top, external effects bottom)

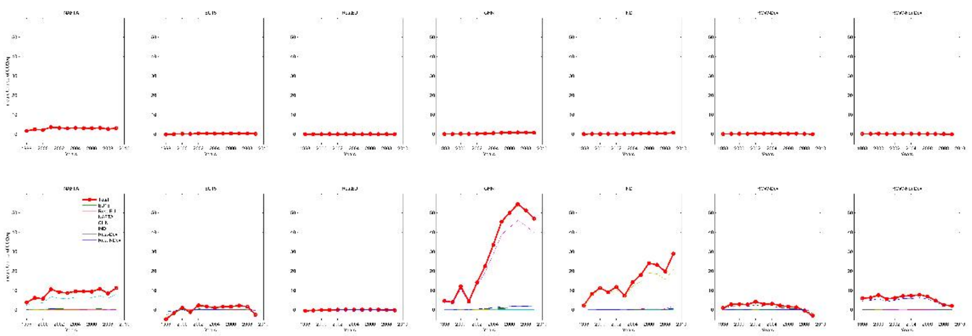

Figure 8 – Trends in decomposed accumulated temporal impacts of external own effect, emissions (local effects top, external effects bottom)

Changes in trade patterns of US industries led to a strong growth in external spillovers throughout the period, particularly in primary, manufacturing and service sectors, besides positively influencing income abroad (Figure 9). Spatially, China and the other NAFTA countries captured most of these gains, followed in a lesser degree by developing nations. In fact, Chinese gains surpassed those of NAFTA after 2004. Such trade changes also benefited the local US economy, although partially offset by a decrease in local spillovers induced by changes in NAFTA's imports. The latter actually increased external spillovers that mainly benefited China.

Changes in Chinese external backward linkages through imports had almost no effect on spillovers from American households, negatively influencing them in the 2008 recession. Evolving trade patterns in the EU-15 positively influenced spillover effects, particularly benefiting the own region and developing countries. Finally, changes in imports of developing nations also induced an increase in spillovers outside the US, with EU-15, China, developing nations and other developed nations benefiting the most from these economic leakages.

Environmental effects closely track spillovers' trends, but they are spatially concentrate in China and developing nations (Figure 10). These growing emission trends are mostly driven by intermediate import changes in the US, EU-15 and other developing nations. Overall, developed countries benefit from trade changes either reducing their emissions from income increases in the US or showing minimal changes.

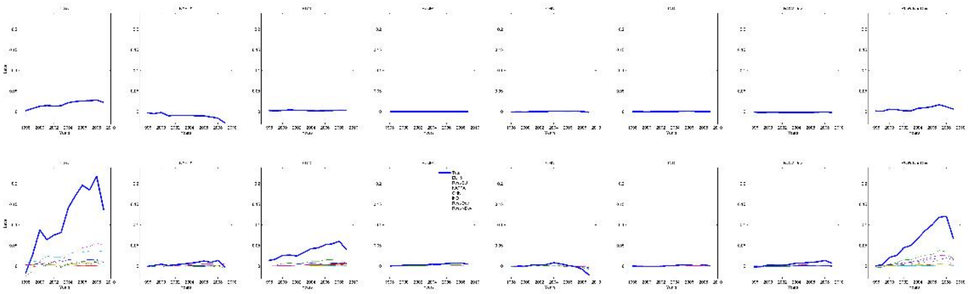

Figure 9 – Trends in decomposed accumulated temporal impacts of trade, multipliers (local effects top, external effects bottom)

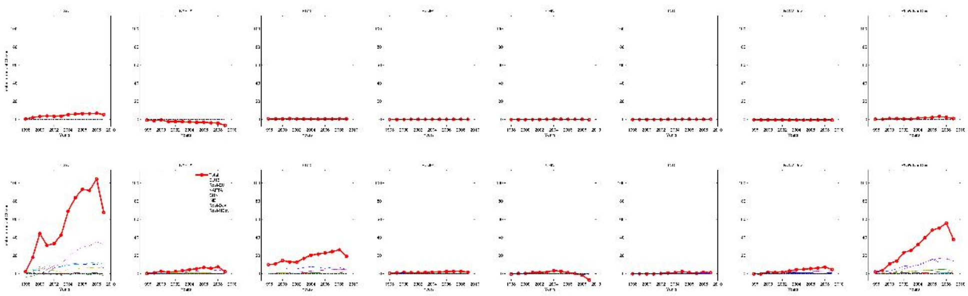

Figure 10 – Trends in decomposed accumulated temporal impacts of trade, emissions (local effects top, external effects bottom)

The structural transition experienced by developed countries towards service industries with outsourcing of most manufacturing sectors has reduced spillovers from American households and increased spillovers in China (Figure 11). Changes in the intra-regional linkages in Canada and Mexico also contributed to the increase in external multipliers (especially for NAFTA). The overall negative trend observed in Figure 4 is mainly due to EU-15, other developed nations and ROW.

