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Dynamics matter: A simulation framework to study diffusion processes on a Dynamic Product Space

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SED Discrete Event Simulation Lab

NetSciX 202
February 7^{th} - 10^{th}

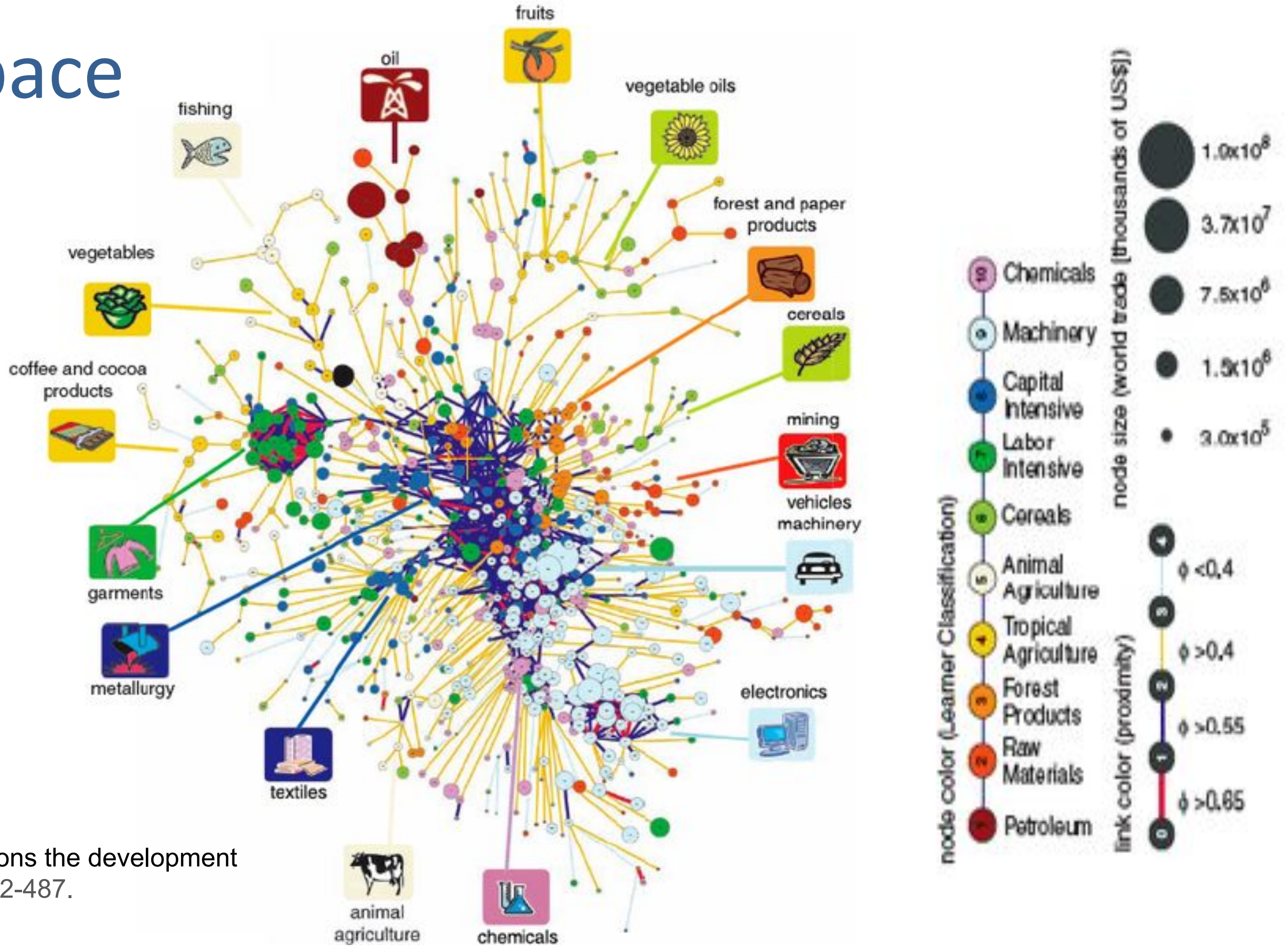
Motivation

- Understanding the patterns of economic growth stands as a **key tool for development planning and economic policy making**.

- The discipline of **Economic Complexity** offers a framework to approach the **study of interconnected economies** as a Complex Adaptive System that evolves in time driven by strongly non-linear dynamics.
- A well known example is the **Product Space** (PS), an analytical framework proposed by Hidalgo et al. (2007) to assess potential paths of development of countries in relation to their import/export capabilities.

Hidalgo et al. "The product space conditions the development of nations." Science 317.5837 (2007): 482-487.

