Three Additive Mechanisms for Interorganizational Hyperlink Network Structures: Homophily, Resource Dependence, and Preferential Attachment

EECS 472 Agent Based Modeling

Final Project Report

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June 8, 2015

Introduction

Although research on interorganizational hyperlink networks has proliferated in recent years (e.g., Shumate & Lipp, 2008), research has yet to focus on the influence of several additive network mechanisms on the configuration of hyperlink network structures. Previous scholarship finds that *homophily*, *resource dependence*, and *preferential attachment* shapes the configuration of interorganizational hyperlink networks. Homophily describes the tendency for actors to search and select similar actors to oneself to create connections (Monge & Contractor, 2003). Resource dependence theory suggests that the more resources an actor has, the more likely it is to attract relationships (Pfeffer & Salancik, 1978). Preferential attachment refers to actors' preference to select and form relationships with actors that are already popular network connection receivers.

However, it is not immediately clear how these three network mechanisms interact with each other to impact the global network structure. As such, the purpose of this project is to examine the influence of *homophily*, *resource dependence*, and *preferential attachment* on interorganizational hyperlink networks. This research makes two contributions to the study of hyperlink networks. First, it emphasizes that the three network mechanisms are additive to each other to influence the global network structure. Second, it finds that preferential attachment effect has stronger effect than homophily and resource dependence.

The rest of the paper is organized as follows. First, I review the literature on hyperlink networks, and highlight how *homophily*, *resource dependence*, and *preferential attachment* influence interorganizational hyperlink networks. Second, I describe the methods employed, including agent based modeling and processes of simulations, and present my findings. And finally, I discuss the implications of these findings for network theories and hyperlink networks.

Literature Review

A hyperlink is 'a technological capability that enables one specific website to link directly to another' (Park, Barnett, & Nam, 2002, p. 157). Hyperlink networks describe the sum of hyperlinks among a set of organizational actors. Organizational hyperlinking is a purposive and strategic communication choice (Lusher and Ackland, 2011; Shumate & Lipp, 2008). Hyperlinks have been described as vehicles for the expression of collective identity, public affiliation, credibility, reputation, authority, and endorsement (Ackland and O'Neil, 2011; Park, 2003; Park et al., 2002; Shumate & Dewitt, 2008).

Previous scholarship has explored interorganizational hyperlink networks from two perspectives: organizational attribute and structural embeddedness. From the organizational attribute perspective, various organizational characteristics, such as organizational type, mission, and mass media visibility, shape hyperlinking behaviors (Gonzalez-Bailon, 2009; Shumate & Lipp, 2008; Yang, 2013). For example, media visibility is considered as a type of organizational resource that attracts hyperlinks (Gonzalez-Bailon, 2009). This perspective uniquely focuses on organizational characteristics that distinguish organizations at the individual organization level irrespective of the macro-level context.

The second perspective emphasizes the structural embeddedness of online organizational behavior in a collective action network. Hyperlink networks are marked by structural signatures that demonstrate the choice to hyperlink to a particular actor influenced by the existing set of organizational hyperlinks (Lusher & Ackland, 2011). Structural signatures, such as degree popularity, reciprocity, and transitivity, describe the unique patterns of connections prevalent in the network (Monge and Contractor, 2003).

Previous scholarship has found that three mechanisms influence the configuration of interorganizational hyperlink networks: *homophily*, *resource dependence*, and *preferential attachment*. First, *homophily* is the tendency to search and select similar actors to oneself to create connections (Byrne, 1971; Monge & Contractor, 2003). Homophily plays an important role in the configuration of interorganizational networks (McPherson, Smith-Lovin, & Cook, 2001). For example, Previous research has demonstrated that organizations with common social aims (Ackland & O'Neil, 2011), similar level of social media follower (Fu & Shumate, 2015), same global region (Shumate & Dewitt, 2008), and similar advocacy (Shumate, 2012) are more likely to create hyperlinks with each other.

Second, *resource dependence* mechanism affects interorganizational hyperlink network. Resource dependence theory suggests that organizations use network relationships with other organizations to manage uncertain environments; in particular, they attempt to link to organizations that control critical resources (Pfeffer & Salancik, 1978). Resource dependence suggests that resources will increase the attractiveness of organizations to receive hyperlinks. For example, the number of social media follower (Fu & Shumate, 2015) and the number of news media coverage (Gonzalez-Bailon, 2009; Pilny & Shumate, 2012) are resources for organizations to attract hyperlinks from other organizations.

Finally, *preferential attachment*, or connecting with actors that already receives a large number of relations, shapes the structure of interorganizational hyperlink networks (Kleinberg, 1999; Shumate, 2012). Receiving a large number of ties in an interorganizational hyperlink network is described to have popularity, social influence, prestige, legitimacy, and perceived credibility (Park, Barnett, & Nam, 2002; Shumate, 2012; Shumate & Lipp, 2008). Organizations desire to align with popular organizations in the network to garner critical resources such as credibility and visibility (Shumate, 2012).

