THE DIFFUSION OF SYSTEM DYNAMICS IN ACADEMIA

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Abstract.

The paper analyzes the geographical diffusion of system dynamics in academia using information on the affiliations of authors who have contributed to the System Dynamics Review. The paper develops and interprets a set of descriptive indicators that allow the identification of sustainable adoptions of system dynamics in a particular country. Longitudinal analyses indicate difficulties in the diffusion process and point at policies potentially advancing the further dissemination of SD.

Keywords.

Diffusion process; geographical diffusion; database study.

THE DIFFUSION OF SYSTEM DYNAMICS IN ACADEMIA

After 50 years of application, system dynamics (SD) is today considered an established method for investigating the structurally induced dynamics of complex systems. Delivering powerful insights into and explanations for the non-linear behavior of complex systems of all kinds, SD has proven its ability to externalize, formally analyze and reframe the often well-hidden mental models of decision-makers. The field has grown substantially, both in scale – the number of people involved – as well as in scope, the diversity of issues examined. Researchers and practitioners have taken up Jay W. Forrester's original ideas, developed and extended them, combined them with new approaches and applied them in numerous arenas. Nevertheless, many system dynamicists report that they perceive their profession rather as hermetism than as a widely-recognized, well-known means of systematic enquiry for treating complex dynamic problems. Jay W. Forrester perceives the discipline to be on an aimless plateau, seeing that "interest in system dynamics is growing faster than the supply of skilled professionals in the field. At present, the bottleneck is in education for system dynamics expertise." (Forrester 2007a; Forrester 2007b) Others passionately point at the achieved growth of the field, and plead for self-confidence. With history told and a lively discussion going on about the necessary next steps to advance the field in quantity and quality (Barlas 2007; Forrester 2007b; Homer 2007; Sterman 2007), yet the community owes formal, empirical clues on the progress of the diffusion process which might support a neutral assessment and allow the identification of leverage points from the hitherto achieved.

In the aftermath of the 50th anniversary of the field, this paper aims at contributing formal, fact-based analyses of the diffusion process of system dynamics. The paper develops and interprets a set of descriptive indicators that allow an assessment of sustainable, quantitative growth of the academic part of the field. The presented analyses may point at obstacles or accelerators of the diffusion process and indicate some potential opportunities to be leveraged to advance the further dissemination of SD.

The paper is organized as follows. First of all, a brief overview of studies addressing or describing the growth of the field is given. The subsequent section lays out why concentrating the analyses on the publication activity within the field – and especially on the System Dynamics Review (SDR) – may deliver particularly valuable insights. With this focus set, quantitative analyses are presented that shed light on the growth of the field from various perspectives. In a first analysis the geographical footprint of SDR authorship is presented. Longitudinal analyses reveal patterns in the diffusion process. After preliminary conclusions have been drawn from the analysis of the empirical data, potential limitations of the chosen approach are discussed. Finally, as motivation for further research, conceptual considerations are presented that draw on the idea of the diffusion of system dynamics being strongly characterized by network externalities .

Related literature

A number of authors have addressed the growth of the field, especially recently due to the historical interest spurred by the field's 50th anniversary (among others, Milling 1999; Morecroft 1999; Andersen et al. 2007; Forrester 2007a; Milling 2007; Morecroft and Wolstenholme 2007). Previously, analyses of the development of the System Dynamics Society and the publication activity in the System Dynamics Review (SDR) have been published to track growth (e.g., Richardson 1991; Eberlein and System Dynamics Society 1995). Aiming for an empirical assessment of the field and insight regarding the actual application of system dynamics, Scholl (1991; 1995) discusses the development of the field, and designs and conducts a large scale questionnaire study collecting the opinions, experiences and perceptions of system dynamicists.

Yet, a structured analysis of the geographical diffusion process has not been conducted, to our notion. The present study therefore aims at complementing the available empirical insights to support the strategic, largely experience-based discussion currently observable in the international system dynamics community.