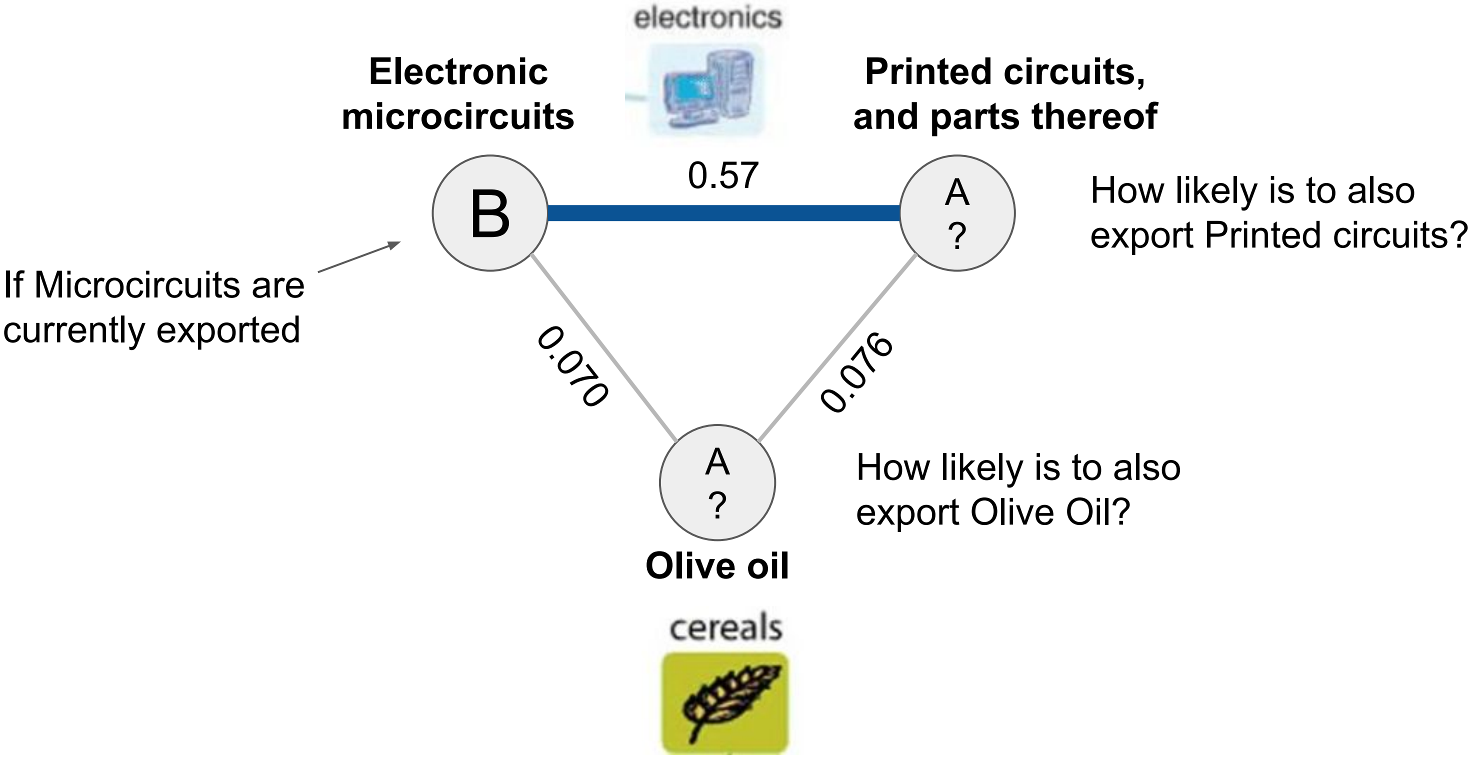
The Product Space



Hidalgo et al. "The product space conditions the development of nations." Science 317.5837 (2007): 482-487.

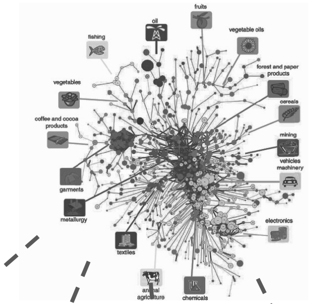
Our goal: Conduct **what-if prospective analyses** using the Product Space framework.

The Product Space - nodes and edges



The **edge weight** represents the probability of exporting **product A** given a country **already exports** another **product B** (and vice versa).