The somewhat unintuitive result that Chinese internal structural changes both produce larger economic spillover effects and smaller emissions is not surprising when we consider [Peters *et al*. 2007; Yuan and Zhao, 2016] (Figure 12). This implies that China's efforts in mitigating pollution without compromising growth are working. In fact, pollution increases induced by increasing income in the US are not due to China, but the US change in import pattern from industries (mainly) and direct final demand consumption.

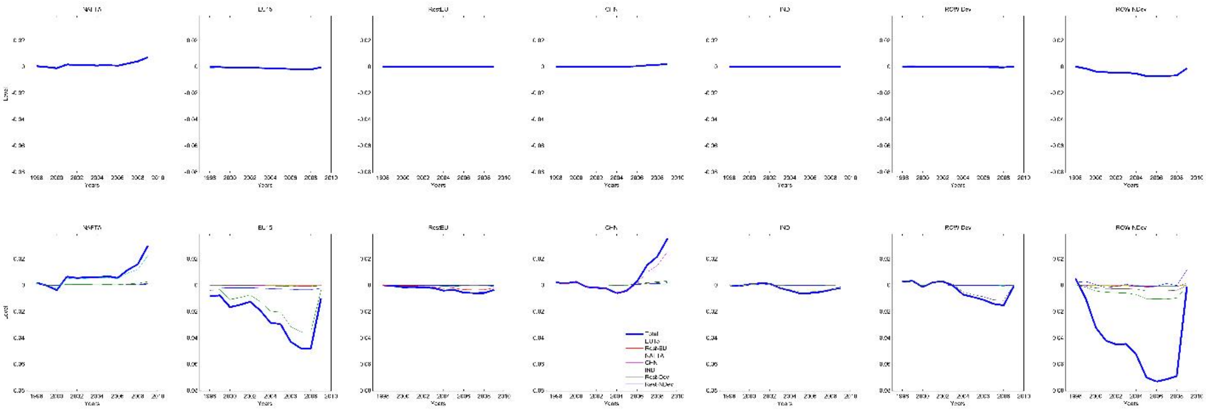

Figure 9 – Trends in decomposed accumulated temporal impacts of external interrelational effects, multipliers (local effects top, external effects bottom)

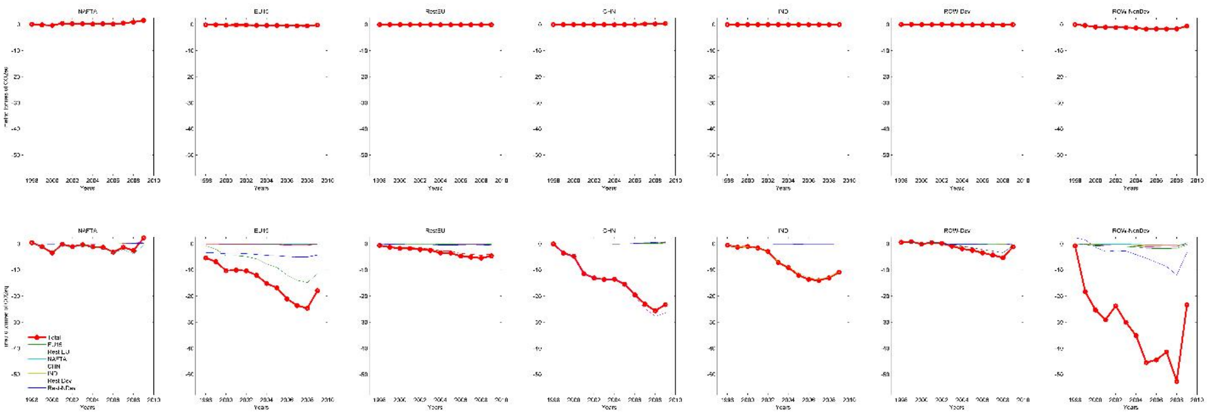

Figure 10 – Trends in decomposed accumulated temporal impacts of external interrelational effects, emissions (local effects top, external effects bottom)

5. Conclusions

[IN DEVELOPMENT]

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