Dataset and underlying assumptions

This study presents a number of database analyses focusing on the authors of articles published in the System Dynamics Review (SDR) in order to obtain a comprehensive picture of the current spread and the diffusion of system dynamics in the academic world. Being the successor of Dynamica, a journal originally published by the System Dynamics Group at Bradford University, the SDR is the official journal of the System Dynamics Society and can today be considered to be one of the primary publications in the field.[i]

SDR authorship is assumed to be a better indicator of a successful and sustainable diffusion than, for example, membership in the System Dynamics Society or similar criteria as it systematically discriminates against cases 'passively' holding a characteristic, i.e. members not actively applying or teaching system dynamics or authors publishing a single study on a conference. The chosen approach aims at identifying academics that actively advance the field and are examples of a sustainable adoption of system dynamics at a high quality level. It systematically reduces the α error (false positives), bringing along a potentially increasing β error (false negatives). Being aware of this methodological difficulty, the analyses, of course, need careful interpretation.

The basis of our analyses is the bibliographic data on all articles published in the SDR from 1985 until 2007 (volumes 1 to 23) with full author information. The core of this data set has been retrieved from EBSCO's *Business Source Complete* data base which holds bibliographic data for the SDR from 1991 onwards and allows the complete export of large bulks of bibliographic data. Unlike other data sources – such as the bibliography published by the System Dynamics Society – the EBSCO data set provides detailed author information and, therefore, allows comprehensive analyses of geographical aspects, among others. Due to embargoes and other access restrictions the data for the years 1985–1990 and 2007 have not been available from EBSCO directly and have been added manually from original prints of the SDR.

For a number of reasons an SDR-based bibliographic data set is a more attractive basis for analysis than alternative sets of publications such as conference proceedings: The SDR represents the widely accepted arena for peer-reviewed academic contributions to the field that

have been acknowledged as valuable, high-quality work. Not discrediting the quality of academic work presented elsewhere, contributions to the journal are supposed to be more selective than, for example, conference proceedings. In addition, due to its inclusion in several bibliographic databases the SDR has a higher visibility than conference proceedings. At the same time a journal can be assumed to be more diverse and representative than the body of books dealing with system dynamics.

A brief analysis of EBSCO's *Business Source Complete* database shows that the SDR apparently includes a substantial part of the entirety of publications in academic journals addressing system dynamics: The *Business Source Complete* database indexes and abstracts more than 11,000 sources of which about 2,240 have been classified as peer-reviewed "academic journals" (EBSCO 2007, 2008b, a). Of all hits retrieved for "system dynamics", the 368 contributions to the SDR listed in the database for the time period from 1991 until 2006 represent 33.3%, and 35.6% of all hits for "system dynamics" in sources categorized as "academic journals". An analysis of SDR authorship is assumed to be a sufficiently representative data set.

The following analyses only consider contributions to the SDR that present original research results or are substantially discussing or responding to it. These pieces are mainly included in the 'Articles', 'Research Problems', and 'Notes and Insights' sections of the journal. Book reviews, announcements, calls for paper, etc have been excluded from the dataset. In total, 382 articles could be identified as suitable for further analysis. These articles have been (co-)written by 392 different authors.

For the present study the authors have been mapped geographically according to the bibliographic data provided by EBSCO. For the years not covered by the EBSCO dataset or if the retrieved data is ambiguous or not available, the dataset has been complemented with author information from original SDR prints. Affiliation has been defined for each author and for each publication separately, and it may thus change for the same author in the course of time. For authors with multiple concurrent affiliations only the *primary* occupation is accounted for. A change of the primary affiliation could be identified for 14 authors. In five cases no sufficient

author information could be retrieved; these authors have been excluded from our analysis, leaving 387 authors in the dataset.

As Figure 1 shows, the number of articles published in the SDR per annum has increased since Volume 1 and ranges between 15 and 22 articles per volume over the last 15 years. Accordingly the number of issues increased over time from initially two issues in 1985 to four issues today.[ii] Particular events induce peaks in publication activity, particularly observable in 2002 (Special Issue "The Global Citizen: Celebrating the Life of Dana Meadows") and 2007 (Special Issue "Exploring the Next Great Frontier: System Dynamics at 50"). As average authorship does not change significantly over time – with peaks in 1995 and 2000 – the total number of authorships by and large changes only in accordance with the number of articles p.a.