Limitations of the PS

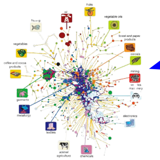


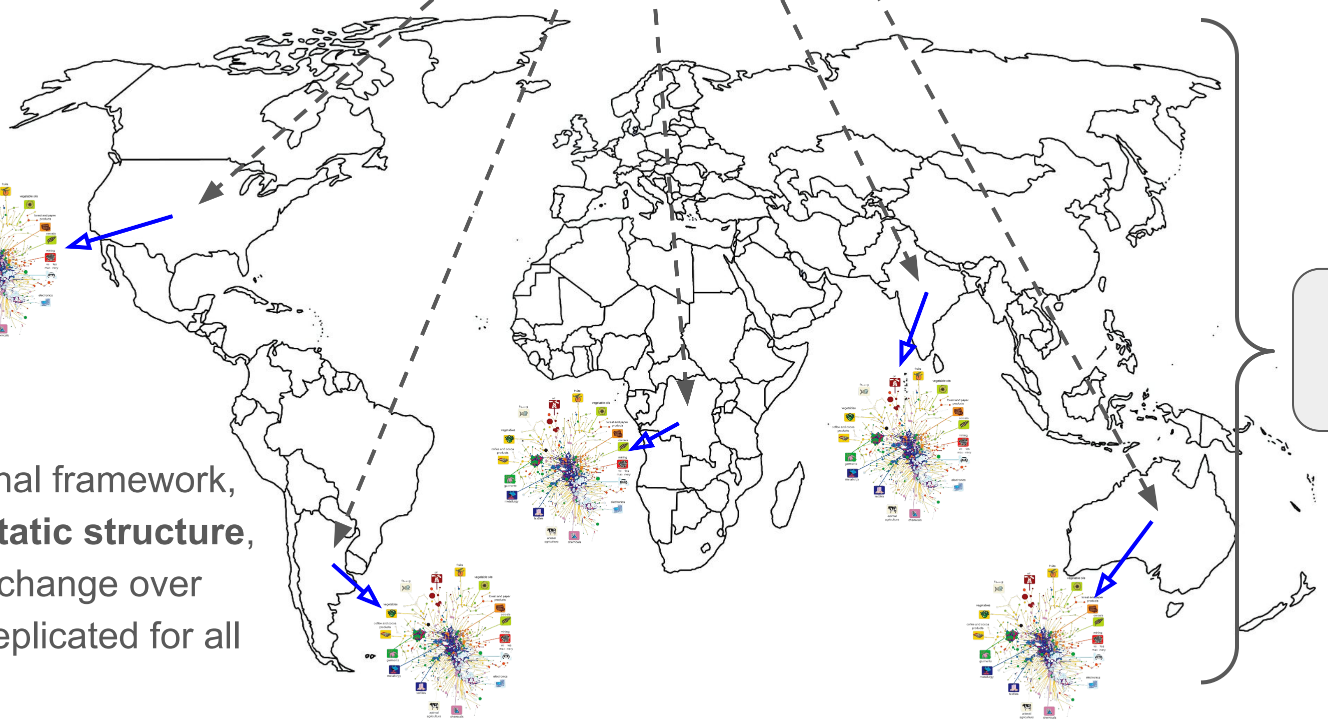
Static

Product Space

(1998-2000: fixed snapshot)

Static copy of the PS

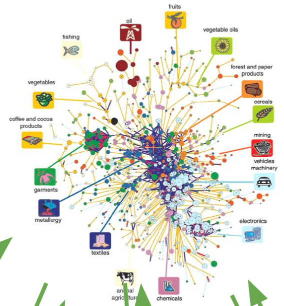




Micro-level only
(countries: isolated agents)

In the traditional framework, **the PS is a static structure**, i.e. it doesn't change over time, and is replicated for all countries.

Goal: A Dynamic PS



Dynamic
Product Space
(1998-2000: initial condition)

Macro-level
Dynamic
Product Space

Micro-level
(countries:
interacting agents)

We aim at building a truly Complex Adaptive System (CAS) with interacting agents.

Data source

We followed the **methodology** used by **Hidalgo et al.** (2007) to simulate diffusion in the PS.

To build the PS we used public datasets:

- generated by the National Bureau of Economic Research (NBER) project (Feenstra et al. 2005)
- world trade flows ranging from 1998 to 2000
- classified using the Standard International Trade Classification rev. 2 at the four-digit level (SITC-4 rev. 2)
- 775 products and 190 countries

Feenstra et al. (2005): "World Trade Flows: 1962-2000". Tech. rep. 11040. National Bureau of Economic Research, 2005

Formal definition of the Product Space

The Product Space is defined based on the **Revealed Comparative Advantage** (RCA) of each country in the list of products, taken from the data:

$$M^0_{c,p} = \begin{cases} 1 & \text{if } RCA_{c,p} > 1 \\ 0 & \text{otherwise} \end{cases}$$

c: country
p: product

The relation between products i and j is given by the **Proximity Matrix Φ**. The proximity must be interpreted as a probability:

$$\Phi_{i,j} = \min\{P_{i,j}, P_{j,i}\}, \text{ with } P_{i,j} = \frac{\sum_c M_{c,i} M_{c,j}}{\sum_c M_{c,i}}$$

c: country
i,j: products

The diffusion process over the PS

The **proximity** Π between a country **c** and a product **p**, in terms of the **potential to export p in the future**, depends on the proximity of the nearest exported good p' in the network:

$$\Pi^t_{c,p} = \max_{p'}\{\Phi_{p,p'} \cdot M^t_{c,p'}\}$$

p: product
p’: exported product
t: simulation time

Diffusion process: Given a **Proximity threshold Ω**, a country will upgrade its economy to produce all products with Π > Ω during the simulation cycle.

$$M^t_{c,p} = \begin{cases} 1 & \boxed{\text{if } \Pi^{t-1}_{c,p} > \Omega} \\ 0 & \text{otherwise} \end{cases}$$

Ω is a
proximity threshold parameter
shared by all countries

Proposal: A **Dynamic** Product Space (**DPS**)

The originally introduced proximity matrix $\Phi_{i,j}$ is a static element, which we consider a **debatable simplification**.

