Physica A 402 (2014) 330–343

Contents lists available at ScienceDirect

Physica A

journal homepage: www.elsevier.com/locate/physa

The impact of network characteristics on the diffusion of innovations

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HIGHLIGHTS

- Directly studies the dependence of new product diffusion on network topology.
- Uses agent-based models on 160 networks for monopoly and duopoly markets.
- Generates networks using random graphs with a planted partition.
- Average-degree and high-degree hubs enhance diffusion.
- Clustering negatively affects diffusion.

ARTICLE INFO

Article history:
Received 8 August 2013
Received in revised form 23 January 2014
Available online 12 February 2014

Keywords:
Clustering
Average degree
Social hubs
Agent-based models
Diffusion of innovations
Word of mouth

ABSTRACT

This paper studies the influence of network topology on the speed and reach of new product diffusion. While previous research has focused on comparing network types, this paper explores explicitly the relationship between topology and measurements of diffusion effectiveness. We study simultaneously the effect of three network metrics: the average degree, the relative degree of social hubs (i.e., the ratio of the average degree of highly-connected individuals to the average degree of the entire population), and the clustering coefficient. A novel network-generation procedure based on random graphs with a planted partition is used to generate 160 networks with a wide range of values for these topological metrics. Using an agent-based model, we simulate diffusion on these networks and check the dependence of the net present value (NPV) of the number of adopters over time on the network metrics. We find that the average degree and the relative degree of social hubs have a positive influence on diffusion. This result emphasizes the importance of high network connectivity and strong hubs. The clustering coefficient has a negative impact on diffusion, a finding that contributes to the ongoing controversy on the benefits and disadvantages of transitivity. These results hold for both monopolistic and duopolistic markets, and were also tested on a sample of 12 real networks.

1. Introduction

The social influence processes that take place in a given network are shaped and affected by the network's topological characteristics. In this paper, we study how the topological or structural characteristics of a social network influence new-product diffusion in that network, in terms of speed of diffusion and the number of adopters.

Classical works in diffusion, focusing on the flow of information among individuals, assumed a fully connected market [1]. More recently, the literature has begun to acknowledge the role of network topology in social influence processes, exploring

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http://dx.doi.org/10.1016/j.physa.2014.02.003
0378-4371/

diffusion in topologies such as small world networks [2] and scale-free networks [3]. Empirical studies have explored how diffusion is influenced by aspects of network structure, including weak, long-distance ties [4] and the existence of social hubs [5], and have examined how network structure affects the performance of marketing strategies such as new-product seeding [6,7].

Despite this interest, to our knowledge, the direct impact of topological network metrics on diffusion has not been studied. Specifically, there has not been a systematic assessment, carried out across multiple networks, testing the *simultaneous* and *direct* impact of multiple topological metrics on the magnitude and speed of diffusion. Although some comparative studies have been conducted, most of them compare network types (e.g. Ref. [8]), referring to the comprehensive set of properties characterizing each network rather than isolating the specific role of each structural dimension.

In this paper, we conduct a methodological investigation of the impact of network topology on the diffusion of a new product to the market. Specifically, we focus on the following structural metrics: the average degree, the relative degree of social hubs (i.e., the ratio between the average degree of the most-connected nodes and the overall average degree), and the clustering coefficient. We apply a graph-theory procedure, a variation on the l-partition model, which uses random graphs with a planted partition, which has so far not been used in diffusion research, and use it to generate 160 networks, with a large range of values of the investigated metrics. We conduct agent-based simulations of new product diffusion in these networks, both in a monopoly and under duopolistic competition. We test the relative influence of each structural metric on the effectiveness of diffusion, measured as the Net Present Value (NPV) of the number of adopters, and controlling for the diffusion parameters and the networks' degree of separation.

Our main findings are:

1. Among the investigated metrics, the average degree and the relative degree of hubs have a strong positive impact on diffusion. The latter result is interesting in light of the controversy on the contribution of social hubs [9,10].
2. The clustering coefficient has a negative impact on diffusion. This result is in line with previous works comparing network types; however, it isolates the role of clustering from that of other topological network metrics. In addition, this finding contributes to an ongoing discussion on the benefits and disadvantages of transitivity (that is, the likelihood that the other nodes connected with a node are also connected to one another), of which clustering is a measure [11], implying the possible drawbacks of transitivity in the context of diffusion.

This paper offers three main contributions: First, it measures the *direct impact* of structural parameters on diffusion. We vary three major network metrics, and run a multivariate regression to explore simultaneously their *relative* roles. Second, we use a network generation method that has not been used so far in diffusion research, to create a set of networks with a wide range of values for the various metrics we examine, without the need to use networks of different types. This is a variation on the l-partition model from graph theory, which is novel in two aspects: it can generate networks which are more realistic than the classical l-partition model, and, more important, it enables to create networks with *pre-specified metrics*, including both degree distribution and clustering coefficient. Third, the agent-based simulation enables us to represent real-life diffusion scenarios by (i) considering both a monopoly and a competitive market; (ii) using a cascade agent activation model [12]; this is the individual-level analog to the Bass diffusion model [1], which is the standard model used to describe diffusion processes; and (iii) evaluating the effectiveness of the diffusion process by measuring the NPV of the number of adopters, which reflects both the reach of the diffusion process and its speed. Previous studies used such simulations, but did not focus on isolating the roles of specific topological metrics in the diffusion process.

The rest of this paper is organized as follows: In Section 2 we review the literature and describe the topological metrics we use and their anticipated influence. Section 3 describes the network generation procedure. Section 4 describes the agent-based model. The results and conclusions are presented in Sections 5 and 6, respectively.

2. Network structure and diffusion propagation

Social influence processes are strongly affected by the topology of the network in which they take place. Thus far, most studies focusing on the relationships between network topologies and social influence have been non-comparative in nature, with each paper focusing on a single network type. To the extent that comparison was done, it focused on comparing performance across different types of networks, and was mostly theoretic without measuring actual diffusion or information flow (see Refs. [13,14]; see Ref. [8] for an exception of an empirical study). For example, in small world networks, which are "rewired" lattice graphs in which several lattice ties are replaced with random connections, information flow and influence processes are expected to be more rapid than in regular lattice graphs, due to the "shortcuts" between nodes[1] [14,15]. Likewise, information flow in fully random graphs is expected to be rapid [16,17].

These studies provide important insights with regard to the influence of network structure on information flow. However, a specific network type usually binds several topological dimensions: For example, small-world networks combine both high clustering and short path length; most random graphs have a Poissonian degree distribution (with some exceptions;

[1] The network literature uses a variety of terms to describe network members and their connections. We use the term "network member" when talking about the real individuals in the network, "node"—to describe this person in the theoretical context, and "agent" when speaking about the agent-based model. In all contexts, we refer to the connections among network members, nodes, or agents as "ties".