Although *homophily*, *resource dependence*, and *preferential attachment* shapes the structure of interorganizational hyperlink networks, researchers have yet to focus on how each mechanism interacts with each other to influence the global network structure. Fu and Shumate (2015) studied news media visibility and social media visibility of organizations by using homophily and resource dependence theory, they found that both homophily and resource dependence theory shapes the structure of interorganizational hyperlink networks. However, resource dependence theory has stronger effects than homophily theory. As such, resource dependence and homophily effects are additive, rather than competitive, to each other to affect interorganizational hyperlink networks. However, beyond this, little is known about how each network mechanism. As such, in the project, I ask two interconnected research questions:

> ***RQ1***: Are these three network mechanisms additive or competitive to each other?
>
> ***RQ2***: How does the three network mechanisms interact with each other to impact the global network structures?

Methods

Agent Based Modeling: An Overview

Agent-based modeling is a computer-assisted methodology to model the interactions between agents and environment to gain insight into the emerging patterns from simple rules (Wilensky & Rand, 2015). Agent-based modeling is a good fit to model the research questions posed in this project because it provides opportunities to examine controlled environments for turtles (organizations), similar to experiments. In addition, because interorganizational networks among organizations are self-organizing, agent-based modeling is appropriate to model the emergent network structures and properties. Further, because of the uncertainty in the network structures, agent-based modeling enables the researcher to change parameters and investigate what is certain from interorganizational networks.

Model Rules and Description

Set up. Each user can determine the number of nodes and links in a network by using the number-of-nodes and number-of-links respectively. Turtles then appear in the interface randomly. Each agent represents an organization and a link represents hyperlinks between organizations. Each organization is assigned some random wealth, ranging from 0 to 30. Based on its level of wealth, the green color of the turtle (organization) is set accordingly such that the richer an organization is, the lighter the green is; the poorer an organization is, the darker the green is.

The most important feature of this model is that a user can adjust the probability of resource dependence effect and the probability of homophily by using the probability-of-RDT and probability-of-homophily slider respectively. Because there are three network mechanisms to be modeled in this model, the probability of preferential attachment effect is thus equal to 100 minus the probability of resource dependence effect and the probability of homophily effect.

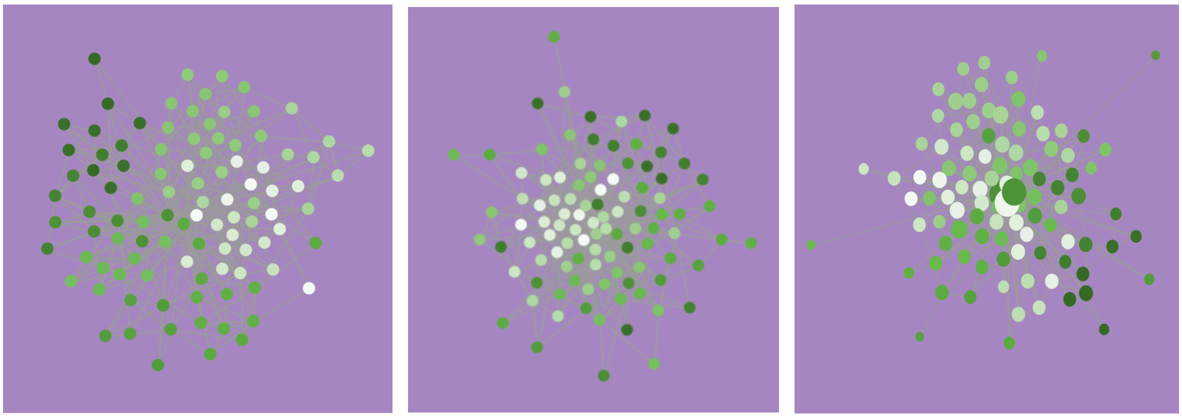
Implementation. If the number of links exceeds the maximum number of links determined by the user, the model stops. At each step, an agent (organization) links to another agent (organization) based on some probability determined by the user. For example, if a user adjusts the probability of homophily to 20 and the probability of resource dependence to 40, the probability of preferential attachment is then 40. With some probabilities, an agent (organization) makes its hyperlinking choice. *Homophily* describes the tendency of an agent to link with another agent that has similar wealth with itself. The level of wealth of the target agent can be slightly higher or slightly lower than the agent's. As for *resource dependence* effect, an agent links to another agent that has more wealth than the agent's own. The rationale is that sometimes organizations do not simply link with the organizations with the most wealth, but those organizations with more wealth than their own.

The advantage of this configuration is two-fold. First, it does not rule out the possibility that some agents with modest level of wealth to have hyperlinks. Second, it makes agents with the highest level of wealth more likely to be hyperlink targets. In terms of *preferential attachment* effect, each round lists the top agents with the highest degree centrality. A user can choose the number of top agents in this model, for example, I want to have top 3 agents with the highest degree centrality. An agent (organization) will then link with one of the three agents because they are considered as popular agents that already have a large number of links. A newly added link is red and prior links turn gray.

