NZIPL Research Statement

Modeling Multi-Regional Macroeconomic Dynamics of Industrial and Trade Policy

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12 March, 2025

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Overview

In addition to my computational and data visualization skills, this document reviews my work on ecological macroeconomic models and the input-output structure of economic production, which follows very closely the agenda of the Net Zero Industrial Policy Lab. It is structured as follows: first, I briefly theoretical review the powerful theoretical framework of stock-flow consistent modeling, which a team at the World Bank headed by Étienne Espagne, Sebastián Valdecantos, and others is already recently working on. Then, I examine our own SFC model for the EU-funded JUST2CE project developed as research fellow at Leeds University, whose main contribution with respect to other ecological macroeconomic models was its multi-regional scope. The MRIO model reveals many important policy insights, which I am now documenting in a paper for *Ecological Economics*. Then, I present a novel data-driven model of multi-sector growth that I developed for my PhD dissertation (Vallès Codina, 2023; Vallès Codina & Semmler, 2024), which I used to explore decarbonization policies such as tax-subsidy schemes that also reduce inflationary pressures. Extensions of this model I want to work on encompass including limited natural resources and tariffs in a two-region setup. Finally, I briefly examine my work for the UCL Institute for Innovation and Public Purpose, where I studied the input-output structure of six middle-income economies.

Stock-Flow Consistent Modeling

Brief Theoretical Excursus

Stock-flow consistent models offer a comprehensive framework for analyzing economic dynamics, ensuring that all stocks and flows are accounted for in a coherent manner (Caverzasi & Godin, 2015; Godley & Lavoie, 2006; Nikiforos & Zezza, 2017). These models are complex dynamical systems of mainly discrete-time difference equations that provide a systematic framework for the dynamical analysis of the complex institutional structure of whole socio-economic systems, using 1) careful, rigorous double-accounting of the stocks and flows through extended social accounting and flow-of-funds matrices and

2) sets of behavioral equations (Caverzasi & Godin, 2015; Nikiforos & Zezza, 2017). The careful book-keeping framework allows to capture all the relevant dynamic interdependencies among variables of the economic system that other approaches may neglect.

Hence the main value-added contribution of early SFC models was their consistent and comprehensive integration of the flows and the stocks for both the real and the financial sides of the economy, which allowed them, unlike conventional macroeconomic models, to successfully anticipate both the 2008 Global Financial Crisis and the 2010-12 Eurozone sovereign debt crisis (Godley, 2012b, 2012a; Godley & Lavoie, 2006). In the pressing context of the climate crisis, a SFC analysis is particularly well-suited to capture the complex dynamic interactions between the environment and the economy (Dafermos et al., 2017, 2018; Jackson & Victor, 2020). SFC models belong to the broader family of system dynamics, of widespread use in the natural sciences and engineering, yet without the optimal control that characterizes conventional macroeconomic models.

Within the broad field of ecological macroeconomics, the integration of environmentally-extended input-output (EE-IO) analysis with stock-flow consistent (SFC) modeling is one of the most promising methods for the simulation, evaluation, and comparison of sustainable strategies and their social outcomes due to its formal treatment of system dynamics, the complex institutional structure of the economy, and the distribution of income (Hardt & O'Neill, 2017). Personal distributions in income inequality can be incorporated using the framework of Dafermos & Papatheodorou (2015). The current and most important challenge of ecological SFC models is the formal treatment of the open economy at the industry level, which would allow a sector-specific understanding of within-country and cross-country economy-environment interactions to better inform government policy at mitigating and adapting to climate change (Berg et al., 2015; Carnevali et al., 2020). At this moment, most ECO-SFC models still aggregate the economy into one or very few sectors, in particular the energy sector (Canelli et al., 2024; Carnevali et al., 2020; Naqvi, 2014; Valdecantos & Valentini, 2017). ECO-SFC models focus on climate and energy transition risks (Dunz et al., 2021; Magacho et al., 2023; Monasterolo & Raberto, 2018), emissions modeling in an SFC macro setting (Naqvi & Stockhammer, 2018; Valdecantos & Valentini, 2017), and the dynamic interactions between the economy and the environment (Canelli et al., 2024), while often only considering aggregate output and thus overlooking the vertical interdependencies between different industries (Carnevali et al., 2020; Dafermos et al., 2017). This also precludes the dynamical analysis of technological upgrading along the value chain, with the exception of Naqvi (2014). Finally, Valdecantos & Mazier (2015) and Valdecantos & Zezza (2015) analyzed potential reforms of the European and global financial monetary system in a multi-regional context, albeit without an industrial structure.

In short, the SFC approach is particularly suited for:

- **Capturing Complex Institutional Interactions** empirically informed by input-output databases and national accounts, SFC models can capture the system-wide interactions between the environment and the economy, including as well as the financial sector, households, and firms, providing a holistic view of economic dynamics.
- **Policy Analysis** These models are powerful tools for dynamic multi-dimensional policy analysis, enabling the simulation of various policy scenarios and their potential impacts on the economy.
- **Incorporating Social and Ecological Dimensions** By integrating social dimensions such as inequalities in gender, class and labor skills, as well as the ecological impact of economic activity empirically informed by environmentally-extended input-output databases such as EXIOBASE (Stadler et al., 2018) or EORA (Lenzen et al., 2013), SFC models can address issues of sustainability and inequality.

EU-funded JUST2CE 2-region project (at Leeds)

The SOCIO-ECO-MRIO SFC macroeconomic model of Passarella, Vallès Codina, et al (Bimpizas-Pinis et al., 2024) included a two-region input-output economic structure with 54 industries, as well as social and ecological extensions, developed for the EU Horizon 2020 JUST2CE project on a socially just transition to a circular economy. A net-zero, circular economy is one of five priorities for the Biden-Harris Administration's *Net-Zero Game Changers Initiative*, while in March 2020 the European Commission adopted the new *Circular Economy Action Plan*, one of the main building blocks of the European Green Deal. The circular economy transition is an essential condition for a resilient industrial system that facilitates new kinds of economic activity, strengthens competitiveness and generates employment (Bastein et al., 2013).

From a geopolitical perspective, circular-economy experts emphasize that nations that transition to a circular economy the earliest will benefit from a first-mover competitive advantage to sell their products internationally (McCarthy et al., 2018; Rizos et al., 2015).

In contrast to most, if not all, current ecological macroeconomic models that are single-region (such as the empirical models developed by the French Development Agency), our model was empirically calibrated to simulate a world economy with two regions, the EU and Rest of the World, with a focus on circular-economy interventions in the Global North such as reducing consumption, closing supply chain loops, more selective government spending, or extending product lifetimes. A main insight from the project are the intricate dynamical interactions between the environment and the core-periphery structure of the world economy (known in the literature as 'ecologically unequal exchange'), in which the low-income economies of the Global South are drained of financial, labor and environmental resources in favor of the richer economies of the Global North, while the Global South is to suffer the brunt of the climate crisis (Dorninger et al., 2021; Hickel et al., 2022). This can be shown employing network analysis of the world input-output table employed in the model.

