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**Path Dependence and opportunities for technological development in
University-Industry cooperation**

An Agent Based approach

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Abstract

In this paper we investigate the effect over time of partner choice criteria on emerging path dependence in university-industry cooperation at the level of R&D projects in which a combination of diverse industry and academic partners collaborate. We execute this by varying the partner choice based on diminishing previous cooperation experience. For this purpose we develop an agent-based model. The properties and behavior of the agents and their environment in this model stem from the descriptive results of empirical research on University Industry cooperation in the Netherlands. As such it is an image of a medium sized University-Industry R&D network resembling the system in the Netherlands. The initial results show that the initial positive effect of rational choice on heterogeneity in the network decreases over time. Also, there are indications that choosing partners based on previous cooperation experience has a negative effect on the development of heterogeneity in the network over time and therefore, an increasing effect on path dependence over time. Furthermore, despite increasing path dependence there still seems to be resource and actor heterogeneity in the network. Whether these heterogeneities are sufficient for innovation will be the subject of further research. Finally our model have to be further tested on correspondence with the causal model and next validation steps have to be taken.

Key words: Agent based modeling; Innovation; Path dependence; Resource and Actor heterogeneity

Introduction

In this paper we investigate the effect over time of partner choice in university-industry cooperation at the level of R&D projects in which a combination of diverse industry and academic partners collaborate. We execute this by varying the partner choice based on diminishing cooperation experience. For this purpose we developed an agent based model. The properties and behavior of the agents and their environment in this model stem from the descriptive results of empirical research on University Industry cooperation in the Netherlands (Raesfeld et al 2012a and Raesfeld et al 2012b). As such it is an image of a medium sized University-Industry R&D network resembling the system in the Netherlands.

Innovation in networks of cooperating organizations rarely presents itself straightforwardly. Constraints in this process are frequently explained by path dependence. In the classic literature on path dependence in economics (David, 1985, Arthur, 1986) and institutional change (North, 1990) it is argued that self-reinforcing mechanisms, such as increasing returns, technical interrelatedness and quasi-irreversibility of technology or institutions constrain change. This view of path-dependence is criticized by several authors within the industrial network approach, for giving too much weight to stability while there are in a path dependence state still sufficient possibilities for change (Håkansson and Lundgren, 1995; 1997, Beyer, 2010; Håkansson and Waluszewski, 2002). A second critique is that too little weight is given to agency (Araujo and Harrison, 2002, Garud et al., 2010). The research interest of the scholars who criticize the path dependence view lies in exploring the possibilities of innovation or path creation, through the interactions of actors, activities and resources given an existing inter-organizational network.

Development of business networks over time, a recurring theme within the Industrial Network Approach (Wilkinson and Young, 2013; Håkansson, Ford, Gadde, Snehota and Waluszewski 2009), creates methodological challenges about how to investigate time and process in business networks (Prekert, 2012). Agent Based Modelling offers one way to investigate dynamic interdependencies between actors, activities and resources as presented in the Industrial network Approach. This paper provides some first results of the model with which we aim to jointly investigate effects of initial conditions, generative processes and the resulting network development over time (Lin, Kitts, Yang and Harrison 2008).

In this paper we answer two questions: 1) To what extent do the initial conditions determine the properties of the network overtime and 2) To what extent does the experimental condition (generative processes) of choosing partners with varying weights of partner preferences based on past cooperation experience determine the heterogeneity of the network development and possibilities of innovation?

The paper is organized as follows. First, we describe three possible options of path development and their consequences for path creation and innovation. Secondly, we present the agent based model of university-industry R&D cooperation projects. Finally, we discuss some initial findings and next research steps in using our agent based model.

Different phases of path dependence and explaining mechanisms

The concept of path dependence was first developed by David (1985) and Arthur (1989) in order to explain why certain technologies are used despite the fact that they seem suboptimal. Path dependence may be attributed to organizational routines (Cyert and March 1963) institutional contexts (North 1990) and technological configurations such as 'dominant designs' (Anderson and Tushman (1990). Path dependence introduces a historical element and the notion of irreversibility

into economic analysis and thus has been critiqued for being over-deterministic. In contrast to the strategic management approaches the notion of path dependence excludes the possibility that actions by the actors can actually shape the path and might cause an escape from the path. Garud and Karnøe (2001) introduced therefore, the idea of path creation, which requires 'mindful deviation' and organizing 'collective entrepreneurship'. So, while the concept of path dependence restricts strategic action to the exploitation of the existing path, the concept of path creation emphasizes the role of agency without neglecting structural and institutional properties.