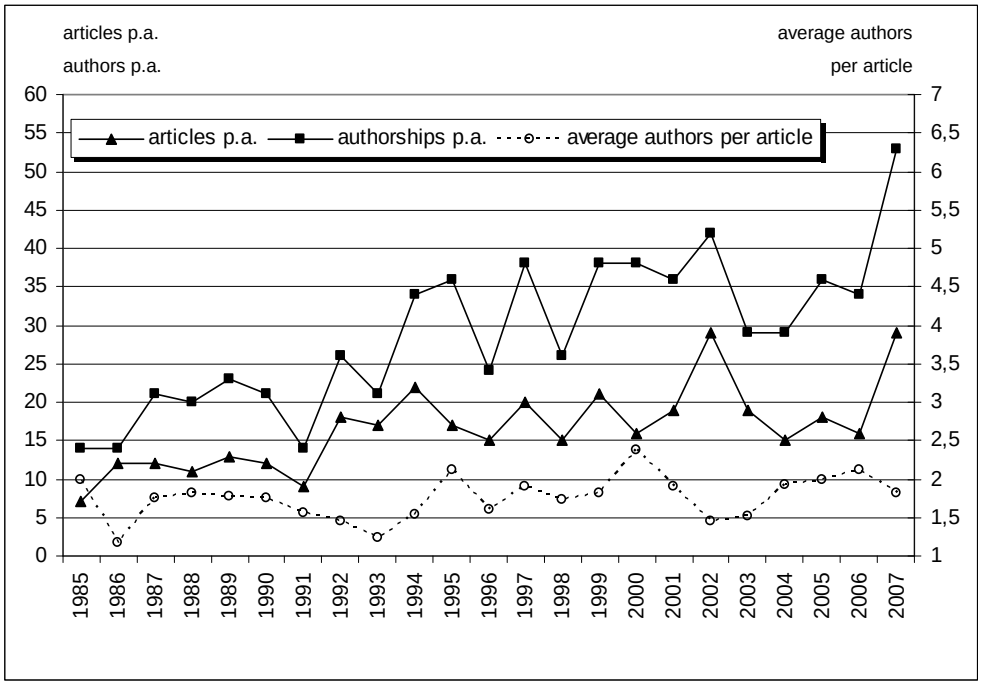

Figure 1: Publication activity in the System Dynamics Review Vol. 1 – Vol. 23

Overview: Geographical footprint of SDR authorship 1985–2007

In a first step the geographic distribution of the authors of SDR articles is analyzed using the information about the authors' primary affiliation. The geographical distribution of SDR authorship is assumed to be a proxy for the regional presence of more-than-average deeply involved system dynamicists. Their primary affiliation describes their respective main 'sphere of influence' in which they actively represent the field and, assumingly, foster further local diffusion.

The identified 387 authors are active in 35 different countries. Figures 2 and 3 shows how they split up according to their primary affiliation. With more than 85% of all authors, system dynamicists from North America and Europe dominate the picture, with both regions showing almost equal strength in numbers. On a country basis, the US account for the largest group of authors, followed by peers from the UK, Germany, The Netherlands, and Spain.

Figure 2: Geographical distribution of SDR contributors 1985–2007

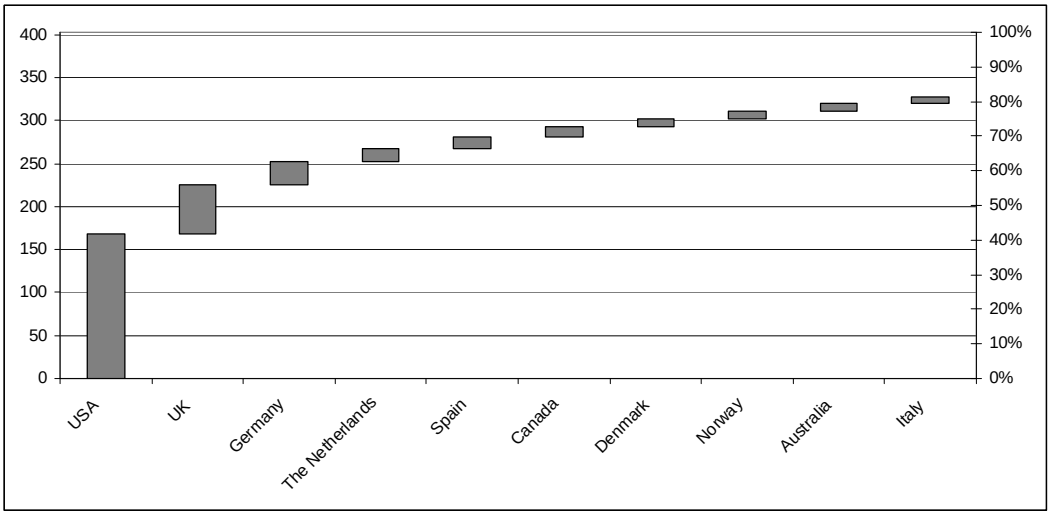

Figure 3: Number of authors per country (top 10 countries only)[iii]