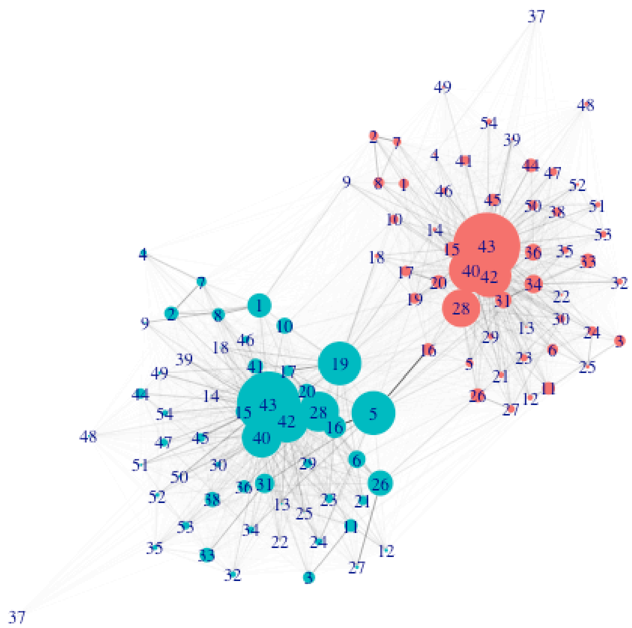


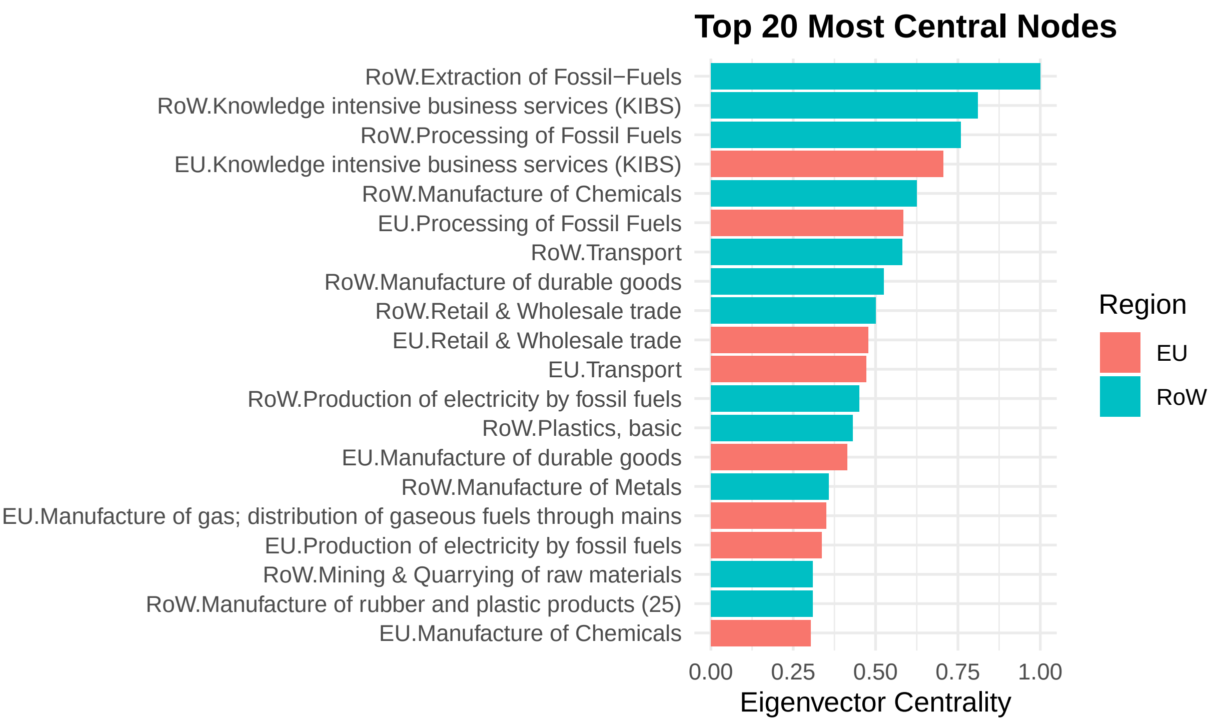
Figure 1: EU (red)-RoW (green) network of global input-output production (nodes are industries, edges are production links, industry list on the next page)

Table 1: List of Industries

number	industry
1	Agriculture
2	Animal Farming
3	Forestry, logging and related service activities (02)
4	Fishing, operating of fish hatcheries and fish farms; service activities incidental to fishing (05)
5	Extraction of Fossil-Fuels
6	Mining & Quarrying of raw materials
7	Processing of meat
8	Processing of other food&beverage
9	Manufacture of tobacco products (16)
10	Manufacture of textiles
11	Manufacture of wood and of products of wood and cork, except furniture; ... (20)
12	Re-processing of secondary wood material into new wood material
13	Pulp
14	Re-processing of secondary paper into new pulp
15	Paper
16	Processing of Fossil Fuels
17	Plastics, basic
18	Re-processing of secondary plastic into new plastic
19	Manufacture of Chemicals
20	Manufacture of rubber and plastic products (25)
21	Manufacture of glass and glass products
22	Re-processing of secondary glass into new glass
23	Manufacture of other non-metallic mineral products
24	Manufacture of cement, lime and plaster
25	Re-processing of ash into clinker
26	Manufacture of Metals
27	Re-processing of Metals
28	Manufacture of durable goods
29	Manufacture of furniture; manufacturing n
30	Recycling
31	Production of electricity by fossil fuels
32	Production of electricity by renewable energy
33	Transmission & Distribution
34	Manufacture of gas; distribution of gaseous fuels through mains
35	Water
36	Construction (45)
37	Re-processing of secondary construction material into aggregates
38	Sale, maintenance, repair of motor vehicles, motor vehicles parts, motorcycles, ...
39	Retail sale of automotive fuel
40	Retail & Wholesale trade
41	Leisure Services
42	Transport
43	Knowledge intensive business services (KIBS)
44	Real estate activities (70)
45	Renting of machinery and equipment without operator and of personal and household goods (71)
46	Research and development (73)
47	Public administration and defence; compulsory social security (75)
48	Education (80)
49	Health and social work (85)
50	Incineration of Waste
51	Biogas & Composting
52	Waste water
53	Landfill of Waste
54	Other Services

Table 2: Top 10 Strongest Links

from	to
RoW.Extraction of Fossil-Fuels	RoW.Processing of Fossil Fuels
RoW.Extraction of Fossil-Fuels	EU.Processing of Fossil Fuels
RoW.Manufacture of Chemicals	RoW.Plastics, basic
RoW.Manufacture of Metals	RoW.Re-processing of Metals
RoW.Animal Farming	RoW.Processing of meat
RoW.Agriculture	RoW.Processing of other food&beverage
EU.Animal Farming	EU.Processing of meat
RoW.Forestry, logging... (02)	RoW.Manufacture of wood and of products of wood and cork, ... (20)
EU.Plastics, basic	EU.Manufacture of rubber and plastic products (25)
RoW.Production of electricity by fossil fuels	RoW.Transmission & Distribution



Currently, I am working to publish the results of our research with Annina Kaltenbrunner, Effie Kesidou, Marco V. Passarella and J. B. R. T. Fevereiro, hopefully at *Ecological Economics*. Our main argument is that under this global context of interconnected production based on ecologically unequal exchange, sustainability strategies exclusively focused on the Global North may seriously threaten economic growth, employment, and financial stability in the Global South, positing the urgent need for a global scope in green policies that include the sustainable development for low- and middle-income economies, especially if compensating policies from the Global North such as the cancellation of Global South public debt are not implemented. At the moment, I am working to explicitly introduce carbon taxes and carbon tariffs in the model as well as migration flows.