Visualization. After the model reaches its number of links, it stops. A user can resize nodes and redo the layout for the visualization purpose. The size of a node is proportional to its degree centrality. The layout is also based on the degree centrality of the agents. In particular, before going into any in-depth analysis, a user can look at the color of the nodes and the size of the nodes to get a sense of the results of the modeling. Does the color (representing wealth) of agents positively related to the size of the nodes (representing degree centrality)? Or does the color (representing wealth) of agents negatively related to the size of the nodes (representing degree centrality)? More specifically, if the probability of homophily is the highest among the three network mechanisms, agents of similar colors are observed to be clustered together. This is because homophily effect leads to segregation (Monge & Contractor, 2003). If the probability of resource dependence is the highest among the three network mechanisms, agents with higher level of wealth (indicated by lighter green) are positioned in the center. Further, if the probability of preferential attachment is the highest among the three network mechanisms, the network is a star-shaped centralized network and the biggest agent with the highest degree centrality is placed in the center of the network.

Figure 1

Network structures varying which one of the three mechanisms has the highest probability



Note. From left to right, homophily, resource dependence, and preferential attachment has the highest probability respectively.

Measures. To examine the global network structure, I added several monitors and plots to track some descriptive network measures. Two plots demonstrate the distribution of betweenness centrality and closeness centrality of agents in the network. In addition, there are a number of monitors to track the average degree centrality, average closeness centrality, average betweenness centrality, clustering coefficient, and average path length in the network. At the node level, degree centrality describes the total number of in-links and out-links of an agent (organization). Betweenness centrality represents "the extent to which a node is directly connected only to those other nodes that are not directly connected to each other" (Monge & Contractor, 2003, p. 38). That is, whether an agent is on the shortest path between pairs of nodes. Closeness centrality measures the extent that an agent is directly or indirectly connected to all agents in the network. At the network level, clustering coefficient accounts for the clustering and transitivity effect of agents in a network. Average path length describes the average number of steps among all the shortest paths for all pairs of nodes in a network (please note that sometimes mean path length is false because all nodes have to be connected in order to have this measure available).

Further, to help the user better understand the probability of different network mechanisms, there are three monitors tracking the number of links formed according to the homophily mechanism, preferential attachment effect, and resource dependence effect respectively. The sum of these three types of links should be equal to the total number of links determined by the user.

Simulations in BehaviorSpace

For a quick recap, there are two research questions in this project:

RQ1: Are these three network mechanisms additive or competitive to each other?

RQ2: How does the three network mechanisms interact with each other to impact the global network structures?

To answer the two research questions proposed, I used the BehaviorSpace to do simulations and experiments. The number of agents (organizations) was set to be 100 and the number of links was set to be 500 throughout. The procedure is as follows. First, I mainly focus on the effect of homophily by controlling for the effect of resource dependence effect. I vary the probability of homophily from 10 to 50 with an increment of 10 and the probability of resource dependence effect was set to be 10. Because the total probability of homophily + resource dependence + preferential attachment is equal to 1, I can only control for one parameter each time. Thus, the probability of preferential attachment varies accordingly based on the probability of homophily. This simulation was repeated for 3 times and network measures described above was collected. Then I vary the probability of homophily from 10 to 50 with an increment of 10 and the probability of resource dependence effect was set to be 20. Next, I vary the probability of homophily from 10 to 50 with an increment of 10 and the probability of resource dependence effect was set to be 30. Finally, I vary the probability of homophily from 10 to 50 with an increment of 10 and the probability of resource dependence effect was set to be 40.

Second, I mainly focus on the effect of resource dependence effect by controlling for the effect of homophily effect. I vary the probability of resource dependence effect from 10 to 50 with an increment of 10 and the probability of homophily effect was set to be 10. Again, the probability of preferential attachment varies accordingly based on the probability of resource dependence effect. This simulation was repeated for 3 times and network measures described above was collected. Then, I vary the probability of resource dependence effect from 10 to 50 with an increment of 10 and the probability of homophily effect was set to be 20. This simulation was repeated for 3 times and network measures described above was collected. Next, I vary the probability of resource dependence effect from 10 to 50 with an increment of 10 and the probability of homophily effect was set to be 30. This simulation was repeated for 3 times and network measures described above was collected. Finally, I vary the probability of resource dependence effect from 10 to 50 with an increment of 10 and the probability of homophily effect was set to be 40. This simulation was repeated for 3 times and network measures described above was collected.

After these simulations, a total of 5 ([10 10 50])*3 (repetitions)*4(variations in the controls)*2 (focus on resource dependence vs. focus on homophily) = 120 experimental/simulation observations were collected (see Table 2 through Table 9). Table 2 to Table 9 present the average network descriptive statistics from the simulations.

[Table 2 to Table 9 near here]

Additional 472 Requirement: Three Separate Models

To fulfill the additional requirement of EECS 472, in addition to the combined version of the model, I did three distinct but related models for homophily, resource dependence, and preferential attachment + contagion effects respectively. These three models are mainly for educational demonstration purposes to facilitate students' understanding in network science.

Set up. Contagion effect emphasizes the importance of social networks as a communication channel on the influence of attitudes, beliefs, and behaviors. I supplemented the contagion effect with the preferential attachment effect because the diffusion process is heavily dependent on opinion leaders and key influential individuals (Southwell, 2013). In this contagion model, by changing the number-of-links, the user can determine the size of this preferential attachment network. A user can then adjust the probability for direct network and indirect network to be influenced through the contagion process by using the "probability-linked-affected" and "probability-other-affected" slider respectively. For example, it may be that the probability for direct network to be affected is 70 percent and the probability for indirect network to be affected is much lower, say 15 percent.