Empirical data on the diffusion of system dynamics in academia 1985–2007

For the further development of our study the focus of the analysis is to shift from the person of the *author* towards the event of '*having authored'* an article, i.e. the *authorship*. This distinction allows longitudinal studies of the presence and activity of regional academic communities and represents a major difference of the present study from related publications.

An authorship-based index rewards two developments: On the one hand, intensive publication activity by few authors is understood as an indicator of the presence of deeply convinced, actively propagating individuals. It can be assumed that their interest in system dynamics also becomes manifest in other activities that support the growth of the field such as SD courses, public speeches, consulting projects, etc. In this case, a high number of authorships reflects a *deep* involvement with system dynamics: Those who contribute to the field extensively on a high level will try to share their passion and fascinate others. In this regard, authorship is considered an indicator of highly *qualitative* diffusion, identifying cornerstones of the SD community consistently spreading their ideas on a level meeting the SDR's quality standards.

On the other hand, few publications written by many authors from one country result in a high authorship value for a particular country. In this case, the indicator reflects that many people are involved with system dynamics to a degree that enables and motivates them to share their ideas on the high academic level demanded by the SDR. It indicates a broad adoption of the method on an academically sufficient level which may support further dissemination, e.g. as a consequence of intensive word-of-mouth propaganda about positive experiences and convincing results achieved with SD. In this regard, a high authorship value is considered an indicator of highly *quantitative* diffusion, with proven quality that at least once has been acknowledged by the SDR. Authorship may thus be a good proxy for the impact system dynamics has in a particular country as both, large communities as well as small, but very active groups of system dynamicists are noticed.

Figure 4 depicts the distribution of authorships for the ten most active countries, in total accounting for more than 85% of all 667 authorships counted for between 1985 and 2007. A comparison with the previous chart shows an only partial match in order and proportion.

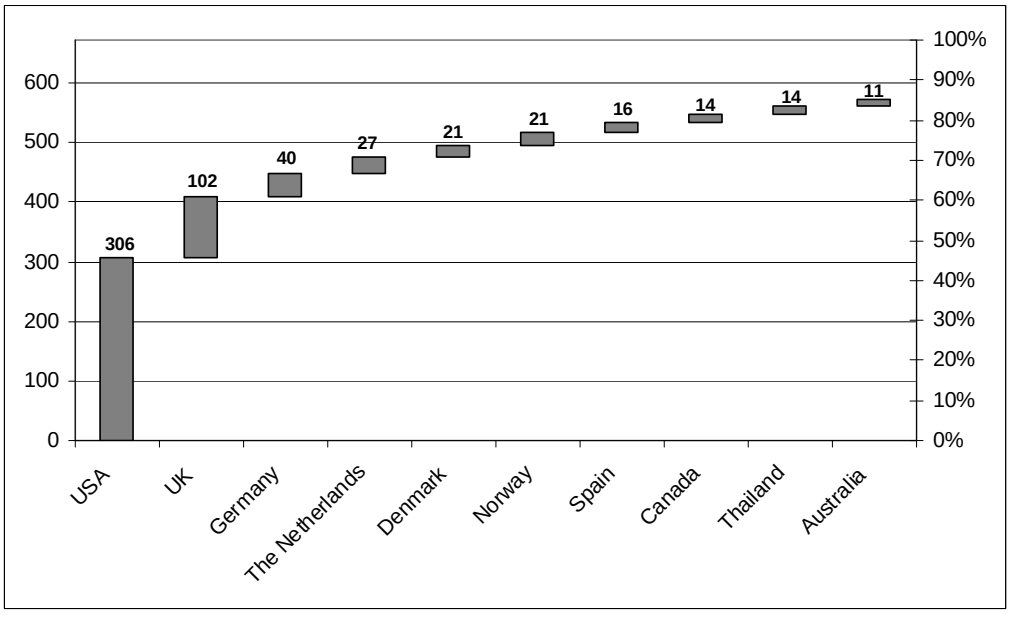

Figure 4: Distribution of authorships, top 10 countries, 1985–2007

The mismatch revealing internationally differing levels of activity may be caused by numerous factors, taking effect individually or in combination. Assuming that the diffusion of system dynamics had not been completed in 1985, a differing length of the presence of system dynamicists in a particular country may be one reason. Therefore, the time pattern of SDR authorships may indicate the geographical progress of the diffusion process. Figure 5 depicts the result of this analysis.