Our model allowed to examine in a stylized way the social, economic, and ecological impact of many policies on the two regions:

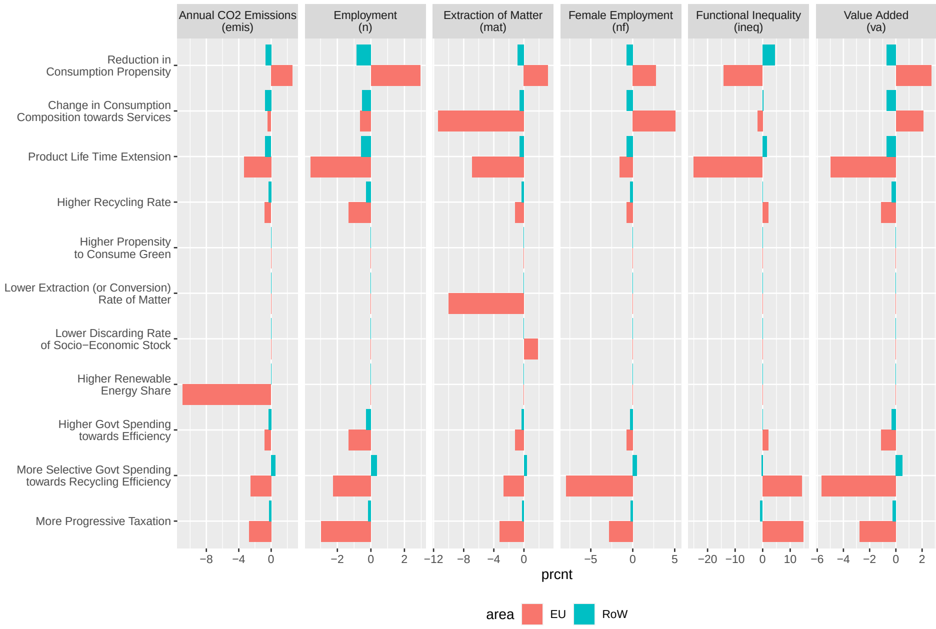


Figure 2: Social, Economic, Ecological Impact of Circular Economy Interventions

or, alternatively, specific complex interventions aimed at product lifetime extension, involving changes in aggregate government real investment, depreciation rate, sector-level household consumption, sector-level durable consumption, and investment:

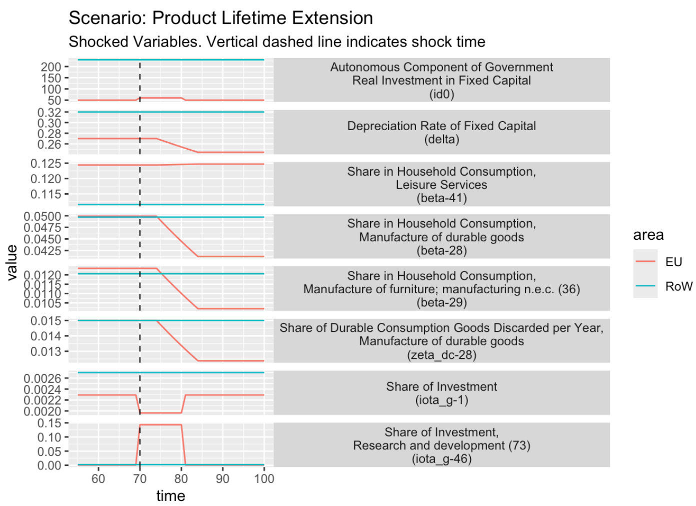


Figure 3: Complex Intervention on Product Lifetime Extension

examining their impact on social, economic, financial, and ecological variables:

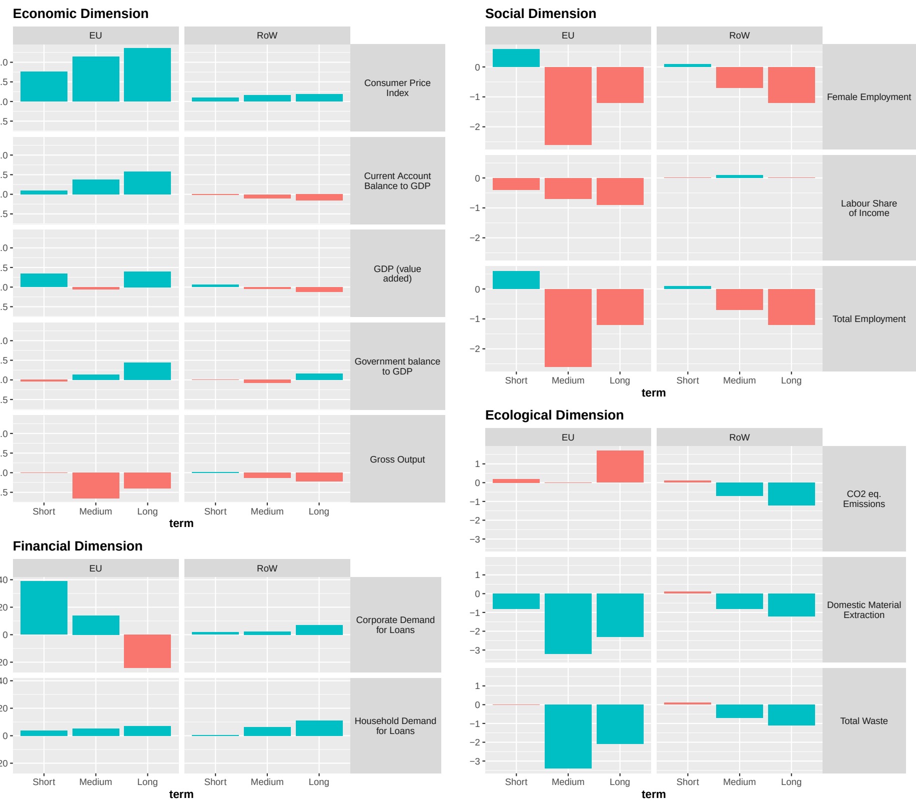


Figure 4: Complex Impact of Product Lifetime Extension

At this moment, the research output of this project amounted to many deliverables and policy reports for the European Commission, available here. In addition, a publication (Fevereiro et al., 2025) was accepted with minor revisions at *Ecological Economics*, a review of the literature on the macroeconomic modeling of the circular economy using a input-output approach.

An important challenge for the proper development of the model into a full multi-regional setup is introducing a flexible exchange rate, which forces the adoption of more complex solver methods than the standard Gauss-Seidel approach (namely, the Broyden solver). Such complication explains why many complex SFC models do not address a flexible exchange rate – a specially critical issue for developing economies. The model may have to be re-coded in `Julia`, which is built to solve optimization and dynamics.