Implementation. A user first clicks on the "go-once" button, and a network based on preferential attachment mechanism is formed and one or in rare cases, a couple of, agent(s) turns green, indicating that it is affected by some attitudes or behaviors. When the user continues clicking on the "go-once" button, each step demonstrates the contagion process.

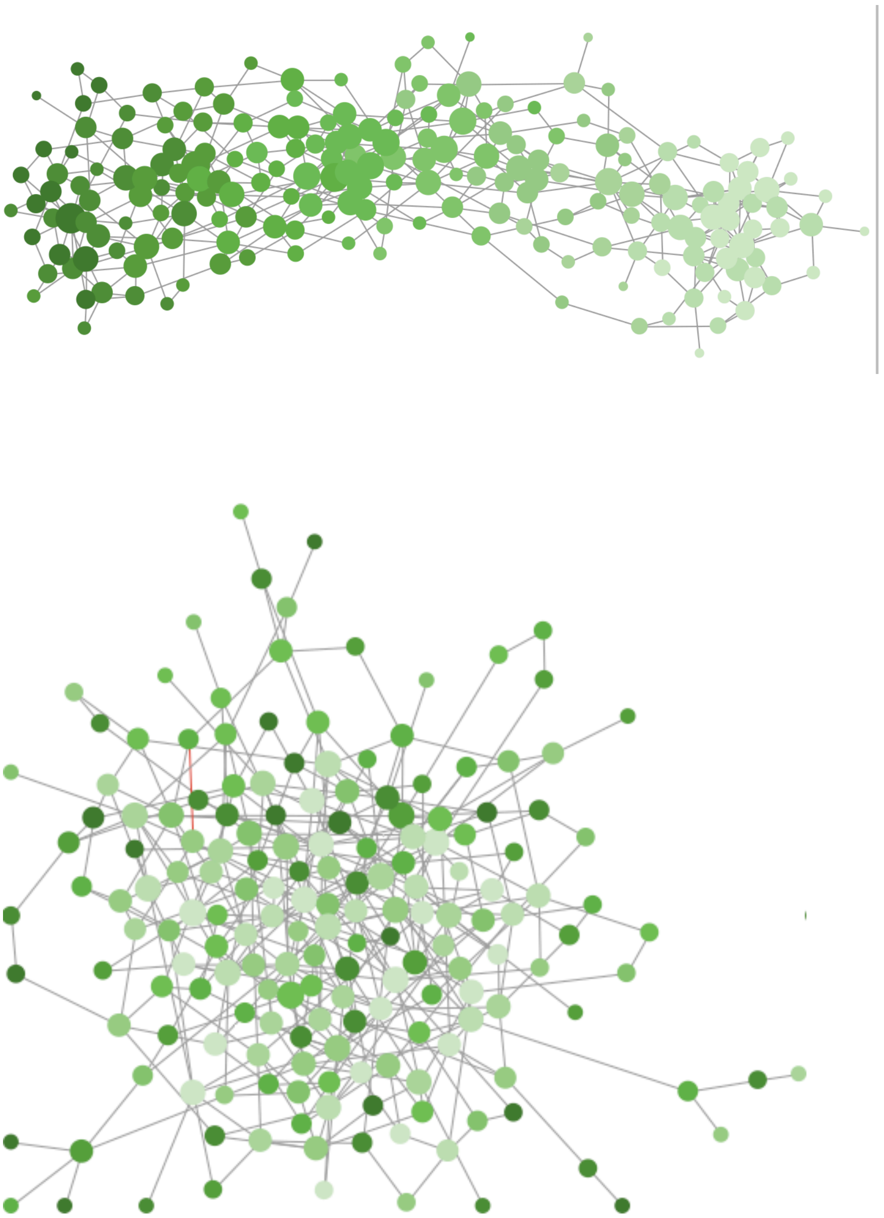
Measures. Three measures are collected for the speed of the contagion process: the number of affected agents, the number of not-affected agents, and the ticks for contagion. The ticks for contagion describes the total number of ticks for the entire network to be affected, turning from red to all green. In addition, the distribution of betweenness centrality is presented in a plot and the average degree centrality is presented in a monitor.

The homophily model and resource dependence model are very similar to how they work in the combined version of the model. As such, the descriptions on homophily and resource dependence model are very brief here. *Homophily* effect demonstrates agents' tendency to select other agents that has similar wealth with the agent's, indicated by similar level of green color. The resulting network of homophily effect is a segregation network composed of different green colors (see Figure 2 below).

Resource dependence effect models the tendency for actors to link to other agents that have rich resources than the agent's. A user can determine the level of wealth that is considered to be "high" in this model and agents will link to another agent that has wealth above this threshold. For example, a user can choose "7" to be considered as high wealth, and because each agent is randomly assigned some wealth under "10", an agent will only link to other agents that has wealth of 7 or above (see Figure 2).