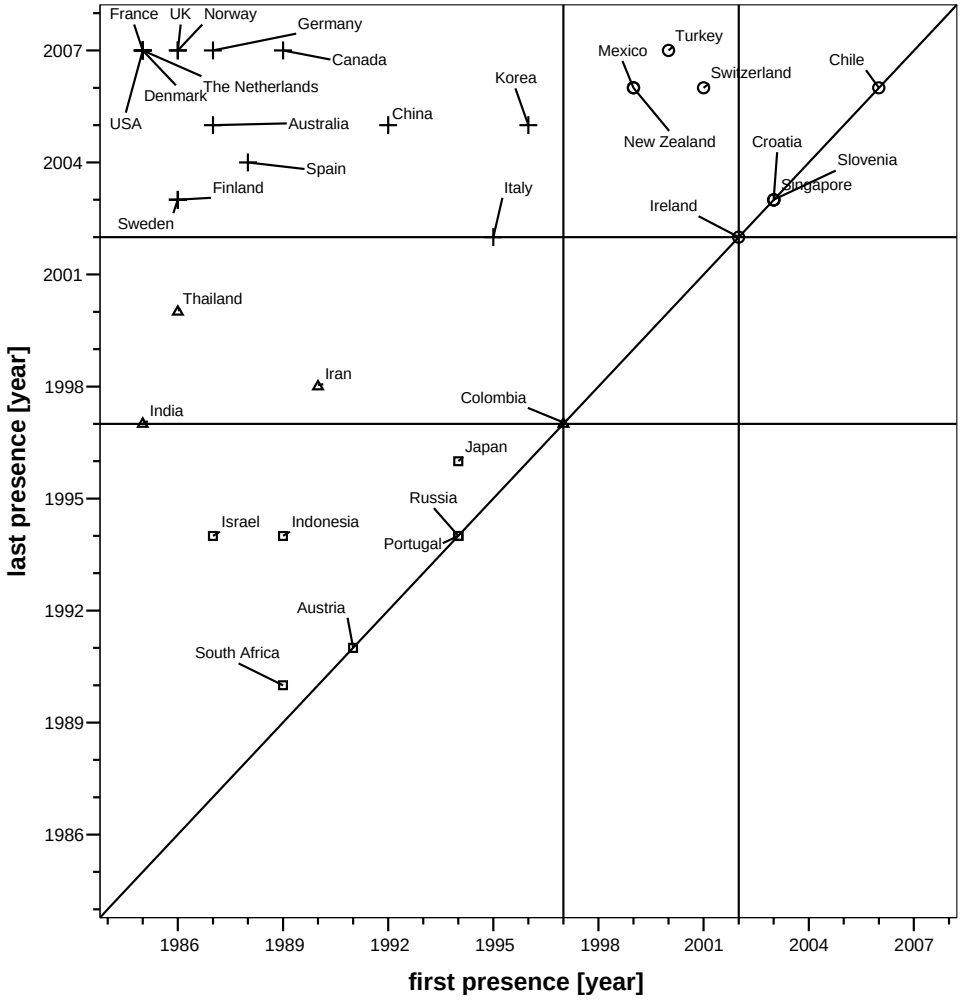

Figure 5: Time structure of national presence in the SDR

The chart clearly shows that the system dynamics approach had already spread from its origins at the MIT substantially before 1985. Within the first two (three) years authors from ten (thirteen)

countries contributed to the SDR. Taking into account the various delays in academic publishing – writing, reviewing, getting a scarce slot in a journal with only two issues per year – academics from these countries presumingly had already adopted Jay W. Forrester's ideas at that point in time. But the chart also reveals that some 'early adopters' have not been present in the SDR for the last ten years (lower left corner). The question arises to what extent this might be an indicator of a loss of academic attendance to system dynamics. On the other hand a number of countries have 'debuted' within the last ten years, some with repeated presence within the last five years (upper right). Some countries have been present only once (countries on the 45° line). A significant number of national communities have been active from the early volumes onwards and have also contributed recently (upper left). For these countries a successful, sustainable diffusion of system dynamics may be assumed. The intensity of the publication activities of those communities may deliver additional insight in this respect. Accordingly, Figure 6 illustrates the continuity of publication activities as well as the average number of authorships in the years of presence.

