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

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ABSTRACT

We developed a simulation framework to experiment flexibly and robustly with the concept of Product Space (PS) including its extension as a Dynamic Product Space (DPS). We show that considering the DPS as a macroscopic emergent network property (at the global economy) impacts noticeably the diffusion processes occurring in the microscopic level (at individual countries), facilitating the production of new products in comparison to the classic (static) PS.

1 INTRODUCTION

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 [8] 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. [7, 6, 5]. In the PS, a bipartite network is built based on worldwide foreign trade data, where countries are associated with the products they exchange in the global economy. The resulting network structure is then used as a proxy to measure the complexity of a given economy.

Namely, the distances between products in the PS can be used as indicators to assess the development potential of countries. This comes from the empirical observation that the PS networked structure impacts considerably on the development opportunities available to a given country. According to this framework, countries develop a so called *Revealed Comparative Advantage* (RCA)[1] in goods that are *closer* to those they already produce and export.

This framework opens up the possibility of conducting *what-if* prospective analyses, which are essentially simulations of a diffusion process on a dynamic network that can be used to assess potential paths of development for a country's productive structure. Such simulation studies on the PS have been attempted before [7].

However, even though these studies proved highly relevant, we argue that the reliability, replicability and transparency of the underlying simulation algorithms still remain under-attended requirements. Limitations that we have identified include:

(1) there is an unmet need to experiment flexibly and robustly with scenarios using of both, fixed and dynamic forms of the PS.
(2) there are no available open access tools to experiment with, and replicate, the simulation exercises.

In this work, we present results obtained by applying a new formal simulation framework to study diffusion processes over the PS to overcome these downsides.

2 METHODOLOGY

We begin by following the methodology explained in [7] to simulate diffusion in the PS, in an effort to replicate the results obtained there. Our numerical results appear, by the naked eye, quite similar to those reported in [7]. Yet, a precise numerical comparison is not possible since neither the original simulation algorithm nor its results are publicly available (our requests for data access have not yet been satisfied).

To build the PS we used public datasets of the world trade flows ranging from 1998 to 2000, classified using the Standard International Trade Classification rev. 4 (SITC-4) with 775 products and 190 countries, generated by the National Bureau of Economic Research (NBER) project (led by R. Feenstra [2])[1]. This way, we can easily reproduce simulations for any listed country and therefore perform comparisons between countries.

We define the *proximity matrix* Φ with elements $\Phi_{i,j}$ representing the *proximity between products i and j* in the PS. Each entry is defined by the minimum conditional probability of some country having RCA>1 in product i given that the same country already has an RCA>1 in product j:

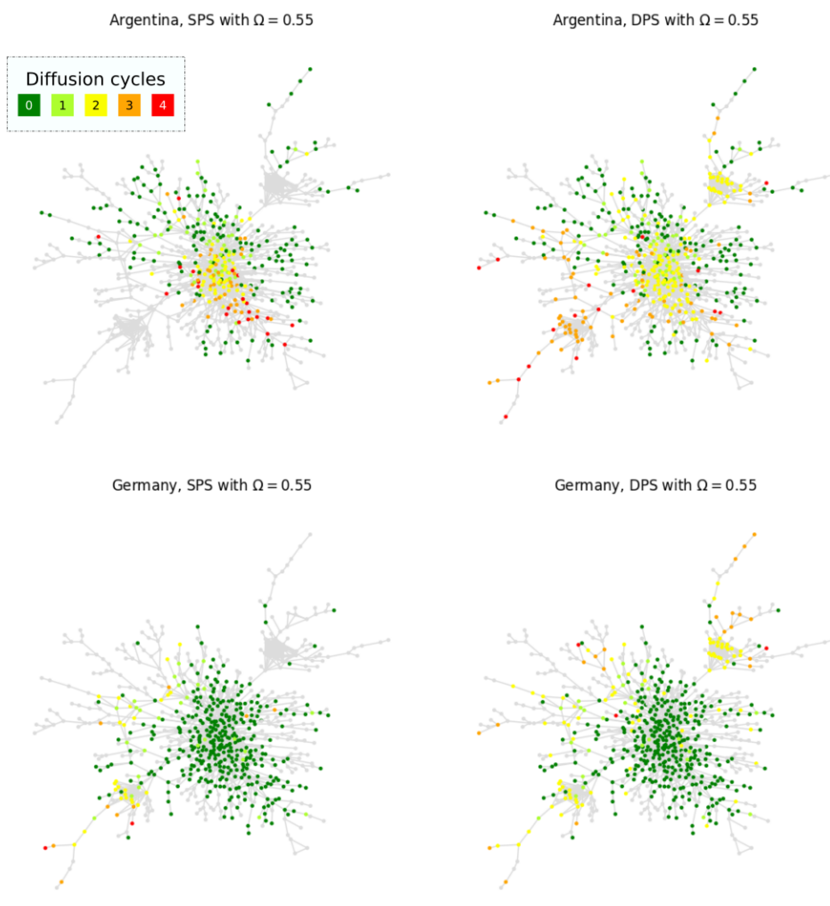
$$\Phi_{i,j} = \min\{P_{i,j}, P_{j,i}\}, \text{ with } P_{i,j} = \frac{\sum_c M_{c,i} M_{c,j}}{\sum_c M_{c,i}} \tag{1}$$