Current Work for the French Development Agency

The French Development Agency is known for developing some of the most sophisticated empirical models for single countries, developing economies more specifically: namely, Tunisia, studying the exposure of its agriculture sector to climate change (Yilmaz et al., 2025); Colombia, studying the exposure of its oil exports to the low-carbon transition by oil-importing countries (Godin et al., n.d.); Vietnam (Magacho et al., 2023), and now Mexico, in collaboration with the Mexican Treasury (Hacienda) and the Central Bank (Banxico). The models are empirically tailored for each country, carefully parsing its national accounts and flow-of-funds accounts in cooperation with government agencies. The industry list covered encompasses agriculture, non-financial firms, energy, the government, and the financial sector. The econometric estimation of the parameters involved is done through the method of simulated moments, but more sophisticated Bayesian approaches are also being employed.

My interest in working with them was due to learning how empirical SFC models are developed at the highest level.

Data-Driven Dynamical Systems of Multi-Sector Growth

In my most recent publications at the *Journal of Economic Behavior and Organization* (Vallès Codina, 2023) and the *Jahrbücher für Nationalökonomie und Statistik* (Vallès Codina & Semmler, 2024), I developed a novel data-driven dynamic model of multi-sector growth incorporating technical change to evalaute how sector-oriented fiscal policies -such as price and quantity controls (e.g. the EU gas price cap) and tax-subsidy schemes (e.g. the US Inflation Reduction Act)- can promote decarbonization while stabilizing inflationary pressures in strategic industries. Extensions of this model I want to work on encompass including limited natural resources and tariffs in a two-region setup.

The general composite model allows to empirically characterize the network structure and intensity of dynamic price-quantity interactions at the sector level, which capture heterogeneous firm behavior by integrating long-run Walrasian price and classical quantity dynamics coupled with short-run Keynesian features in the form of target rate of return pricing and demand-led investment. A Bayesian hierarchical model on US BEA data empirically estimates the linear adjustment coefficients and stable combinations are computed. The US economy is shown to feature a highly hierarchical network structure of intermediate production that is particularly vulnerable to micro-economic shocks driven by wars and climate change. By effecting directed technical change, tax-subsidy schemes are shown to be the most effective in reducing inflationary pressures and economy-environment interactions at the same time.

Goodwin Classification of Micro-Economic Adjustment Processes (Goodwin, 1983)

Category	Process	Description
{**Cross-Dual**	*Walrasian Law of Excess Demand*	if demand d_i is above (below) supply x_i, price p_i rises (falls)
Cross-Dual	*Classical Law of Excess Profitability*	if price p_i above (below) $cost_i$, quantity x_i rises (falls)
Dual	*Oligopolistic Markup Pricing*	if price p_i above (below) $cost_i$, price p_i falls (rises)
Dual	*Inventory Adjustment*	if demand d_i is above (below) supply x_i, quantity x_i rises (falls)

I employ an original computational method that re-purposes the classic theoretical literature in micro-economic adjustment processes (Flaschel, 2010; Hicks, 1939, 1947; Jorgenson, 1960; Mas-Colell, 1986; Morishima, 1981) to build empirically-calibrated dynamical input-output models of multi-sector growth with green process innovation and fossil-fuel process extinction within specific industries (Flaschel & Semmler, 1987, 1992). Presuming the optimality of competitive equilibrium, the *stability* of the market system is explored in this literature by considering specific adjustment processes and their dynamics out of equilibrium. These can be characterized by particular reaction coefficients in the form of stylized facts as dynamical laws of motion, which, resembling state-of-the-art machine-learning approaches, can be empirically calibrated using real training data.

In contrast to existing highly aggregated approaches like integrated assessment modeling, this novel, sector-oriented method separates prices and quantities and is highly transparent in its abstract simplicity: the baseline cross-dual adjustment in prices in quantities relies on two very stylized dynamical laws, the Walrasian law of excess demand and the classical law of excess profitability, which model industry price and quantity changes as linear reactions to supply-demand and profitability imbalances, respectively. While it can also show asymptotic convergence to equilibrium as a rest state through Keynesian dual price-price and quantity-quantity effects (see table), cross-dual stability in its simplest form generates complex Lotka-Volterra oscillations of prices and quantities around their equilibrium values. /Users/parvulesco/Documents/R/Journal of Economics and Statistics/figures/

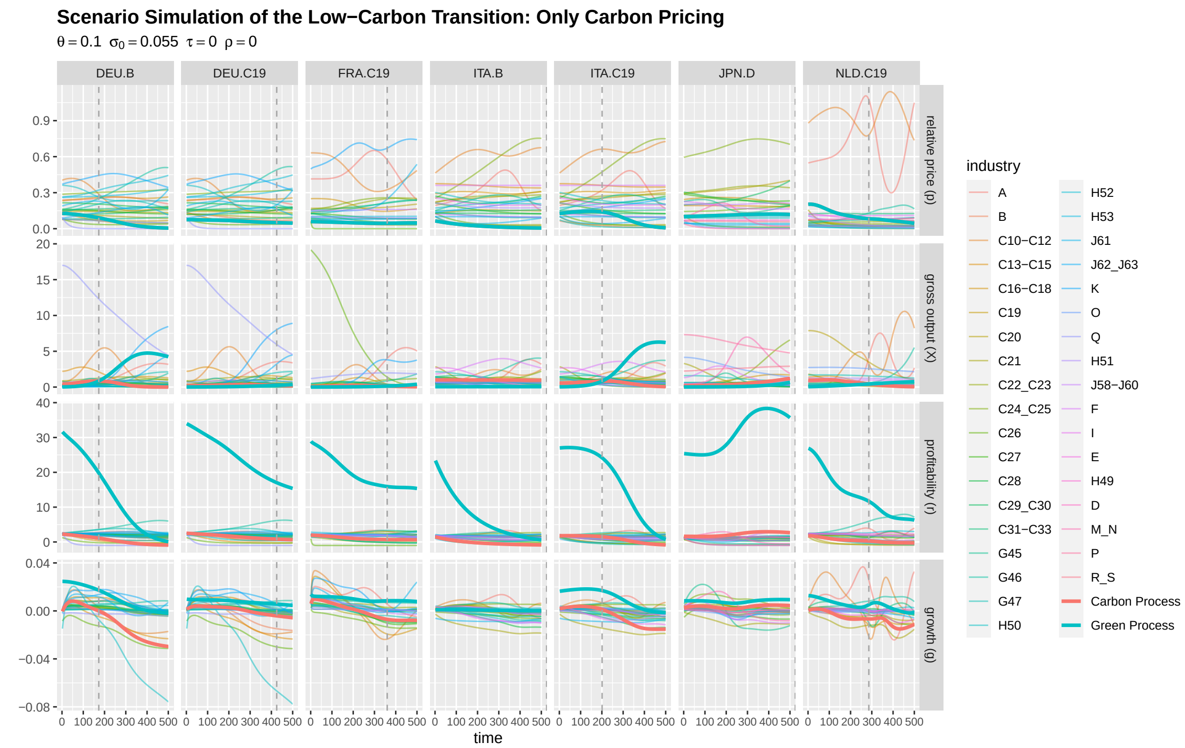


Figure 5: Sector-level decarbonization in six developed economies, with only carbon pricing: decarbonization is feasible, but takes very long

