When does it really make a difference? Experimenting with the level of actor-heterogeneity in the context of modeling socio-technical transitions

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Abstract
This study constitutes a methodological inquiry in a larger research context on transition dynamics, and it focuses on the issue of actor heterogeneity in modeling such processes. On the one hand heterogeneity at the actor level (i.e. heterogeneity among actor groups, heterogeneity among actors in a particular group, etc.) seems to be a very important source for complexity in the observed dynamics, on the other hand introduction of that heterogeneity into the models has a cost of losing some potential of the models to lead to insight development, since they become hard to comprehend in the detail level needed to incorporate mentioned heterogeneity. Hence, as a sub-topic in our wider research objectives regarding transitions, we conducted an experiment on the potential consequences (i.e. gains and losses) of ignoring or recognizing the actor heterogeneity. Three models of the same historical transition case with different types of actor heterogeneity are used in the experimentation procedure. The conclusions include direct outcomes of the experiments, as well as experience of the authors during the process of constructing these three different models that bring about differing challenges.

1. Introduction:

This study constitutes a methodological inquiry in a larger research context on transition dynamics. Briefly, transitions can be defined as long-term structural change processes spreading over several aspects of a societal system, such as, culture, technology, institutions and infrastructure [1-5]. Examples of such transitions are discussed in [3-9]. Research on transition dynamics aims to understand dynamic behavior patterns observed during these processes in terms of the underlying system components and interaction among them. Given the interconnected nature of the social and technical (physical) components of such systems and the multi-dimensional nature of transitions, understanding the dynamics of such processes or at least developing some useful insights relevant to policy design is almost impossible by just relying on qualitative analysis. That is the main reason underlying the choice for utilizing quantitative simulation models in exploring transition dynamics. Hence the overall aim is to come up with a set models that represent dynamic hypotheses regarding ongoing/historical transitions and gather some insight about the complex nature of these processes during the development and experimentation stages of this modeling study.

As in almost all other modelling studies, the model aimed at is the simplest one that provides a good (i.e. satisfactory, useful regarding policy design perspective) account of what is going on and why it is going on that way. During the conceptualization stage a very important issues relevant to simplification and abstraction is the heterogeneity among the actors (i.e. decision-making bodies like individuals, group of individuals, or organizations that are relevant to the process-of-interest) relevant to a socio-technical transition.

Considering an even modest scale socio-technical transition, it is possible to recognize a multiplicity of parties being involved in the process. These actors/actor groups may differ in their objectives, preferences, power, response speed, and role in the system. This important aspect of the transitions is highlighted with the multi-actor concept discussed by Rotmans [1]. Also Yucel and Meza introduced four different actor roles that can be recognized in a range of historical socio-technical transition cases [10]. Finally, looking at the diffusion of innovations field, which is one of the main fields that influence transition studies, relevance of different actor groups (i.e. front-runners, laggards, etc.) regarding the diffusion process of a novelty is commonly discussed [11].

On the one hand heterogeneity at the actor level (i.e. heterogeneity among actor groups, heterogeneity among actors in a particular group, etc.) seems to be a very important source for complexity in the observed dynamics, on the other hand introduction of that heterogeneity into the models has a cost of losing some potential of the models to lead to insight development, since they become hard to comprehend in the detail level needed to incorporate mentioned heterogeneity. Hence, as a sub-topic in our wider research objectives regarding transitions, we conducted an experiment on the potential consequences (i.e. gains and losses) of ignoring or recognizing the actor heterogeneity.

In order to do so, we have selected a well-documented historical socio-technical transition case, where different types of actors can easily be recognized in the context of the documented transition. The selected case is the transition from the sail ships to steam ships in naval transportation in the Great Britain, which is discussed by Geels from the transition perspective [3]. Based on the documented quantitative data and qualitative descriptions of the change process, three different models with differing levels of actor aggregation are constructed, and the development and experimentation processes related to these models served as the basis of our discussion on ignoring or recognizing actor heterogeneity in this context.

In the following section, the historical case study used as the basis is briefly summarized Section 3 and 4 are devoted to the introduction of the models developed using different actor aggregation levels, and information about their implementation. Section 5, which demonstrates the results obtained by experimenting with these three models, will be followed by discussions and conclusions.

2. Summary of the Historical Transition From Sail Ships to Steam Ships

In this section, a brief summary of the selected socio-technical transition case will be given. A more comprehensive overall discussion of this historical case with a transition perspective can be found in [3]. Apart from that more specific aspects of the process and technologies that are involved can be found in [12-15].

As mentioned before, the selected historical transition takes place in the naval transportation system of the Great Britain. As a result of this transition, which took place between late 18th and early 20th centuries, the dominance in naval transportation shifted to steam-ships from the formerly dominant option of sail-ships.

The beginning of the transition period can be characterized by the clear dominance of the sail-ships, and related economic and social practices in the transportation of goods, passengers and mail to overseas. Despite already being in use during those times, due to short-comings such as range, operating cost and performance in open seas, the utilization of the steam-ships was limited mainly to transportation on inland waterways.