We propose instead a **Dynamic Proximity Matrix Φ^t**:

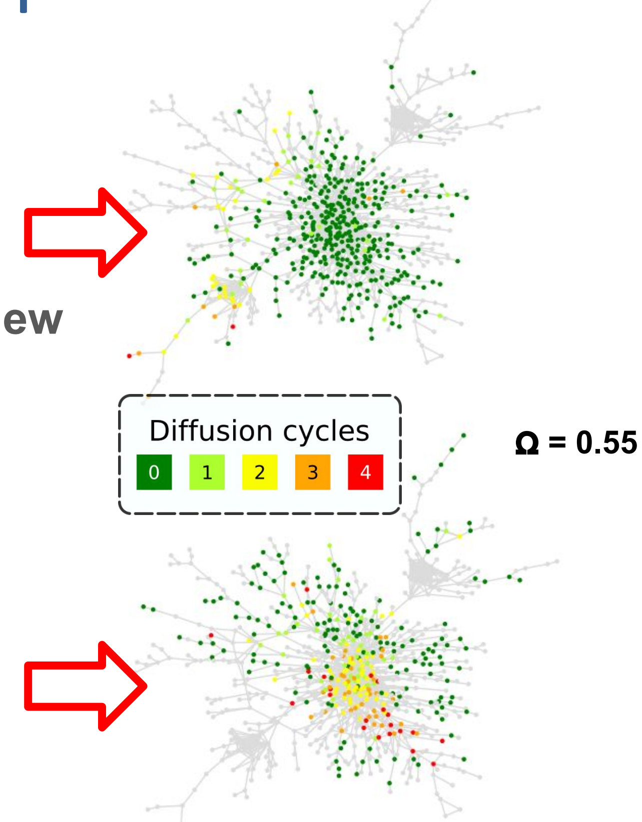
$$\Phi^t_{i,j} = \min\{P^t_{i,j}, P^t_{j,i}\}, \text{ with } P^t_{i,j} = \frac{\sum_c M^t_{c,i} M^t_{c,j}}{\sum_c M^t_{c,i}}$$

The **discrete time dynamics $\Phi^t = f\,(\Phi^{t-1})$** are a consequence of the use $\Pi^{t-1}_{c,p}$ in the definition of $M^t_{c,p}$.

Network diffusion comparison: DPS vs. SPS

Germany starts with **354 products** placed **mostly in the core** of the PS (cycle 0).
With the SPS, Germany develops **63 new products** (17.8% growth).

Argentina starts with **163 products** **mostly** distributed **in the periphery** of the PS, and manages to develop up to **157 new products** (96.3% growth) in 4 cycles.