Figure 2

Pure homophily (up) and resource dependence effect (down)



Results and Discussion

Descriptive

The distribution of betweenness centrality in the model is highly skewed and the distribution of closeness centrality is similar to a normal curve irrespective of the probability of resource dependence effect, homophily effect, and preferential attachment effect in the model. Consistent with previous scholarship that preferential attachment results in a highly skewed centrality distribution (Albert, Jeong, & Barabasi, 1999; Shumate & Contractor, 2013), Figure 3c demonstrates that if preferential attachment has the highest probability, the distribution of betweenness centrality is more extremely skewed than it has a lower probability (see Figure 3c).

Regression Analyses

To determine how each network mechanism interacts with each other to impact the global network structure of interorganizational hyperlink networks, I conducted a series of regression analyses in Stata using the 120 experimental/simulated results (see Table 1a, Table 1b, and Table 1c). Please note that sometimes the average path length is not available, the total number of observations for the mean path length as a dependent variable is 108. Because the probability of homophily + probability of resource dependence effect + probability of preferential attachment is equal to 100 percent, only two probabilities can be entered into the regression instead of three (one will be automatically dropped due to multicollinearity problem). Table 1a presents the effect of homophily and resource dependence on network structures. Table 1b presents the effect of homophily and preferential attachment effect on network structures. Table 1c presents the effect of preferential attachment and resource dependence effect on network structures. The independent variables are the number of links based on homophily, resource dependence, or preferential attachment. There are five dependent variables in the regression models: average degree centrality, average betweenness centrality, average closeness centrality, clustering coefficient, and mean path length.

Table 1a

Regression results of the effect of homophily links and resource dependence links on network structures

	Path Length	Clustering Coefficient	Degree Centrality	Closeness Centrality	Betweenness Centrality
#Homophily links	0.0013**	-0.001**	0.005**	-0.00027**	.066**
#Resource dependence links	0.0011**	-0.002**	0.008**	-0.00023**	.053**
Constant	1.855**	.753**	5.856**	0.534**	42.122**
R^2	.914	.924	.879	.925	.907
N	108	120	120	120	120

Note. ** $p < .001$. Some coefficients have more decimals for the purpose of comparison.

Table 1b

Regression results of the effect of homophily links and preferential attachment links on network structures

	Path Length	Clustering Coefficient	Degree Centrality	Closeness Centrality	Betweenness Centrality
#Homophily links	.00027**	.00049**	-.003**	-.00004**	.0133**
#Preferential attachment	-.001**	.00168**	-.008**	.00023**	-.0529**

links					
Constant	2.388**	-0.086**	9.899**	.418**	68.567**
R^2	.914	.924	.879	.925	.907
N	108	120	120	120	120

Note. ** $p < .001$. Some coefficients have more decimals for the purpose of comparison.

Table 1c

Regression results of the effect of of preferential attachment and resource dependence links on network structures

	Path Length	Clustering Coefficient	Degree Centrality	Closeness Centrality	Betweenness Centrality
#Preferential attachment links	-.0013**	.0012**	-.0048**	.00028**	-.066**
#Resource dependence links	-0.0003**	-.0005**	.0033**	.00004**	-.013**
Constant	2.521**	.161**	8.253**	.396**	75.239**
R^2	.914	.924	.879	.925	.907
N	108	120	120	120	120

Note. ** $p < .001$. Some coefficients have more decimals for the purpose of comparison.

***RQ1*: Are these three network mechanisms additive or competitive to each other?**

Overall, the regression models have high R-squared (about 0.90) and both parameters in each of the models are highly significant at the 0.001 level, indicating that homophily effect, resource dependence effect, and preferential attachment effect significantly impact the structure of interorganizational hyperlink networks. More importantly, the results suggest that the three network mechanisms are not competitive to each other. Rather, they are additive to each other to influence the global network structure. As such, future research should consider the effects of homophily, resource dependence, and preferential attachment in hyperlink networks and specify them properly in the models. Otherwise, a complete picture of the hyperlinking mechanisms among organizations are lacking, resulting in partial understanding of organizations' online behaviors in general and hyperlinking behaviors more specifically.

***RQ2*: How does the three network mechanisms interact with each other to impact the global network structures?**

Table 1a presents the effect of homophily and resource dependence on network structures. Both parameters are highly significant to influence the five network measures and the signs of the number of homophily links and the number of resource dependence links on the five dependent variables are consistent. The number of homophily links and resource dependence links on average path length, degree centrality, and betweenness centrality are positive, and the number of homophily links and resource dependence links on clustering coefficient and closeness centrality are negative. However, the magnitude of the two parameters vary. For average path length, closeness centrality, and betweenness centrality, the magnitude of the number of homophily links are larger, but for clustering coefficient and average degree centrality, the magnitude of the number of resource dependence links are larger.

Table 1b presents the effect of homophily and preferential attachment effect on network structures. Both parameters are highly significant to influence the five network measures, however, their signs are not consistent to predict the five network measures. The number of homophily links is positively related to mean path length, clustering coefficient, and betweenness centrality are positive, and the number of homophily links is negatively related to degree centrality and closeness centrality. The number of preferential attachment links is positively related to clustering coefficient and closeness centrality, but the number of preferential attachment links is negatively related to mean path length, degree centrality, and betweenness centrality. In addition, in terms of magnitude, overall, preferential attachment effect has significantly larger effects on global network structures than homophily effect.