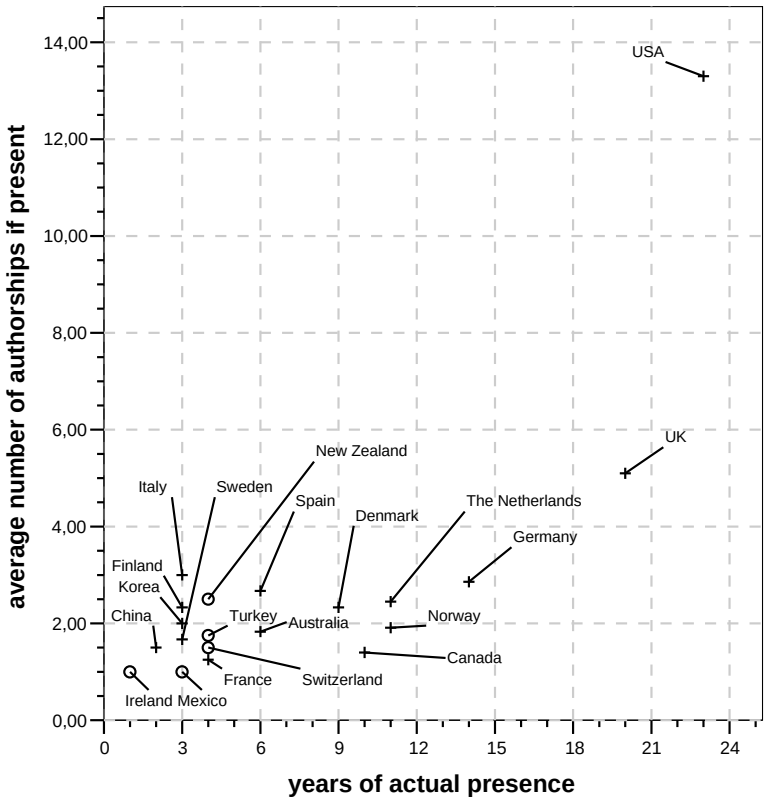

Figure 6: Intensity of publication activities for countries present after 1997

The analysis clearly underlines the dominance of authors from the US and, even though to a lesser degree, the UK. These two (positive) outliers show both more continuity as well as more contributions per annum. The rest of the countries considered in this analysis show a diverse picture ranging from highly or frequently active countries such as Germany or the Netherlands to only sporadically present countries such as France or Sweden, of which both have already been represented in the very first volume of the SDR, rarely afterwards, but again recently.

Drilling down the results to the level of individual authors the data explains the strong presence of particular countries, and shows that they share an interesting combination of *qualitative* and *quantitative* diffusion. Figure 7 shows how many individuals per country have reached a particular level of presence in the SDR, measured by the total number of authorships for each individual and the number of years in which this person has contributed to the journal.