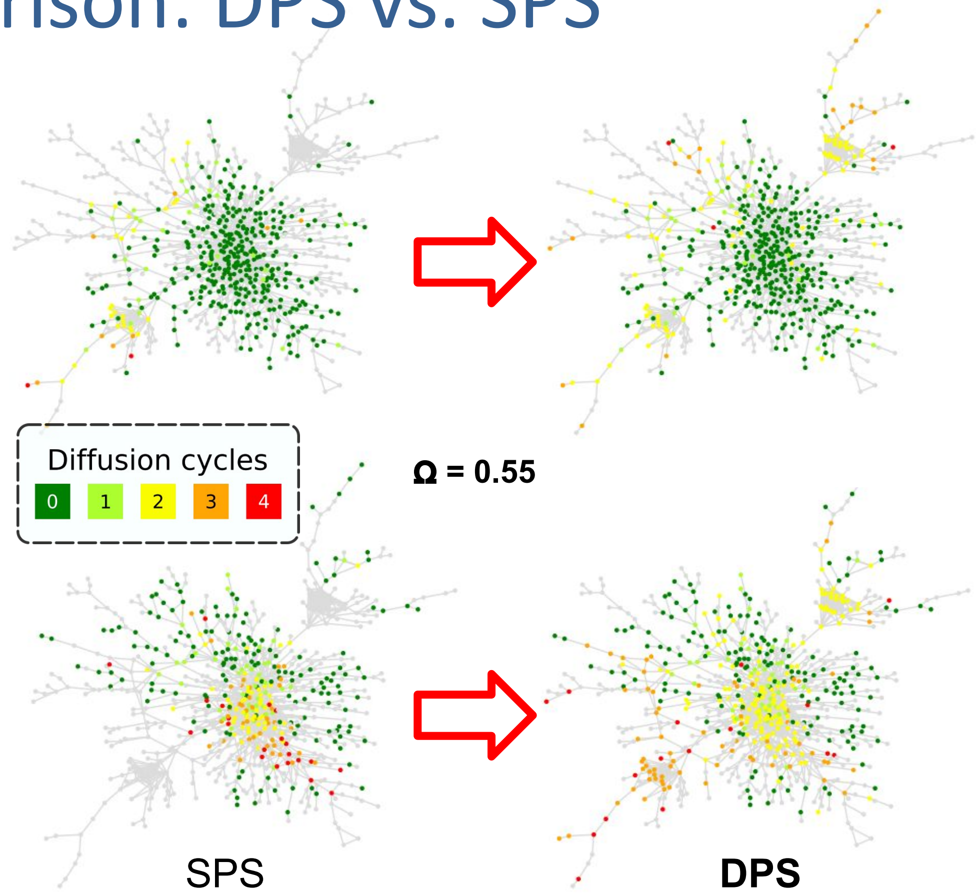
SPS

The network visualization helps with understanding and discovering potential development opportunities.

Network diffusion comparison: DPS vs. SPS

Using DPS, **Germany** develops **131 new products** (37.0% growth).

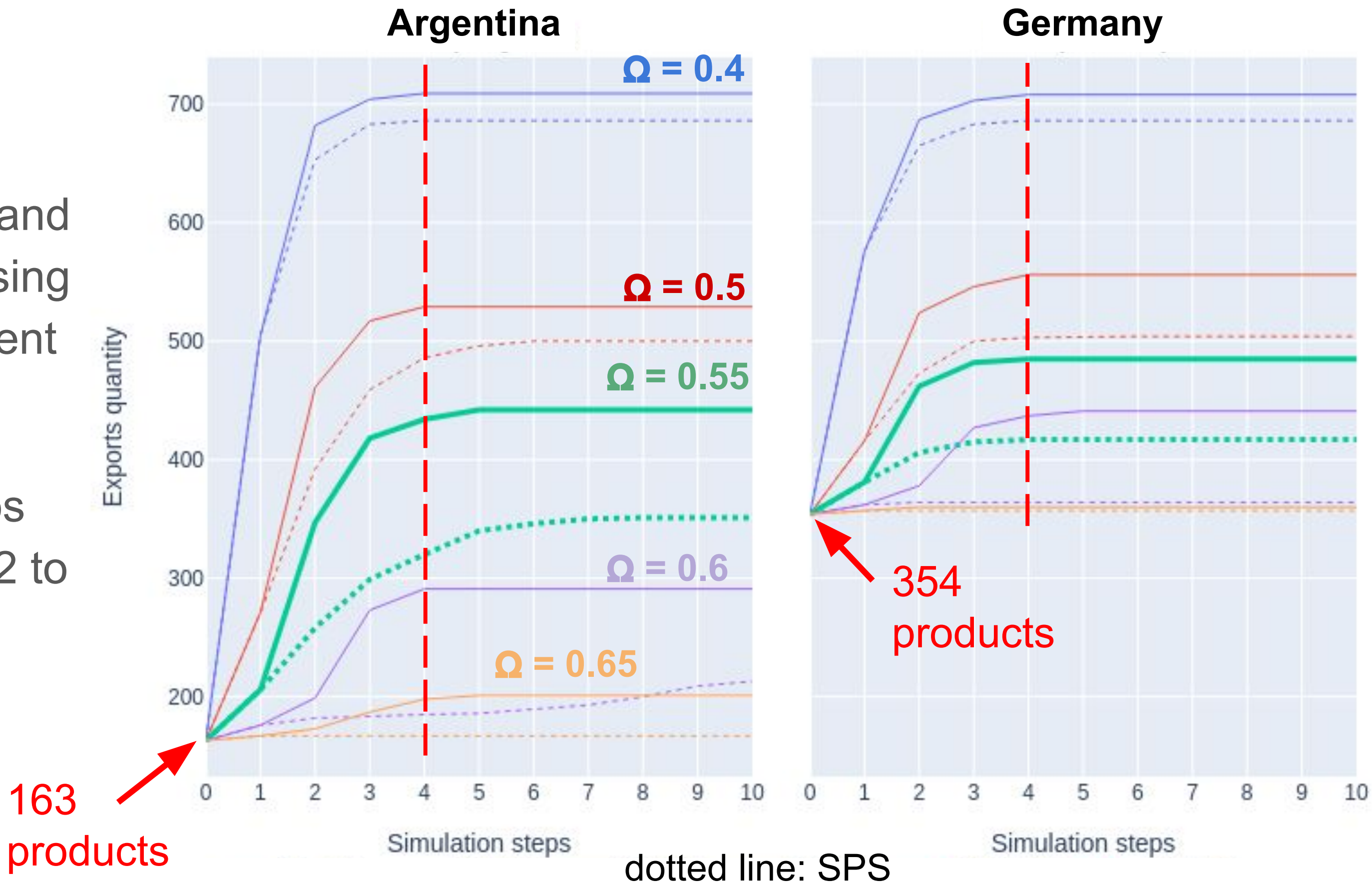
Meanwhile, **Argentina** develops **271 new products** (171.2% growth).