where $P_{i,j}$ is the conditional probability (or frequency) of producing a product i provided that product j is already being produced (and vice versa for $P_{j,i}$). As we mentioned before, this matrix is built based on worldwide foreign trade data and therefore it is general for all countries.

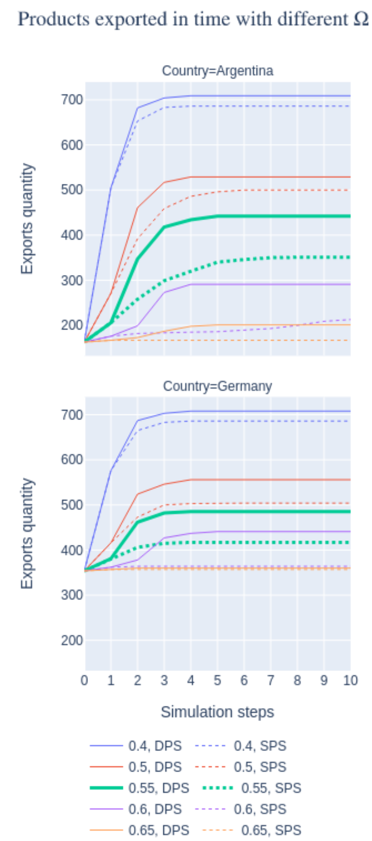
This defines a symmetrical dissimilarity matrix of size 775×775 with elements between 0 and 1, for $0 \leq (i, j) < 775$. To join the data for the period (1998-2000), we took the average of the corresponding Φ matrices for the three years.

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 (the proximity must be interpreted as a probability):

[1]Available at https://cid.econ.ucdavis.edu/data/undata/undata.html, accessed the 1st of october, 2022.



(a) Network representation of the PS for 4 diffusion cycles over the SPS and DPS.



(b) Evolution of exported products throughout diffusion cycles for different Ω.

Figure 1: Diffusion processes in the Product Space for Argentina and Germany. (a) Network representation for Argentina (top) and Germany (bottom) for the Static (left) and Dynamic (right) versions of the PS with $\Omega = 0.55$. Argentina starts with fewer products, and its productive structure shows enough potential to diffuse into several new products. Germany already produces most of the products it has potential for. The DPS presents a noticeable difference to the SPS, which is stronger for Argentina. (b) Diffusion simulations for Argentina and Germany considering different threshold values. Most scenarios converge within 2 to 4 cycles, while equilibrium values differ noticeably between SPS and DPS. Curves for $\Omega = 0.55$ correspond to the networks in panel (a).

$$\Pi^t_{c,p} = \max_{p'}\{\Phi_{p,p'} \cdot M^t_{c,p'}\} \tag{2}$$

where $\Phi_{p,p'} \in [0,1]$ are the elements of matrix Φ and $M^t_{c,p'} \in \{0,1\}$ indicates whether or not a country c features $RCA > 1$ in a product p' at time t.

Next, the diffusion process over the PS is presented. Given a threshold Ω, a country will upgrade its economy to produce all products with $\Pi > \Omega$ during the simulation cycle. We define the matrix M^t as:

$$M^t_{c,p} = \begin{cases} 1 & \text{if } \Pi^{t-1}_{c,p} > \Omega \\ 0 & \text{otherwise} \end{cases} \tag{3}$$

This matrix is initialized as follows:

$$M^0_{c,p} = \begin{cases} 1 & \text{if } RCA_{c,p} > 1 \\ 0 & \text{otherwise} \end{cases} \tag{4}$$

Then, M^t is a 190×775 binary matrix which indicates if a country c develops $RCA > 1$ in a product p, while $M^0_{c,p}$ for the initial cycle ($t = 0$) comes from the data (this matrix was introduced in [6, 5]).