Sydow, Schreyögg and Koch (2009) conceptualized organizational path-building processes that can be distinguished by their diminishing scope of action. In a similar but a bit more elaborate way Håkansson and Lundgren (1997) discussed inter-organizational path dependence at the level of industrial networks. According to Håkansson and Lundgren (1997) the degree to which history matters depends on the stability of activity patterns, resource constellations and actor webs and overlap or similarity between these three structures in industrial networks. Varying degree of overlap and stability in networks can be classified in three general categories: low, medium and high path dependence. For organizational path dependence Sydow et al (2009) distinguish three phases of path dependence that resemble the three categories identified by Håkansson and Lundgren (1997). A first phase or category is the most unrestricted in choice and might resemble the situation outlined in the rational choice tradition. Rational choice assumes no embeddedness and connection to previous developments. In reality such a situation does not exist but in new networks it might occur and overtime if networks mature it will disappear. In our model this situation is represented by organizations that gain cooperation experience over time. So in the beginning of the development of a network choice for a partner is less based on previous cooperation's but over time path dependence based on former cooperation's increases leading to an decrease of heterogeneity in the network Therefore our first hypothesis is:

Hypothesis 1: The initial positive effect of rational choice on heterogeneity in the network decreases over time.

In a second phase the scope of action is narrowed because of the 'pull' of the evolving path, such as increasing stability of the structures or increasing overlap between these structures. This phase of path dependence still provides enough choice to create new paths. In the third phase the scope is further restricted and lock-in arises, such as in the case of stable structures and large overlap. This is in fact the situation described by the traditional path dependence literature (David, 1985 Arthur, 1986; North, 1990). Following this stream of research we formulate the following hypothesis.

Hypothesis 2: Choosing partners based on past cooperation experience has a negative effect on the development of heterogeneity in the network over time and therefore, an increasing effect on path dependence over time.

Opposing the traditional path dependence view Håkansson and Lundgren (1997) and Håkansson and Waluszewski (2002) propose and show that innovation can take place because of path dependence This is the case because in networks "actors, activities and resources meet and habit and routines are confronted and combined" (Håkansson and Lundgren 1997:129). So even in a path dependent situation there is enough variety in possible combinations to take new paths. Therefore, we propose.

Hypothesis 3: Choosing partners based on past cooperation experience has a positive effect on heterogeneity of the network at each point in time and is not impacted by path dependence

Besides the three phase description of diminishing scope of action Sydow et al (2009) also indicated the need for explanation of the development by self-reinforcing social mechanisms such as coordination effects, complementarity effects, learning effects, adaptive expectations effects and possible contextual effects. These social mechanism can be seen as particular specifications of network stability and overlapping structures. Some of these mechanisms are included in our model. For example coordination effects we modeled by preference for former collaboration, complementarity we modeled in the properties of projects, learning effect are part of our outcome variable reflected in experience with partners and resource types, in future research we plan to investigate contextual effects by varying the initial conditions

The ABM model of university-industry collaboration

Agent based modeling studies emergent phenomena by simulating the preferences of individual agents. In our model the agents are organizations that choose several partners to cooperate with. The emergent phenomena are the developing actor and resource structures.

Our model simulates the behavior of networks of organizations undertaking innovative projects in various scientific disciplines and industries, such as computer science and biotechnology. Its world contains a predetermined number (1000 in this experiment) of organizations of various types (e.g university departments, companies, health care institutes, government agencies, and NGO's) and, some of which can initiate projects and all of which can take part in them. The organizations have properties such as the number of projects they can run simultaneously and the skills they hold. These properties are set at the beginning of each run via configurable stochastic distributions. The number of projects to be started per year is also part of the model's input. The most important varying quantities are the organizations' possession of the various types of resource (XP), and their preference for working with the other organizations in the population ('partnership preference' or PP). The formal algorithm of the model is provided in appendix A and B. The model is based on the descriptive results of empirical research on cooperation portfolios of University-Industry R&D projects in the Netherlands. Distributions of boundary conditions reflect the Dutch system. Such a medium sized system is large enough to randomly choose partners from industry, health care, academia and government in a way that reflects reality.