Products exported in time with different Ω

Number of products developed for Argentina and Germany is compared using SPS and DPS with different values of Ω.

Most simulation scenarios converge already within 2 to 4 cycles.



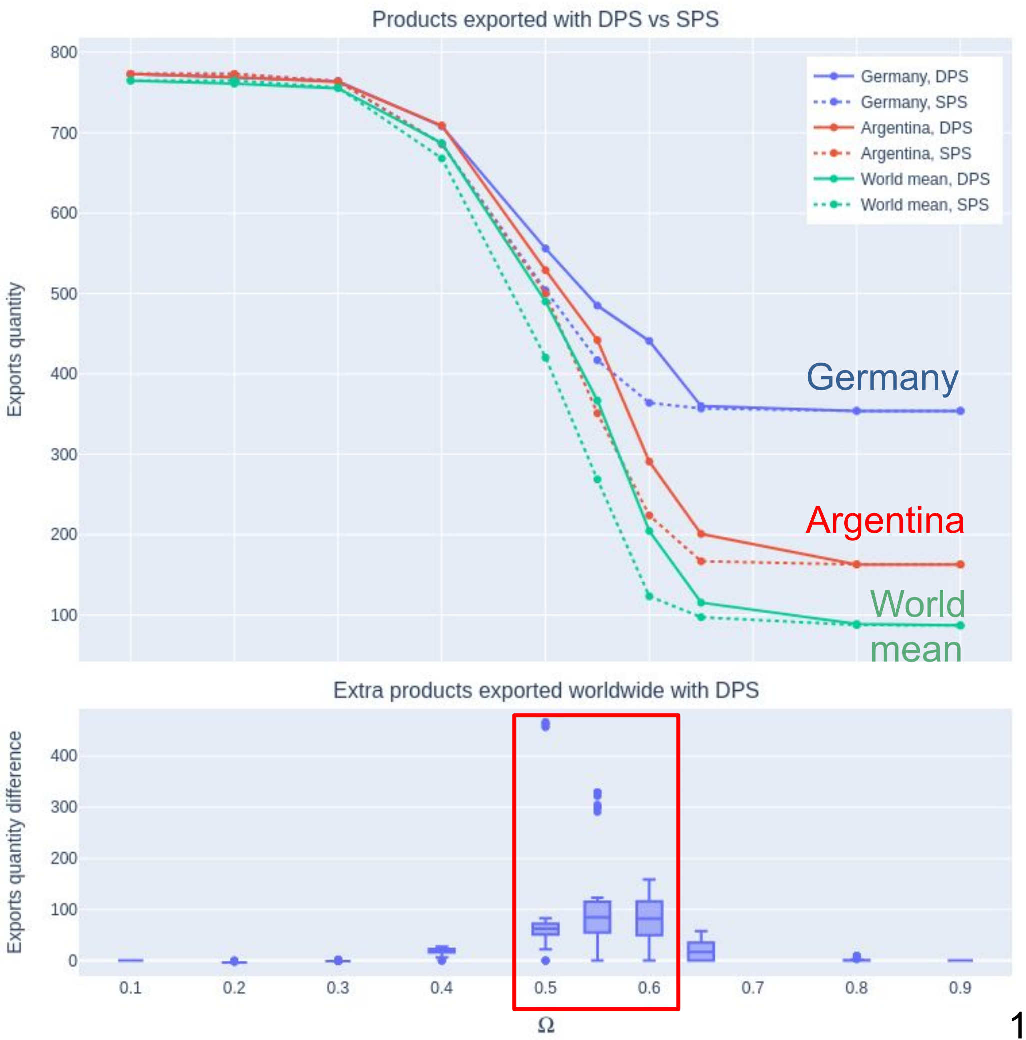
dotted line: SPS
solid line: DPS

Exports quantity at the end of simulation

<u>Top panel</u> Compare Argentina and Germany against the global mean.

<u>Bottom panel</u> Distribution of the differences between SPS and DPS for all countries.

Clear **non trivial differences** are observed between simulation scenarios for Ω between 0.5 and 0.6 suggesting that **<u>in the PS framework, dynamics matter</u>**.



The EB-DEVS formalism

Experimentation: we developed a simulation framework based on the **Emergent Behavior-DEVS** (EB-DEVS) formalism (Foguelman et al. 2020).