3 A DYNAMIC PRODUCT SPACE

Thanks to the modularity of our tool (see Section 5), extensions and modifications in the model can be introduced straightforwardly. In the original work the $\Phi_{i,j}$ proximity matrix was introduced as a static element, which we consider a debatable simplification. We therefore propose a Dynamic Product Space (DPS) model that updates Φ by taking into account the changes in the exports of all countries as time evolves:

$$\Phi_{i,j}^t = \min\{P_{i,j}^t, P_{j,i}^t\}, \text{ with } P_{i,j}^t = \frac{\sum_c M_{c,i}^t M_{c,j}^t}{\sum_c M_{c,i}^t} \quad (5)$$

(and analogously for $P_{j,i}^t$).

The discrete time dynamics $\Phi^t = f(\Phi^{t-1})$ are a consequence of the definition of $\Pi_{c,p}^{t-1}$, see Eq. (3). We stress the difference between our dynamic approach (DPS) compared to the static version (termed here SPS) proposed in [7].

4 RESULTS

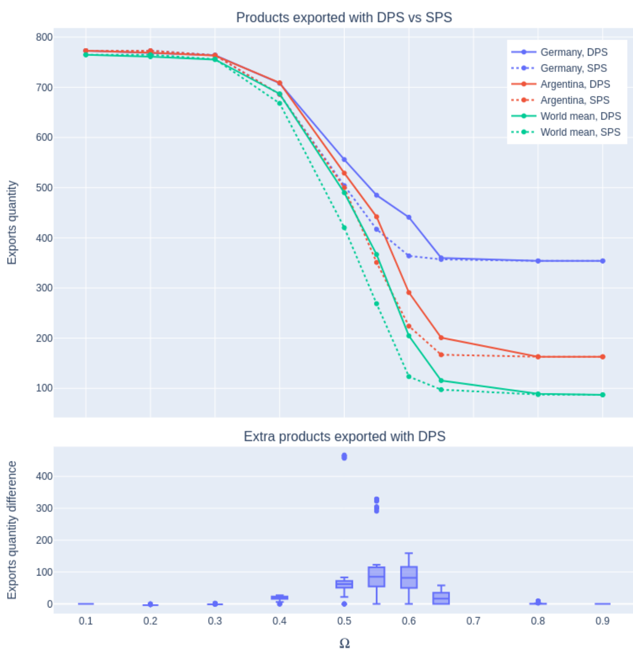


Figure 2: Comparison of products exported with SPS and DPS. For extreme values of Ω, both models behave almost identically. Yet, for intermediate values (between 0.5 and 0.6) a significant difference is observed.

In Figure 1b we compare the number of products developed, using SPS and DPS, for Argentina and Germany with different values of Ω. We can see that most simulation scenarios converge already within 2 to 4 cycles. While countries develop several new products in the first steps, from the fifth cycle onward few changes are observed.

In Figure 1a we show the diffusion process for the SPS and DPS with $\Omega = 0.55$, during 4 simulation steps. Germany starts with 354 products placed mostly in the core of the PS (cycle 0). With the SPS, Germany develops 63 new products (a 17.8% growth). Meanwhile, Argentina starts with 163 products mostly distributed in the periphery of the PS, and manages to develop up to 157 new products (a 96.3% growth) in 4 cycles. The network type of visualization can help with understanding and discovering potential development opportunities.

In Figure 2 we compare the dynamic (DPS) and static (SPS) alternatives while sweeping the threshold Ω. In the top panel we compare Argentina and Germany against the global mean, while in the bottom panel we show the 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 in the PS framework dynamics matter.

In some cases the advantage in exports for the global simulations are very significant, while for those with very high or very low thresholds, there does not seem to be a difference. This is consistent with the idea that, at very small values of Ω, the discovery is made very easy and at very high values it is very hard. Yet, for intermediate values of Ω between 0.5 and 0.6 we observe a significant difference. As what is being plotted is $DPS - SPS$ and the difference is positive, we interpret that the dynamic version facilitates the diffusion in these cases.

5 A MULTI-LEVEL AGENT-BASED SIMULATION FRAMEWORK

The simulation framework we developed for experimenting with the PS is based on the Emergent Behavior-DEVS (EB-DEVS) formalism [3]. It provides means to specify models mathematically that are unambiguous by construction, making them easy to understand and to reproduce. EB-DEVS is specifically designed to model complex adaptive systems, where each agent at the microscopic level is a unit of generalized behavior (with discrete and/or continuous dynamics) and, in turn, has access to information at a macroscopic level, with the capability of producing properties that emerge from the states and the interactions among agents [4].

In our PS model, each country is an agent, whereas the matrix Φ^t is a macroscopic state variable that can be influenced by all of the countries in the system. In turn, Φ^t influences the evolution of each agent (whether it will produce or not a new product). Such micro-macro interaction is formally defined in EB-DEVS.

6 CONCLUSIONS

In this work 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 used in [7], 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. We expect that this tool will allow for richer simulation-based research, focused in specific countries and/or products, to explore development strategies.

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