When an organization starts a project, the needed resources and the number of partners in the project are chosen. The potential project partners are selected based on partner preference (PP) of the initiator and the partner preferences of the other potential partners. The degree to which each score matters is an input variable of the model. As projects are completed, the participants gain both experience in the projects' resources and partner preference towards their fellow participants, which affects their chances of being selected for future projects. In this way, the model world evolves its collective experience in cooperation partners and the resources. The increase in and variety of resources is seen here as decreasing path dependence and an opportunity for innovation.

Experimental condition

Partner preference (PP) varies from 100-0 % in steps of 5, we thus have 21 experimental conditions that vary in degree of PP. Each experimental condition starts with a new initial situation randomly generated from the properties in the model and the same initial situation is 4 times repeated. The

21 * 4 = 84 random experimental conditions are simulated with projects starting every 2 months, outcomes are reported for each year over 50 years to represent the network development over time. For each organization is reported for each year, the experimental condition, the type of organization, total number of collaborations with all others, number of projects participated in, quantity and kinds of resources acquired

In this paper we analyzed the first experimental results. The number of project partners, the core skills, the initial partner preferences, and the institutional properties are randomly assigned given configurable probability distributions. It provides a first test of the model but also by comparing the varying degree of partner preference (PP) the research questions can be answered.

Causal model: Effect of partner selection on emerging path dependence

Dependent variables

As indicators for path dependence we used two heterogeneity measures and two network measures. The heterogeneity of resources is measured with the Herfindahl index and the network efficiency index. The Herfindahl index computes concentration of particular type of a resource as the sum of the squared proportions of different resources types of a organization, high index outcomes indicate a concentration of one type:

$$\sum_{i=1}^n PR_i^2$$

Where PR_i is the proportion of resource i of a organization, and N is the number of resources. Thus, for a organization that has four resources in equal proportions, the Herfindahl index equals $(0,25)^2 + (0,25)^2 + (0,25)^2 + (0,25)^2 = 4 \times 0,0625 = 0,25$. We calculated the mean score of the Herfindahl index per year as a heterogeneity measure, high scores indicate low heterogeneity and a strong path dependence.

The network efficiency index of Baum et al (2000) computes the heterogeneity as one minus the sum of the squared proportions of different resource types divided by the organization's total number of resource types, high index outcomes indicate an equal distribution of the different types so a high heterogeneity :

$$\left[1 - \sum_{ij} (PR_{ij})^2 \right] / NR_i$$

Thus, for an organization with six resource types, of which two in healthcare, two in pharmaceuticals and two in agriculture would score:

$$\left[1 - \left[\left(\frac{2}{6}\right)^2 + \left(\frac{2}{6}\right)^2 + \left(\frac{2}{6}\right)^2 \right] \right] / 6 = 0,111$$

We calculated the mean network efficiency per year as an indicator of heterogeneity, low scores indicate a strong path dependence.

The two network measures are the number of unique type of partners of a firm and the total number of partners.

The independent variable

In our experimental condition we manipulated the partner choice by varying the partner choice based on a diminishing former cooperation experience. In the next section we analyse the effect of the experimental condition over time on path dependence

Initial results

Table 1, presents tests of our hypotheses by several variables to estimate the effect of diminishing partner preference over time on path dependence. In hypothesis 1 we propose that the initial positive effect of rational choice on heterogeneity in the network decreases over time. The change in mean network efficiency and the estimated of the effect on network efficiency provides some evidence in support for hypothesis 1. The mean network efficiency is the highest in the initial years and the effect on network efficiency is positive up till 7 years after which it becomes negative. This shows that the effect on mean network efficiency is decreasing over time.