EB-DEVS formalism:

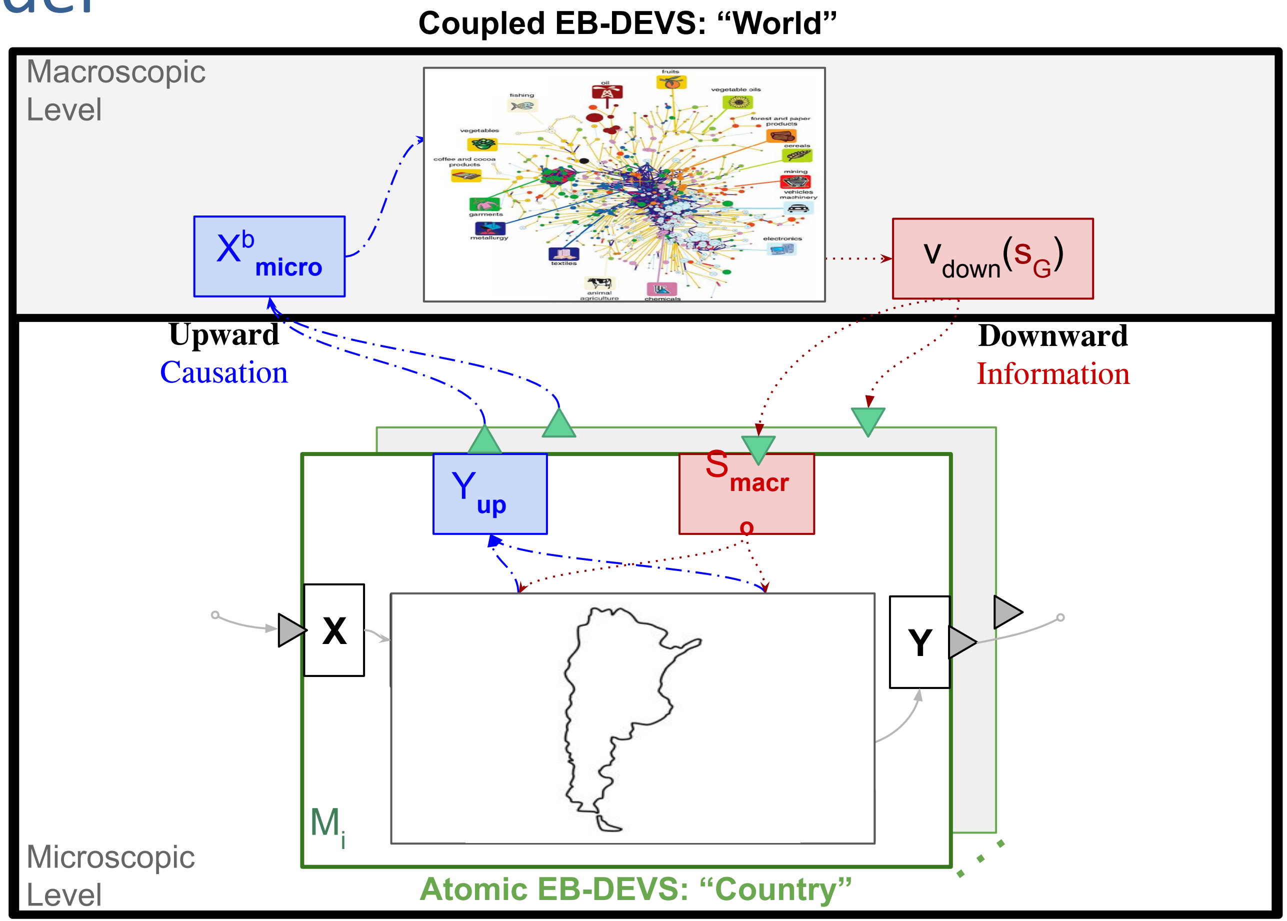
- Specifies mathematical models that are unambiguous by construction => making them easy to understand and reproduce.
- Specifically designed to model **complex adaptive systems**.

Foguelman et al. "EB-DEVS: A formal framework for modeling and simulation of emergent behavior in dynamic complex systems." Journal of Computational Science 53 (2021): 101387.

EB-DEVS agents model

The Dynamic Product Space model in EB-DEVS:

- Each **country** is an **agent.** Matrix Φ^t is a **macroscopic state** variable.
- The **macroscopic state** can be influenced by all countries.
- Φ^t influences the evolution of each agent (whether it will produce a new product or not).



- This **micro-macro interaction** is formally defined in EB-DEVS.

Conclusions

- We introduced **a simulation framework to test diffusion processes** over the Product Space, including a dynamic extension termed Dynamic Product Space.
- We **compared this model against its static counterpart**, showing that for some relevant parameters **the difference in the results can be significant**.
- Our framework allows to flexibly study different network metrics, PS representations and types of dynamics.
- This simulation tool will allow for richer simulation-based research, focused in specific countries and/or products, to explore development strategies.
- **Next steps:**
  - Make the Ω threshold a function of the country.
  - Study regional trading blocs.
  - Interaction with labor flows network (collaboration with V. Semeshenko and S. De Raco).