Table 1c presents the effect of preferential attachment and resource dependence effect on network structures. Both preferential attachment and resource dependence parameters are highly significant to influence the five network measures, their signs and magnitude vary substantially. First, the number of preferential attachment links is positively related to the clustering coefficient and closeness centrality, the number of preferential attachment links is negatively related to mean path length, degree centrality, and betweenness centrality. In contrast, the number of resource dependence links is positively related to the average degree centrality and closeness centrality, the number of resource dependence links is negatively related to mean path length, clustering coefficient, and betweenness centrality. As for magnitude, overall, preferential attachment effect has significantly larger effects on global network structures than resource dependence effect.

In sum, the three network mechanisms, namely homophily, resource dependence, and preferential attachment, are additive to each other to impact the global network structure. This is manifested in the significant coefficients of homophily, resource dependence, and preferential attachment parameters in the regression models. In addition, each network mechanism has its unique effects on the global network structure, but the effect of preferential attachment on global network structure is significantly larger than either homophily effect or resource dependence effect. This finding is consistent with previous literature that preferential attachment and highly skewed indegree distribution are the defining characteristic of hyperlink networks (Shumate & Contractor, 2013).

Conclusion

This project began with three network mechanisms that have been shown to impact interorganizational hyperlink networks: *homophily*, *resource dependence*, and *preferential attachment*. First, I asked if these three network mechanisms are additive or competitive to each other to influence the global network structure. Second, I asked how each of the three network mechanisms interacts with each other to impact the global network structures. Agent-based modeling was used to answer the two questions; simulations were conducted in BehaviorSpace; and simulation results were used for regression analyses. The results indicate that the three network mechanisms, namely homophily, resource dependence, and preferential attachment, are additive to each other to impact the global network structure. In addition, each network mechanism has its unique effects on the global network structure, but the effect of preferential attachment on global network structure is significantly larger than either homophily effect or resource dependence effect.

Although significant, this project has some limitations that need to be addressed in future extensions. First, the model in this project largely deals with the attributes of organizations. As such, future research should consider some structural signatures, such as reciprocity and transitivity, in the interorganizational hyperlink networks. Second, the model provides a cross-sectional perspective of interorganizational hyperlink networks. However, networks are dynamic and constantly evolving. Thus, future extensions should consider the possibility of tie breakups in interorganizational hyperlink networks and some feedback mechanisms of tie maintenance and dissolution, such as limited attention and a lack of reciprocity and compatibility.

In conclusion, the purpose of this project is to examine the influence of *homophily*, *resource dependence*, and *preferential attachment* on interorganizational hyperlink networks. This research makes two contributions to the study of hyperlink networks. First, it emphasizes that the three network mechanisms are additive to each other to influence the global network structure. Second, it finds that preferential attachment effect has stronger effect than homophily and resource dependence to impact the global structure of interorganizational hyperlink networks. This suggests that future research should consider the effects of multiple, additive network mechanisms in interorganizational hyperlink networks and other types of networks to gain a holistic picture of linking processes and dynamics. In addition, future research should address why some network mechanism has stronger effect than others.

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Table 2

Simulations in BehavioralSpace by changing probability (homophily) and probability (resource dependence)

	Model 1	Model 2	Model 3	Model 4	Model 5
Pr(Homophily)	10	20	30	40	50
Pr(Resource Dependence)	10	10	10	10	10
Pr(Preferential Attachment)	80	70	60	50	40
# Homophily links	48	95	139	190	249
#RD links	47	45	49	48	48
#PA links	405	360	312	262	203
Path length	2.01	2.03	2.07	2.13	2.22
Clustering coefficient	0.69	0.60	0.51	0.45	0.36
Average degree	6.09	6.57	6.99	7.36	7.45
Betweenness centrality	50.06	50.96	52.89	56.00	60.53
Closeness centrality	0.50	0.50	0.49	0.48	0.46

Note. Pr(Homophily): [10 [10] 50]; Pr(Resource Dependence): 10; Number of nodes: 100; Number of links: 500; Repetitions: 3; pr(homophily) + pr(resource dependence) + pr(preferential attachment) = 1.

Table 3

Simulations in BehavioralSpace by changing probability (homophily) and probability (resource dependence)

	Model 1	Model 2	Model 3	Model 4	Model 5
Pr(Homophily)	10	20	30	40	50
Pr(Resource Dependence)	20	20	20	20	20
Pr(Preferential Attachment)	70	60	50	40	30
# Homophily links	51	97	147	197	259
#RD links	88	307	261	207	151
#PA links	360	96	92	96	90
Path length	2.05	2.08	2.17	2.20	2.32
Clustering coefficient	0.56	0.49	0.40	0.35	0.30
Average degree	6.65	7.15	7.41	7.85	7.82
Betweenness centrality	52.08	53.46	57.87	59.17	65.12
Closeness centrality	0.49	0.48	0.47	0.46	0.44

Note. Pr(Homophily): [10 [10] 50]; Pr(Resource Dependence): 20; Number of nodes: 100; Number of links: 500; Repetitions: 3; pr(homophily) + pr(resource dependence) + pr(preferential attachment) = 1.