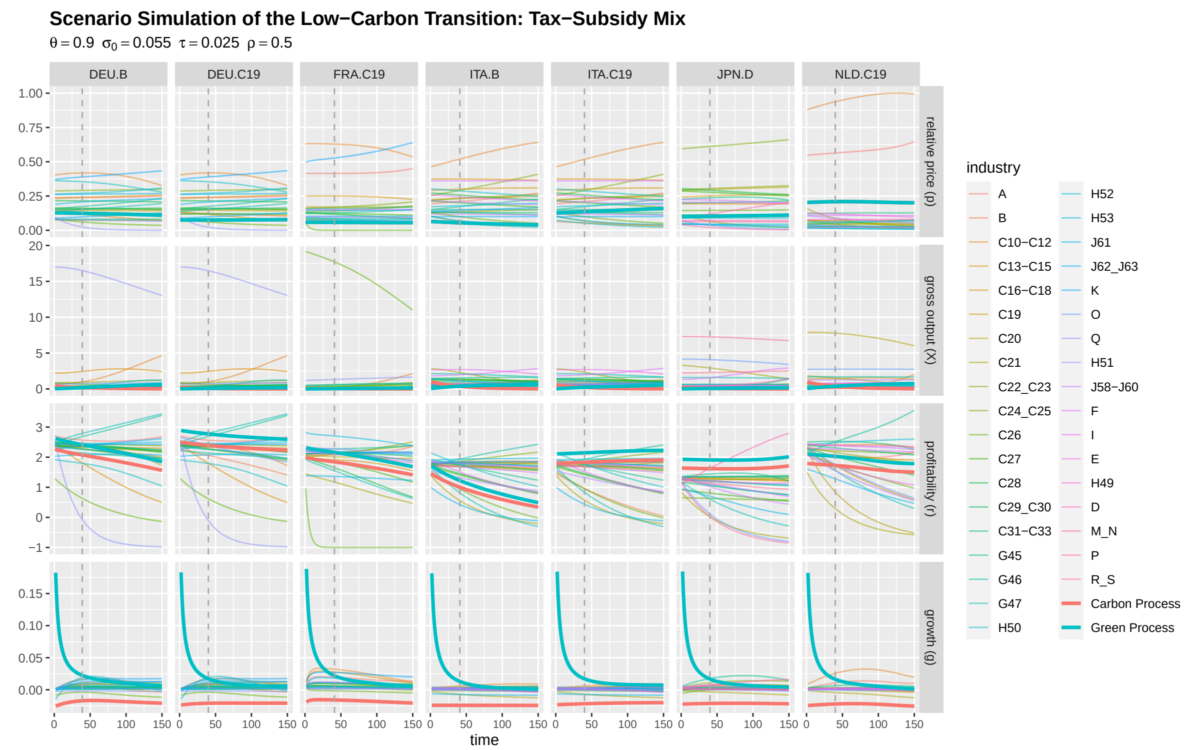


Figure 6: Sector-level decarbonization in six developed economies, with a tax-subsidy mix: decarbonization happens much faster

By impacting on the profitability and growth differentials of carbon phase-out and green phase-in in specific carbon-intensive industries, our theoretical framework shows how fiscal policy and instruments can effectively decarbonize in time to meet the Paris Agreement taking advantage of the complex, self-organizing dynamics of structural change of the market system.

Though the tax itself has an impact on the speed of decarbonization, it is significantly improved by green subsidies and green investments. The cost advantage of the green over the carbon technology is shown to have a negligible impact on decarbonization speed by itself. Without ambitious fiscal policy, especially in the form of green investment support, this substitution process appears to be too slow to reach decarbonization in a timely manner.

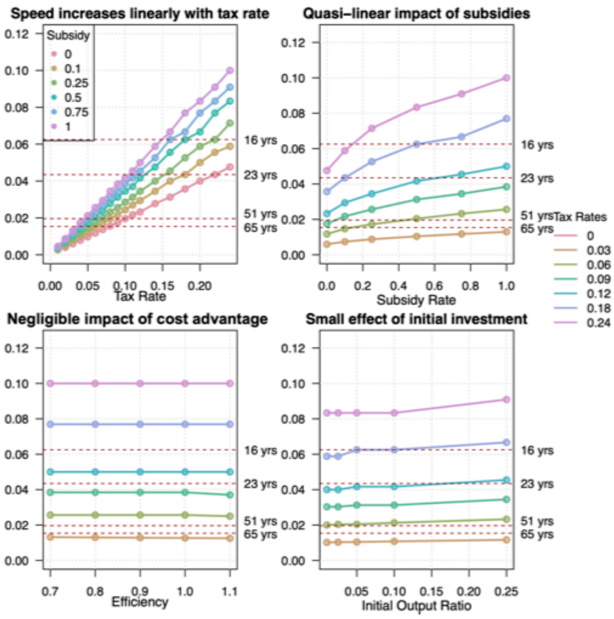


Figure 7: Impact on decarbonization speed of four policy parameters

The dynamic model evaluates the imbalances between supply and demand and in profitability using input-output tables. For the *JEBO* paper (Vallès Codina, 2023), I focused on the US, with the following structure:

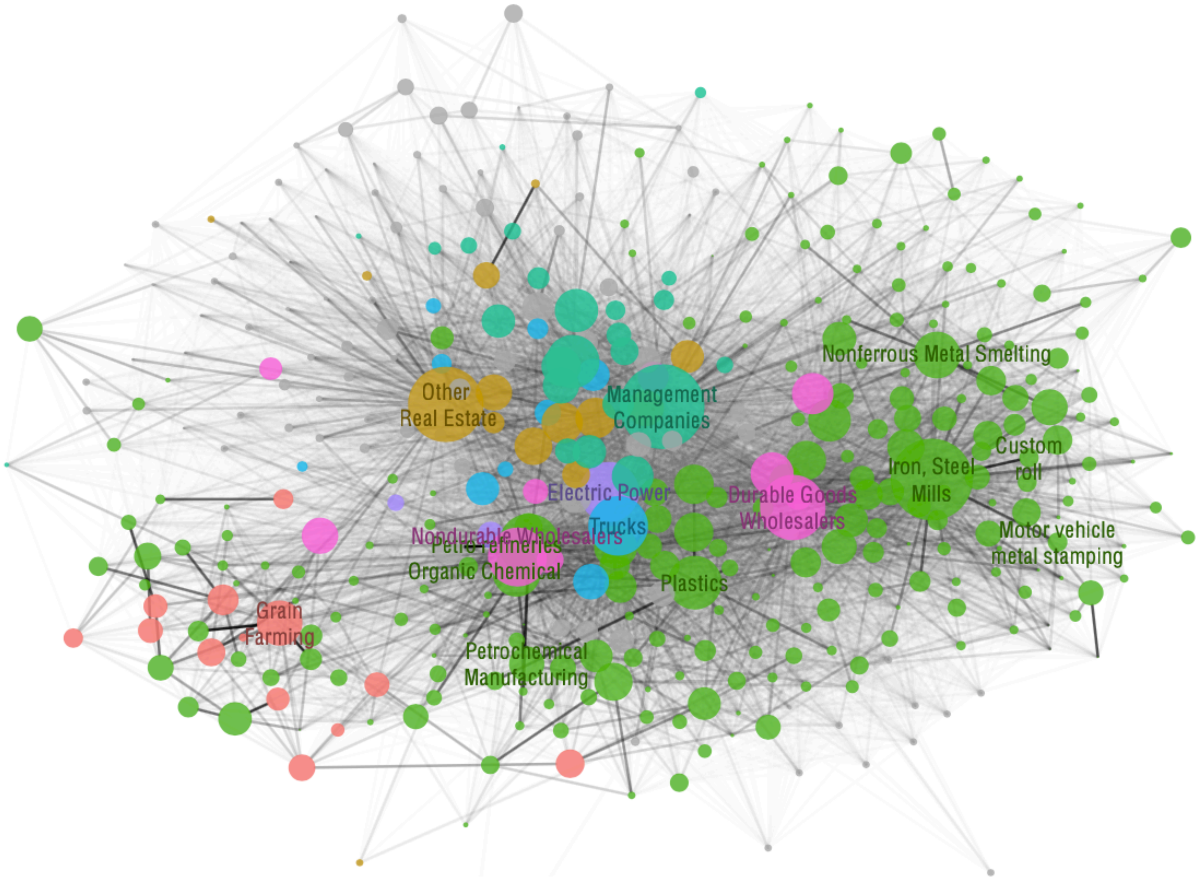


Figure 8: Visualization of the input-output linkages of 400+ industries for 2012 US BEA data, colored by its industry classification

The input-output structure of the US production network is highly hierarchical, with few very well-connected core industrial hubs (such as electricity production and distribution or iron and steel mills, especially industries corresponding to manufacturing) catering to a large number of peripheral, smaller industries as customers downstream. The top-left cluster corresponds to services, manufacturing is located on the bottom-right, and agriculture on the bottom-left. Albeit sparse, the network is tightly connected, as all nodes are connected either directly or through a third industry. The distributions of input-output linkages show that while most industries require a similar number of inputs of around 100 industries, the number of output linkages are very uneven and cluster around the extreme values of either less than 10 or 400 (that is, the whole economy): industries sell outputs either to the whole economy (such as utilities) or to less than 10 industries.Such is the asymmetric, star-shaped network structure that will considerably amplify, rather than damp, micro-economic shocks at the industry level. The following figure shows the most central nodes according to its shares of intermediate output and the standard commodity (eigencentrality), colored by its industry classification.

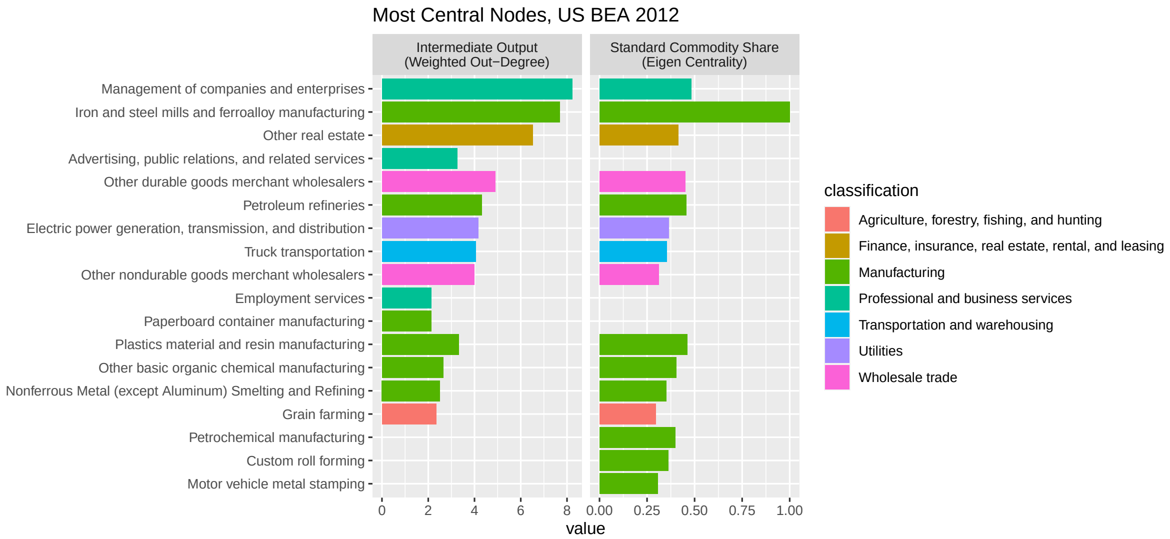


Figure 9: Most central industries in the US

I also produced ecologically-extended simulations:

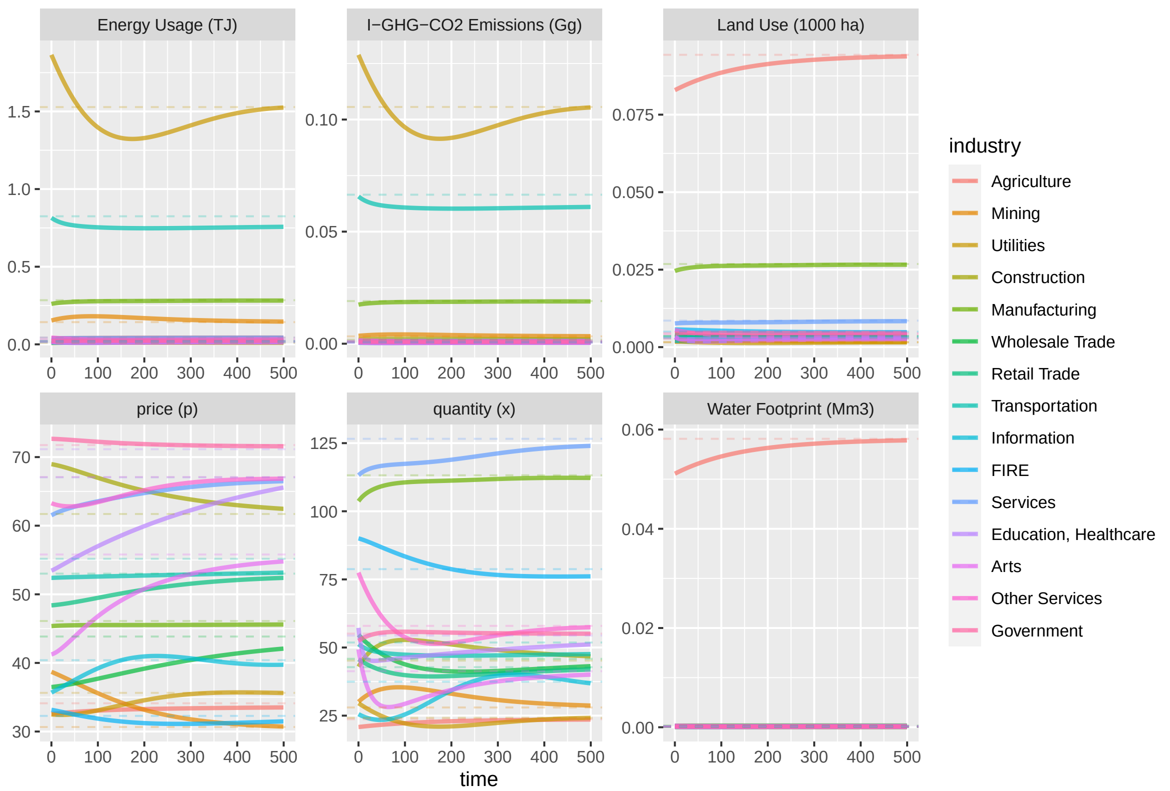
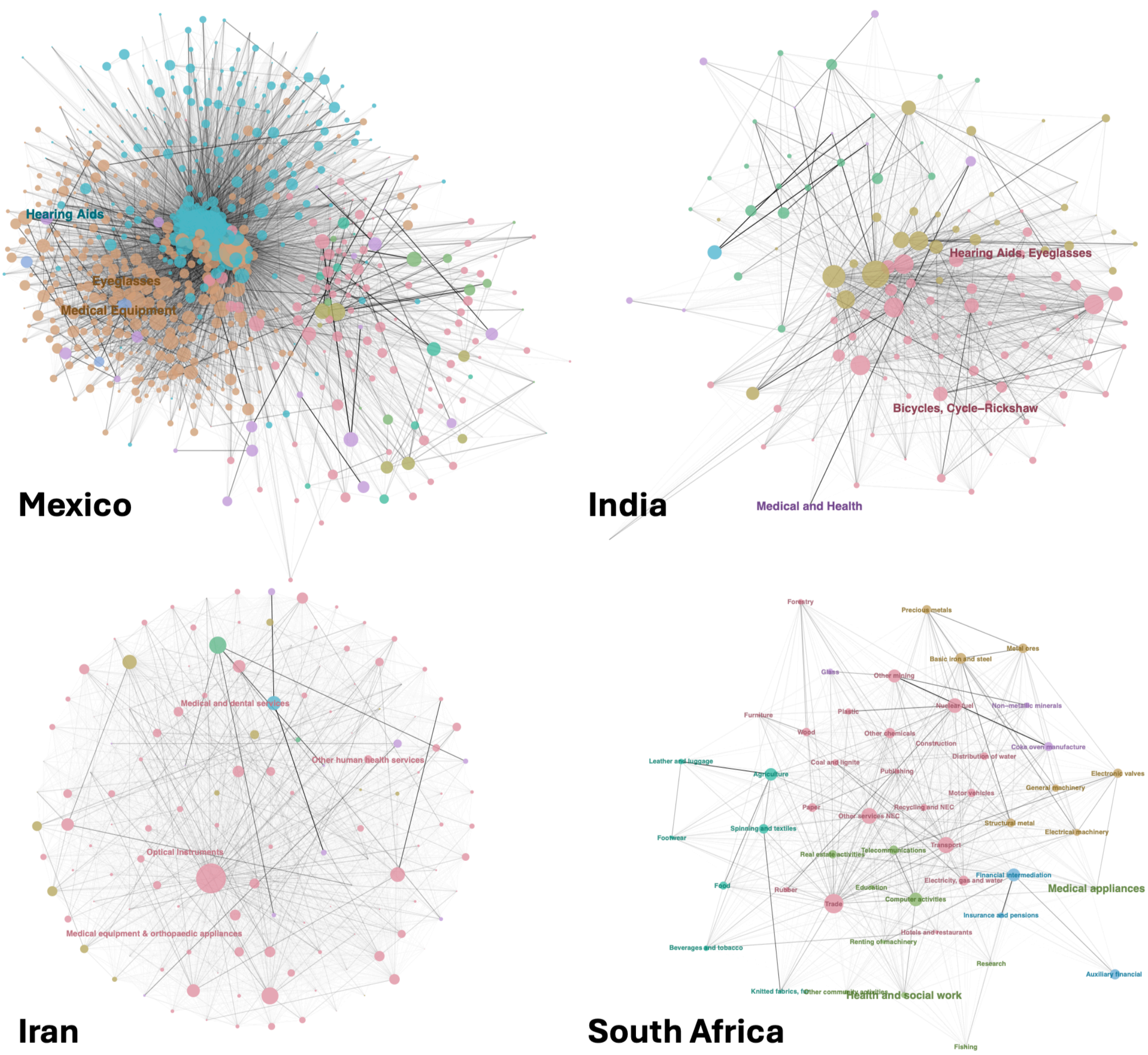


Figure 10: Ecologically-extended multi-sector growth model

Work for the UCL Institute for Innovation and Public Purpose

As research fellow at the UCL Institute for Innovation and Public Purpose, I published a working paper on the benefits of investing in universal healthcare within the input-output structure of intermediate production in seven middle-income economies (Iran, India, Mexico, Philippines, South Africa, Ukraine, Uzbekistan). Once again, the input-output structure is shown to be highly hierarchical.



Specifically, I examined the supply- or demand-led spillovers driven by sector-level investment in health along their value chains.