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Thanks for your attention!

Questions?

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https://git-modsimu.exp.dc.uba.ar/tobiascarreira/product-space

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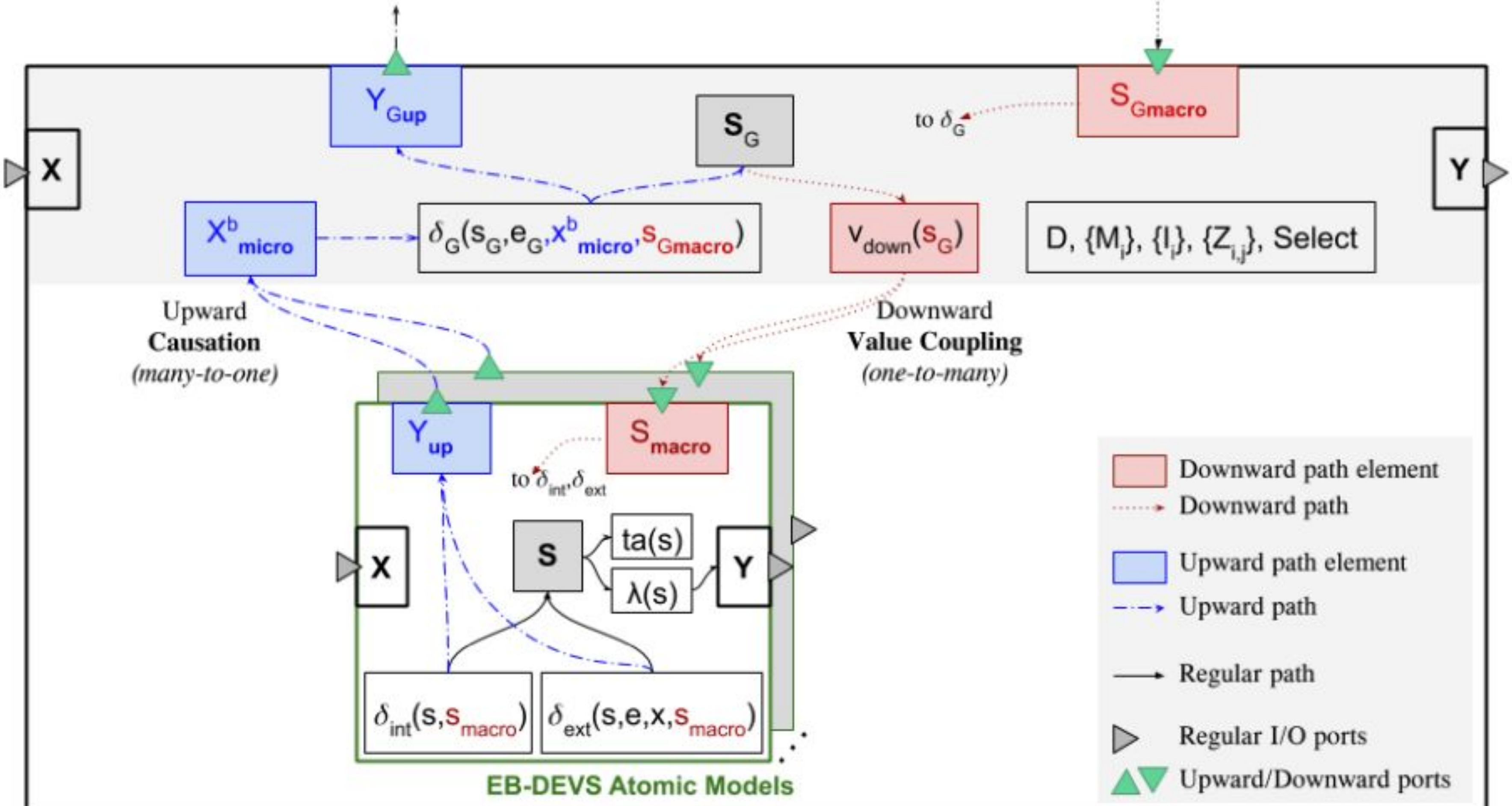

EB-DEVS Coupled Model

```python
class Country(AtomicDEVS):
    def __init__(self, name=None, competitive_exports=None):
        super(Country, self).__init__(name)
        self.state = {"competitive_exports": competitive_exports}
        self.in_port = self.addInPort("diffusion")

    def __lt__(self, other):
        return self.name < other.name

    def extTransition(self, inputs):
        for port, value in inputs.items():
            if port.name == "diffusion":
                self.diffuse(value, self.parent.getContextInformation(ProductSpaceProps.PHI_MATRIX))
                self.y_up = (self.name, self.state["competitive_exports"])
        return self.state

    def diffuse(self, big_omega, phi_matrix):
        pi = (phi_matrix @ np.diagflat(self.state["competitive_exports"])).max(1)
        self.state["competitive_exports"] = pi > big_omega
```