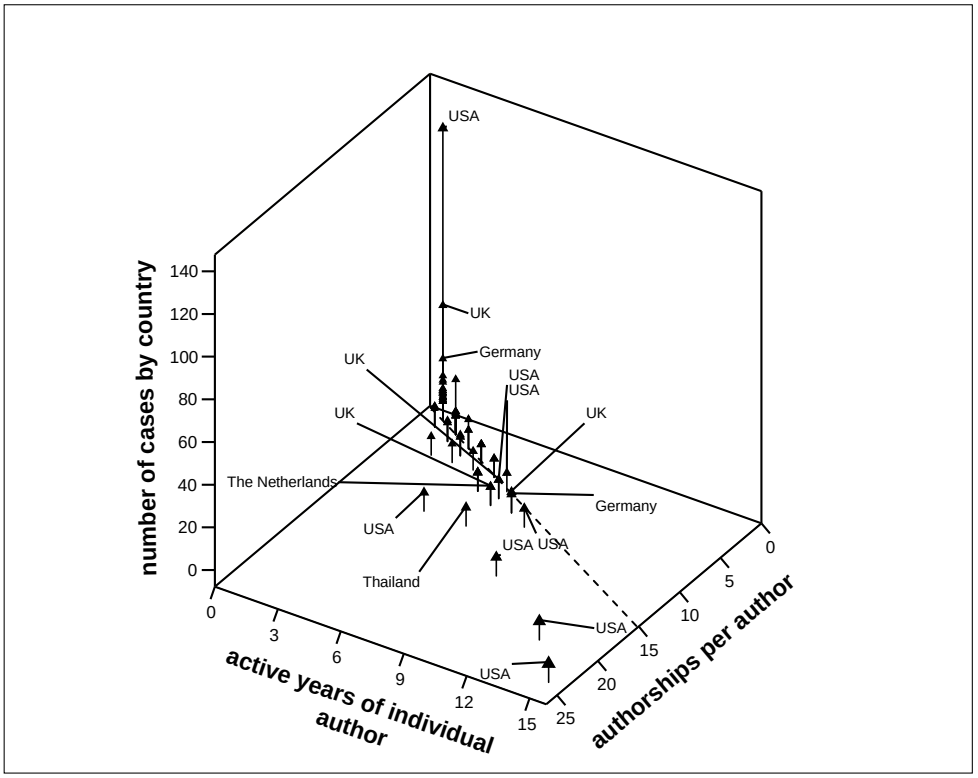

Figure 7: Indicators of quantitative and qualitative diffusion of system dynamics

Authors ranking high on the total number of authorships and being present in many years are examples of successful and sustainable *qualitative* diffusion. The larger the deviations from the dotted line, the higher the average number of contributions made in the years of presence. The data clearly shows that the high presence of the most active countries results from a combination of *qualitative* and *quantitative* diffusion as both, the overall most active individuals as well as the majority of the large group of authors contributing only once are affiliated with institutions in the US, the UK, and Germany.

Preliminary results

The hitherto presented analyses deliver several insights. First, the diffusion of system dynamics in the academic world has continued during the last 20 years, even though – second – diffusion does not always imply a growth of the field as the presence of academics from a substantial number of countries has decreased at the same time, potentially pointing at a loss of momentum of the diffusion process in those countries, both in terms of quantitative as well as of qualitative diffusion. A closer analysis of the reasons for the loss of presence may reveal particular risks the system dynamics community should be aware of. For example, many of the countries positioned in the lower left corner of Figure 5 are not surrounded by other regions of high system dynamics practice. Different from the very active US-american and European national communities, the lack of supporting groups situated close-by might be one reason that increase the necessary effort to establish a stable 'SD cell'. Third, those countries most actively contributing to the journal have apparently achieved a broad (quantitative) adoption of system dynamics fostered by a stable basis of highly active individuals (qualitative diffusion). The presence of 'cornerstones' of the field actively spreading their passion for system dynamics seem to be of major importance for broad adoption.

Limitations of the approach

For a number of reasons the focus on SDR articles may be considered critical. Space limitations and the review process exert biases on the dataset. Yet, the variation in the number of SDR articles implies that space limitations are loosened as more potentially publishable submissions are received. The published articles have passed two filters ensuring a sufficient quality of the work: First, authors have to assume that their work has the substance to become accepted. Second, the reviewers and the editor have to share this impression during the double-blind selection process. As our analysis aims at the identification of cases of a sustainable adoption of system dynamics, the filtering may actually increase the quality of the dataset. Still, both effects may lead to a delayed perception of the actual diffusion of system dynamics into a particular geographical area. The here presented analysis may therefore exhibit a tendency to underestimate the status quo of the diffusion process. On the other hand, perception delays avoid premature recognition of promising, but not yet sustainable adoption.

Furthermore, the focus on SDR articles systematically disregards the possibility of successful diffusion in a non-academic context, i.e. (business practice). By definition our dataset is not useful in answering this question. Yet, several observations indicate that the diffusion in academia is a necessary prerequisite for successful adoptions in other contexts (Barlas 2007; Forrester 2007b), and that the application of system dynamics in business practice stills lags behind and is not satisfying (Warren 2003). An additional query of the *Business Source Complete* database further supports this notion: Leveraging the database's broad coverage of more than 11,000 sources including about 2,240 peer-reviewed academic journals a comparison of the presence of a particular concept in academic and non-academic publications (such as Business Week and other general business interest magazines) is possible. The analysis compares the number of hits that a query for "system dynamics" produces in the complete database vs. in 'academic journals' only. In addition to "system dynamics", ten popular and well-circulating concepts from business practice have been queried. These management 'buzz words' have been extracted from Bain & Co.'s "Management Tools and Trends" survey (Rigby and

Bilodeau 2005), a successor of the study underlying Warren's (2003) original thoughts on difficulties in communicating SD to managers. Table 1 presents the results of this analysis.