year	Mean Network Efficiency*10**2	Effect on Herfindahl: b*10**5	Effect on Network Efficiency *10**5	Effect on firm's Unique Partners 10**3	Effect on Number Partners 10**3
5	3,55	-1	3,2	0	0
6	2,93	-1,5	0,25	0	0
7	2,75	-2,2	-1,1	1	1
8	2,66	-2	-0,9	1	1
9	2,4	-3	-1,6	1	2
10	2,11	-3,1	-3	2	3
11	1,95	-2,8	-2,6	2	3
12	1,88	-2,2	-2	2	2
13	1,8	-2	-2,2	2	2
14	1,7	-3,1	-3,3	3	4
15	1,6	-2,9	-3,2	3	4
16	1,53	-2,4	-3,3	3	4
17	1,48	-2,5	-3,4	3	4
18	1,44	-2,7	-3,2	3	4
19	1,39	-2,7	-3,2	3	5
20	1,35	-2,2	-2,3	3	5
21	1,32	-2,3	-2,3	4	5
22	1,29	-3,3	-2,5	4	6
23	1,25	-3,1	-2,5	4	6
25	1,2	-2,6	-2,6	4	6
30	1,1	-2,8	-2,9	5	8
35	1,02	-2,8	-2,6	6	11
40	0,96	-2	-2,4	6	12
45	0,91	-1,8	-2,2	7	14
50	0,87	-2,7	-2,3	8	18

Table 1: Mean network efficiency over time and, effect of diminishing partner preference over time on path dependence

In Hypothesis 2, we pose that choosing partners based on past cooperation experience has a negative effect on the development of heterogeneity in the network over time and therefore, an increasing effect on path dependence over time. The estimates in table 1 provide some contradictory evidence on the one hand the increasing positive effect of decreasing partner preference over time on number of unique and total number of partners in combination with an decreasing effect on the concentration of resource types (the effect on the Herfindahl score) confirms hypothesis 2. On the other hand the estimates of network efficiency show the opposite a negative effect on heterogeneity of decreasing partner preference. Given the way network efficiency is scored, the outcome might also be that there is variation but also redundancy in resource types. Important to notice is that the effects on both the Herfindahl and the network efficiency scores are very low. Hypothesis 3: Even when path dependence increases there is still enough heterogeneity for possible new innovations, cannot be answered in this phase of our study. But what we see is that there is an increasing variety in terms of actors and some but decreasing variety in terms of the resource heterogeneity.

Development of the experiment

Further testing the model on correspondence with the causal model and validation steps have to be taken. In particular programmatic testing and test scenarios have to be conducted. For example the role and type complementarity were probably unduly constraining the outcome of the experiment, so we have to further check this by varying the weight of type and role complementarity in addition to resource diversity.

Until now we only manipulated the importance of partner preference and studied its effect on various characteristics of path dependence. The first extension we plan will be the addition the effect of importance of resource diversity.

Appendix A: The Model description

Model variables

The model operates on the following variables:

- N organisations (1000 in our experiments);
- D disciplines (27 in our experiments);
- P projects (number not predetermined);
- T organization types (9 in our experiments); OT_a holds the type of organization a ;
- R organization roles (3 in our experiments); OR_{ar} indicates whether organization a can fulfill role r ;
- I , a list of “initiators”, or organizations allowed to initiate projects. $I_a = 1$ Signifies that organization a can initiate projects. This is determined based on the organization type OT_a ;
- PP , a matrix of “partnership preferences”, where PP_{ab} represents the preference of organization a for working with organization b relative to the other organizations;
- XP , a matrix of “experience”, where XP_{ad} represents of organization a in discipline d ;
- OC , a list of “project capacities”, where OC_a represents the number of concurrent projects organization a can take part in;
- SBI , a matrix of “core disciplines”, where SBI_{ad} indicates whether or not organization a has discipline d as one of its core disciplines. Core disciplines indicate an organization’s core business and experience in it will not depreciate over time, unlike other experience;
- PD , a list of “project durations”, where PD_p specifies the duration (in years) of project p . The duration is determined for each project at startup according to a weighted distribution.
- PO , a matrix of “project participants”, where $PO_{pa} = 1$ specifies that organization a took part in project p ;
- PS , a matrix of “project subjects”, where $PS_{pd} = 1$ specifies that project p has discipline d as one of its subjects. Project disciplines are chosen from the SBIs of the project partners, with at least one coming from the initiator;
- The “project fuel” f is a scalar that allows the initiation of a new project as soon as $f \geq 1$. f increases over time, in a stochastic fashion according to a Poisson distribution, with $0 \leq P(1) \leq 5$ per year, repeated for each initiator (which means that, on average, each initiator can attempt to start one project each year).