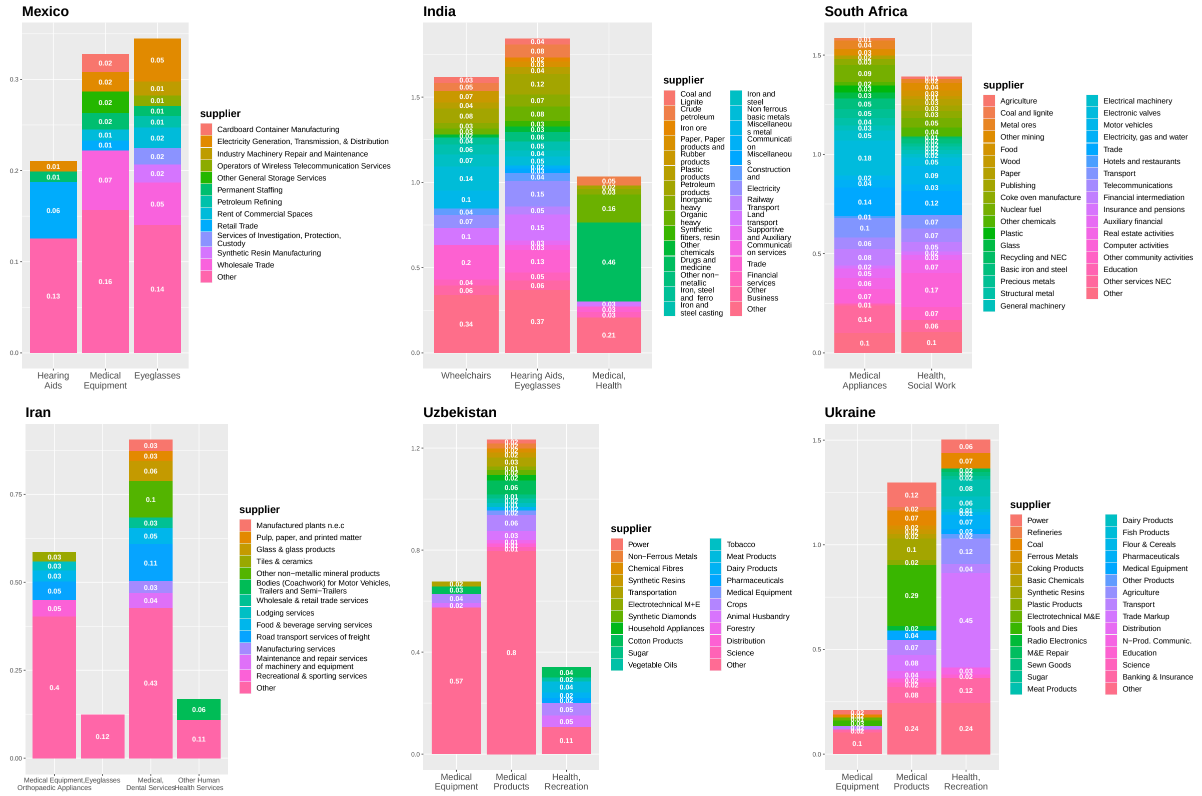


Figure 11: Total Leontief Sector Multipliers of Health Industries

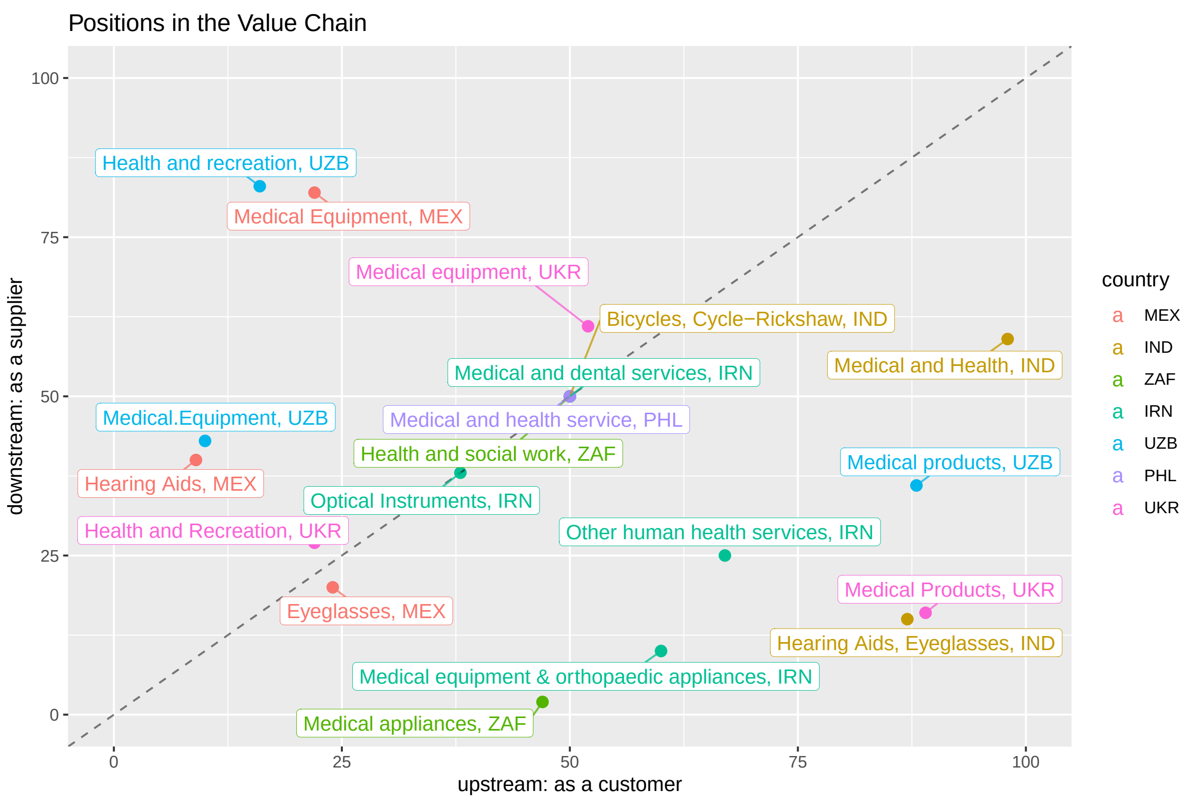


Figure 12: Positions along the Value Chain

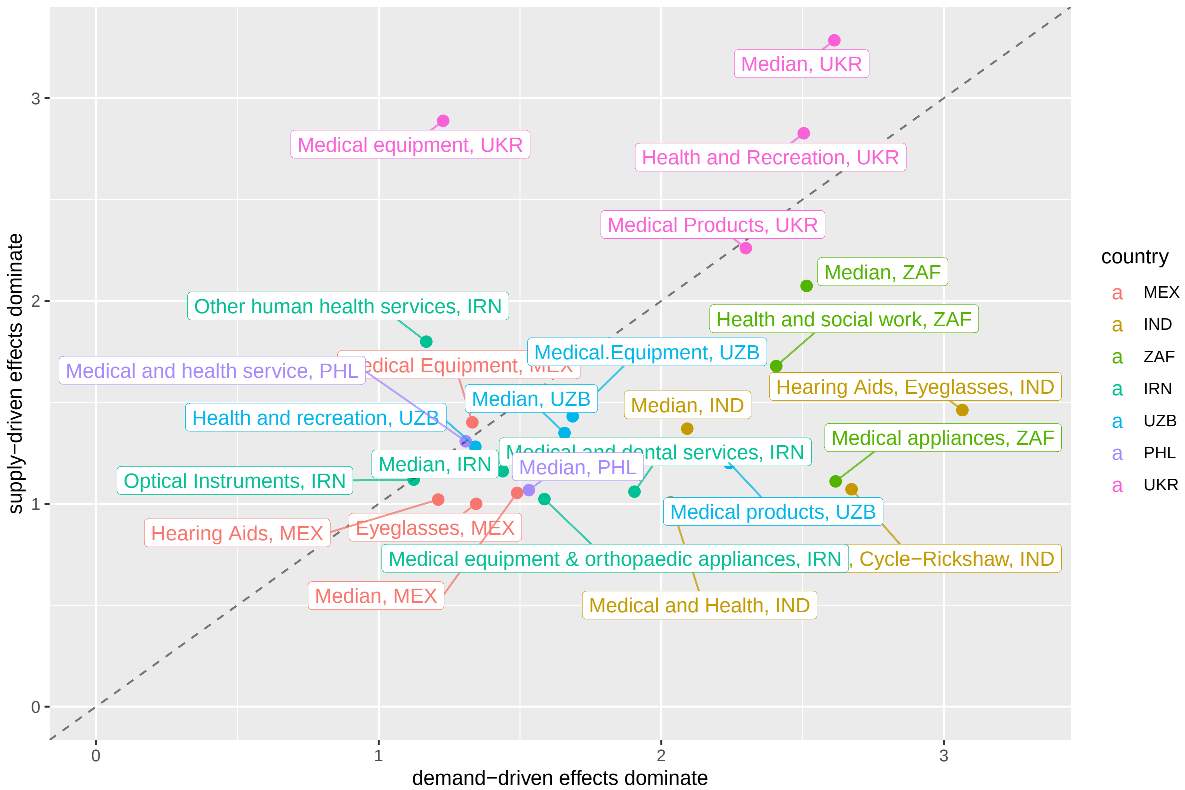


Figure 13: Spillover Effects of Sector-level Investment

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