Table 4

Simulations in BehavioralSpace by changing probability (homophily) and probability (resource dependence)

	Model 1	Model 2	Model 3	Model 4	Model 5
Pr(Homophily)	10	20	30	40	50
Pr(Resource Dependence)	30	30	30	30	30
Pr(Preferential Attachment)	60	50	40	30	20
# Homophily links	51	99	148	198	251
#RD links	139	253	213	142	147
#PA links	310	148	139	160	103
Path length	2.06	2.11	2.21	2.27	2.40
Clustering coefficient	0.47	0.35	0.32	0.27	0.23
Average degree	7.21	7.72	7.91	8.08	8.05
Betweenness centrality	52.52	55.02	59.79	61.51	69.09
Closeness centrality	0.49	0.48	0.46	0.45	0.42

Note. Pr(Homophily): [10 [10] 50]; Pr(Resource Dependence): 30; Number of nodes: 100; Number of links: 500; Repetitions: 3; pr(homophily) + pr(resource dependence) + pr(preferential attachment) = 1.

Table 5

Simulations in BehavioralSpace by changing probability (homophily) and probability (resource dependence)

	Model 1	Model 2	Model 3	Model 4	Model 5
Pr(Homophily)	10	20	30	40	50
Pr(Resource Dependence)	40	40	40	40	40
Pr(Preferential Attachment)	50	40	30	20	10
# Homophily links	45	103	148	198	268
#RD links	186	191	190	196	180
#PA links	269	207	162	106	51
Path length	2.10	2.20	2.24	2.32	2.48
Clustering coefficient	0.40	0.29	0.24	0.20	0.20
Average degree	7.67	8.02	8.10	8.35	8.09
Betweenness centrality	54.52	57.58	61.37	65.50	72.47
Closeness centrality	0.48	0.46	0.45	0.43	0.41

Note. Pr(Homophily): [10 [10] 50]; Pr(Resource Dependence): 40; Number of nodes: 100; Number of links: 500; Repetitions: 3; pr(homophily) + pr(resource dependence) + pr(preferential attachment) = 1.

Table 6

Simulations in BehavioralSpace by changing probability (homophily) and probability (resource dependence)

	Model 1	Model 2	Model 3	Model 4	Model 5
Pr(Resource Dependence)	10	20	30	40	50
Pr(Homophily)	10	10	10	10	10
Pr(Preferential Attachment)	80	70	60	50	40
# Homophily links	52	46	54	50	57.67
#RD links	43	99	137	193	201.33
#PA links	405	355	309	257	241
Path length	2.02	2.03	2.09	2.12	2.22
Clustering coefficient	0.66	0.55	0.45	0.37	0.26
Average degree	6.03	6.72	7.15	7.61	8.05
Betweenness centrality	50.53	50.94	52.65	55.44	59.99
Closeness centrality	0.50	0.50	0.48	0.48	0.46

Note. Pr(Resource Dependence): [10 [10] 50]; Pr(Homophily): 10; Number of nodes: 100; Number of links: 500; Repetitions: 3; pr(homophily) + pr(resource dependence) + pr(preferential attachment) = 1.

Table 7

Simulations in BehavioralSpace by changing probability (homophily) and probability (resource dependence)

	Model 1	Model 2	Model 3	Model 4	Model 5
Pr(Resource Dependence)	10	20	30	40	50
Pr(Homophily)	20	20	20	20	20
Pr(Preferential Attachment)	70	60	50	40	30
# Homophily links	102	97	102	100	103
#RD links	50	94	147	185	246
#PA links	348	309	251	215	150
Path length	2.05	2.10	2.17	2.17	2.25
Clustering coefficient	0.50	0.46	0.30	0.30	0.21
Average degree	6.67	7.04	7.91	7.91	8.46
Betweenness centrality	52.19	54.24	57.83	57.83	61.96
Closeness centrality	0.49	0.48	0.47	0.47	0.45

Note. Pr(Resource Dependence): [10 [10] 50]; Pr(Homophily): 20; Number of nodes: 100; Number of links: 500; Repetitions: 3; pr(homophily) + pr(resource dependence) + pr(preferential attachment) = 1.

Table 8

Simulations in BehavioralSpace by changing probability (homophily) and probability (resource dependence)

	Model 1	Model 2	Model 3	Model 4	Model 5
Pr(Resource Dependence)	10	20	30	40	50
Pr(Homophily)	30	30	30	30	30
Pr(Preferential Attachment)	60	50	40	30	20
# Homophily links	149	151	155	150	156
#RD links	46	92	147	194	244
#PA links	305	257	198	156	100
Path length	2.06	2.13	2.18	2.23	2.31
Clustering coefficient	0.48	0.40	0.31	0.25	0.18
Average degree	7.03	7.49	8.01	8.40	8.56
Betweenness centrality	52.28	54.70	58.58	61.03	64.78
Closeness centrality	0.49	0.48	0.46	0.45	0.44

Note. Pr(Resource Dependence): [10 [10] 50]; Pr(Homophily): 30; Number of nodes: 100; Number of links: 500; Repetitions: 3; pr(homophily) + pr(resource dependence) + pr(preferential attachment) = 1.