Model initialization

The model is initialized as follows:

1. Each of the N organizations is assigned a single type (OT_a) according to a weighted distribution (see figure below for the types chosen for our experiment). The type also determines the maximum number of concurrent projects (OC_a).

Type (T)	Small company	Medium company	Large company	Government	Hospital	University	University (initiator)	NGO	Research organisation
Frequency (%)	45	8	3	5	10	10	4	5	10
Project capacity OC_a	1	3	15	1	1	1	2	1	1

2. Each organization is also assigned one or more possible roles (OR_a) according to a weighted distribution (see figure below for the values chosen for our experiment). The number of possible roles for each organization is fixed at 1.

Role (R)	Producer	User	R&D
Frequency (%)	30	30	40

3. Each organization is assigned a primary and a secondary disciplines as their SBI (SBI_a) according to discrete uniform distribution. They are assigned a randomly chosen amount of experience (XP) in each of these SBIs: $0 \leq N(1, 0.5) \leq 2$ for the primary one; $0 \leq N(0.5, 0.25) \leq 1$ for the secondary one;
4. The initial relationships between all organizations are chosen by prefilling PP , with each element chosen according to the distribution $0 \leq N(0.1, 0.1) \leq 1$;

The run can progress at any resolution of time. For our experiment we have chosen a resolution of 2 months ($\frac{1}{6}$ year) as a reasonable approximation of the resolution of organizational decision making regarding projects.

Model operation

An experiment does the following each tick of time:

1. The project fuel is increased by $\frac{0 \leq P(1) \leq 5}{6}$ units per initiator;
2. While there is enough fuel to start a project ($f \geq 1$), do the following:
 - a. Choose an initiator i who has not yet reached their project capacity ($PC_i = 2$);
 - b. If there is no such initiator, go to step 3;
 - c. Choose a project duration PD_p from a weighted distribution (see table below for the values used in our experiments);

Project duration	3 years	4 years	5 years
Frequency (%)	15	75	10

- d. Choose the number of project partners $\sum PO_p$ according to the Poisson distribution $2 \leq P(5) \leq 19$;
 - e. Select the project partners according to the selection algorithm listing in appendix B;
 - f. If the project partners cannot be chosen, do not create the project; continue to step 3;
 - g. Choose the project subjects (PS_p) from a combination of the following:
 - i. 1-2 (equally probable) of the initiator's SBIs;
 - ii. $1 \leq P(1)$ of the SBIs of any of the project partners (including the initiator). All SBIs are scored equally, which means that SBIs that occur more than once among the project's participants are more likely to be chosen.
3. If any project has been running for as long as its duration (PD_p), end it by doing the following:
 - a. Increase the partnership preference (PP) for each of the participants towards each of the other participants by 1;
 - b. Increase the experience (XP) of each participant in each of the project subject disciplines by 1.

Appendix B: Partner selection algorithm

The project partner selection algorithm operates on a project initiator and a number of candidates for participation, progressing through rounds by eliminating one or more candidates each round until exactly the desired number of candidates remain, at which point these are all promoted to project partner. Each round all candidates are scored on four factors; experience, partnership preference, type complementarity and role complementarity. The candidate or candidates with the lowest total score are eliminated.

The initial candidates are all organizations c in the model who have not yet reached their project capacity (OC_c).

The algorithm operates on the following variables:

1. w , the weights of each subscore type in the calculation of the total score of a candidate. The sub-score types are experience s_x , preference s_p , type complementarity s_t and role complementarity s_r . In our experiments, w_t and w_r are both kept at 1, while w_x and w_p vary in such a way that, at all times, $w_x + w_p = 1$.
2. s^c , the score of each candidate c . The score is calculated from the sub-scores $\sum_{i \in (x,p,t,r)} w_i s_i^c$

The sub-scores are calculated as follows:

- s_x is the average of the organization's experience (XP_{cd}) in the project subjects ($d \in PS_p$);
- s_p is the average of the partnership preference (PP) of the candidate to the initiator, the PP of the initiator to the candidate, the PP of the candidate to each of the other candidates and the PP of each of the other candidate to the candidate;
- s_t is the inverse of the number of candidates that have the same type as the candidate;
- s_r is the average of the inverse of the number of candidates that could fulfill each of the same roles as the candidates;

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