Table 1: Visibility of system dynamics and popular management concepts in EBSCO's *Business Source Complete*

Concept	hits in Business Source Complete *(limited to period 01/01/1991–12/31/2006)*		
	# of total hits	**# of hits in academic journals**	ratio academic / total publications
Strategic Planning	33739	**9647**	.286
Total Quality Management	6637	**4332**	.653
Knowledge Management	9306	**4233**	.455
Outsourcing	23816	**2797**	.117
Benchmarking	7763	**2738**	.353
Supply Chain Management	8704	**2702**	.310
Strategic Alliances	22618	**2452**	.108
Change Management	2825	**1598**	.566
system dynamics	1105	**1033**	.935
Customer Relationship Management	8337	**935**	.112
Balanced Scorecard	1005	**527**	.524

Certainly, the raw numbers displayed here are biased by a number of hits that are actually not accountable to the intendedly queried concepts. Nevertheless, for the purpose of the presentation these biases might be negligible: The major result to be extracted from this table is not the absolute rank of system dynamics in the presented list of tools as the compilation does neither claim to be all-embracing, nor showing particular rigor in the selection of the benchmarked concepts. Yet, to our notion, it covers key concepts from the management discourse of the last 15 years. After all, the column that should be focused on is the ratio of hits in academic journals to the total number of hits. In this respect, system dynamics is the clear and indisputable outlier with more than 90% of all database entries being published in academic journals. This clearly supports the notion that despite its diffusion in academia, the spread to non-academic arenas has not been accomplished to a satisfying degree. The focus of the present paper on the diffusion in academia may therefore limit the interpretability only to some extent.

Further research: The diffusion of SD and network externalities

Some preliminary conclusions regarding possible chances or risks in advancing the diffusion of system dynamics have been presented. According to the results of our analyses, sustainable adoption of SD in a particular geographical region is the result of a combination of successful qualitative and quantitative diffusion. The presence of outstanding, passionate multipliers may trigger the development of a large, active and well-educated regional community spurring further dissemination of the approach. Presumingly, the existence of a regional network in neighboring countries supports the development of a community. A lack of direct contact with peers in geographical proximity might prevent the long-term adoption of system dynamics in a country.

As diffusion processes have frequently been analyzed formally also with the help of system dynamics models, a rich pool of knowledge exists within the community to extend the here presented empirical analyses. Numerous contributions examine the diffusion of various types of goods, and describe and explain general patterns that can be observed in this process. Most of these studies are based on the well-known and widely-applied Bass diffusion model (Bass 1969; Sterman 2000). With respect to the findings from the present analyses, the approach introduced by Thun, Größler and Milling (2000) may be of particular interest for further, formal research on the diffusion of system dynamics. The approach discusses the diffusion of goods characterized by network externalities, i.e. the features of a diffusion process "if the utility of a product for a customer depends on the number of customers who have also bought this product." (Thun, Größler, and Milling 2000: 3) Assuming that system dynamics – and scientific methods in general – share this characteristic, the extended diffusion model combined with the findings from the present paper might advance the identification of particular policies supporting a sustainable diffusion of system dynamics. A better understanding of the successes and setbacks during the diffusion of system dynamics may imply policy recommendations regarding the further activities of the (scientific) SD community in order to advance the further growth of the field, both in research as well as in practical business applications: "The following utilization of the network product is important for the diffusion process as well." (Thun, Größler, and Milling 2000: 4)

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[i] More information on Dynamica and the full set of articles published in this journal can be found at http://www.systemdynamics.org/dynamica.

[ii] To be correct, Vol. 1 consisted of No. 1 and the special issue counted as No.2–3. The following volumes consisted of two issues until 1991. Volumes 8 and 9 (1992 and 1993) consisted of three issues, and from 1994 onwards the SDR has been published in four issues p.a.

[iii] Due to international migration of authors and the corresponding changes in affiliation in total 403 affiliations of the 387 authors have been taken into account in this analysis.