Table 9

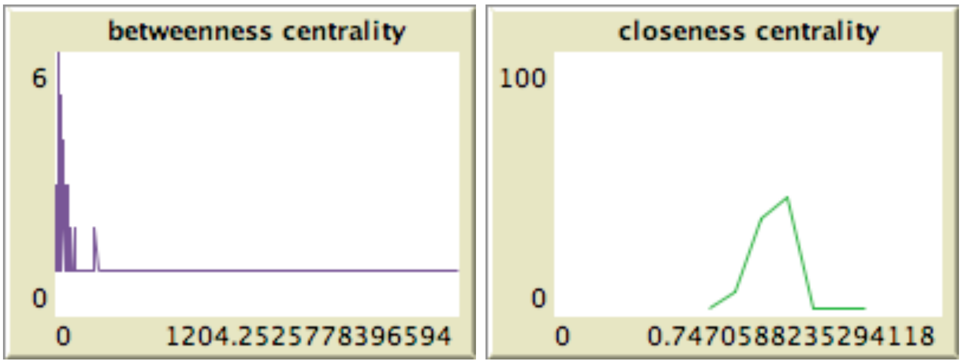
Simulations in BehavioralSpace by changing probability (homophily) and probability (resource dependence)

	Model 1	Model 2	Model 3	Model 4	Model 5
Pr(Resource Dependence)	10	20	30	40	50
Pr(Homophily)	40	40	40	40	40
Pr(Preferential Attachment)	50	40	30	20	10
# Homophily links	200	190	200	210	204
#RD links	42	99	146	189	240
#PA links	258	211	154	101	56
Path length	2.15	2.20	2.30	2.37	2.41
Clustering coefficient	0.41	0.35	0.26	0.19	0.15
Average degree	7.23	7.69	7.98	8.23	8.35
Betweenness centrality	56.80	59.47	62.56	66.66	69.57
Closeness centrality	0.47	0.46	0.45	0.43	0.42

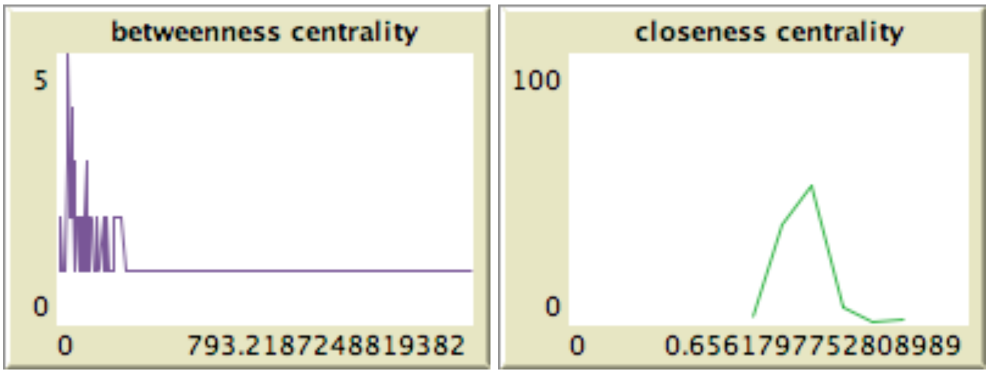
Note. Pr(Resource Dependence): [10 [10] 50]; Pr(Homophily): 40; Number of nodes: 100; Number of links: 500; Repetitions: 3; pr(homophily) + pr(resource dependence) + pr(preferential attachment) = 1.

Figure 3a ~ Figure 3c

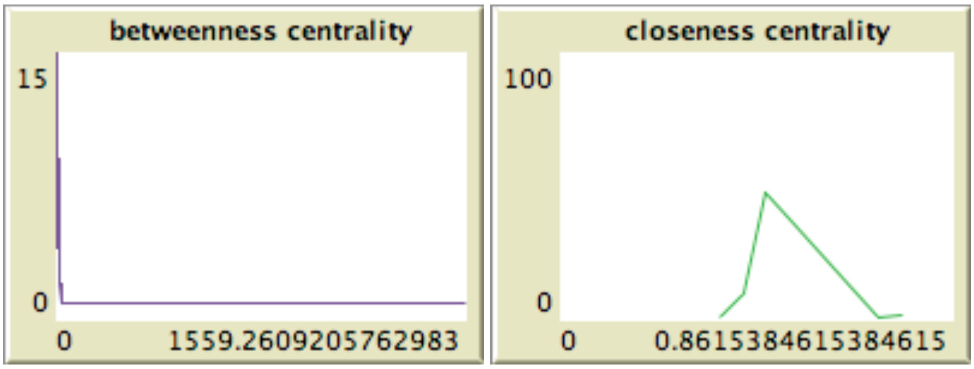
Distribution of betweenness centrality and closeness centrality varying which one of the three mechanisms has the highest probability



Note. Probability of resource dependence = 50; probability of homophily = 20; number of nodes = 100; number of links = 500; max-number = 3



Note. Probability of resource dependence = 30; probability of homophily = 60; number of nodes = 100; number of links = 500; max-number = 3



Note. Probability of resource dependence = 20; probability of homophily = 20; number of nodes = 100; number of links = 500; max-number = 3