Three main markets existed for these 'competing' transportation options; merchandise, passengers and mail. Being independent of winds, the steam-ships were much more reliable in terms of travel times, and also they were faster on average. With those characteristics, they were quite desirable for mail and luxury passenger markets. However, their technical shortcomings as range (due to coal supply) and operating cost were balancing the advantages and probably preventing the further utilization of them apart from inland water transportation. Especially range was a significant problem for long-distance merchandise to/from North America or India.

Due to an increasing demand for regular and fast mail services, the steam-ships started to diffuse this market segment, mainly induced by the subsidies provided by the government for mail transportation with steam-ships. Parallel to this, significant technological developments were realized. These were partially due to the exogenous developments attained in other fields where steam engines were used (e.g. increase in fuel efficiency). On the other hand, wider utilization of steam-ships also resulted in some gradual improvements. Learning-by-doing and economies of scale can be proposed as potential mechanisms of these improvements. Especially the construction of refueling stations, and the improvements in the fuel efficiency made the steam-ships a viable option even in the long-range transportation. These developments during the transition period put the steam-ships at a strong competitor position against the sail-ships.

Toward the end of the transition period, the steam-ships were evaluated to be superior to sail-ships in most of the aforementioned market segments. Despite this fact, the sail-ships were still in use, especially in the more cost sensitive segments as low value freight transported to long distances. To summarize the change in figures, the Great Britain naval transportation market in which 95% of the vessels (in terms of tonnage) were sail-ships around 1850s, transformed into a steam-ship-dominated state by 1910. At the terminal point, only 5% of the vessels were sail-ships.

3. Overview of the Models

In line with the objectives stated in the introduction section, three different models aiming to capture and explain the dynamics of the selected case have been developed. Despite the fact that they all represent the same system, the level of heterogeneity with respect to actors involved in the process (i.e. level of actor aggregation) varies significantly. Apart from this difference, the models were almost identical in the sense that the set of dynamic mechanisms included is the same (e.g. a mechanism like change in option properties due to economies-of-scale is represented in all three models, but implemented in different ways due to the differences in aggregation levels). These three models will be briefly introduced below.

a. Model 1:

This is the version in which the level of aggregation is the highest, and the model can be seen as a more detailed variant of simple innovation diffusion models [16, 17]. The state of the system can be summarized by two stock variables representing the market shares of the options. The rates of change manipulating these stock variables are assumed to be a function of the performance difference between the options, and the current market share values. The corresponding model structure that constitutes the backbone of the model is given in Figure 1.

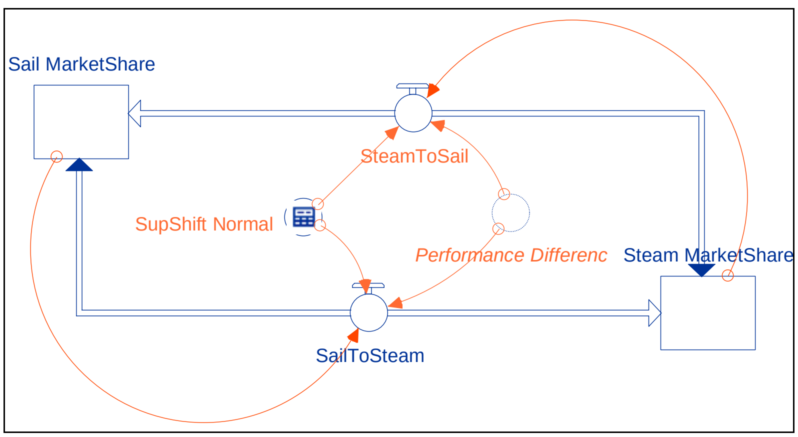

Figure 1: Backbone of Model-1

Although the relevant aspects that can be utilized for the evaluation of competitive advantage of options are several, a single aggregate performance measure is used in this model. The changes in this performance measure are assumed to be driven by a set of mechanisms. First of all, it is assumed that each option (i.e. steam-ship or sail-ship) has a *best performance level* defined by the technological possibilities. This best level is defined as an exogenous parameter, and actual performance of the options is assumed to converge to this level in a goal-seeking manner. Under normal circumstance, it is expected to observe a slow performance improvement. The speed of this improvement is influenced by two mechanisms. One of them can be labeled as “resource-flow mechanism.” It assumes that periods of increasing market share of an option also resemble a faster resource flow in that direction (e.g. capital, R&D effort, etc). Hence, increased market share gains are conceptualized to trigger faster improvement. The second mechanism is related to the so called "sail-ship effect" discussed in [3, 18]. According to this mechanism the decrease in the utilization of a particular option (i.e. loss in market share) triggers some effort to improve the performance of the option in order to fight back new coming competitor. Hence, it will be referred to as "fight-back mechanism". These two mechanisms can be seen in Figure 2. Finally, it is assumed that some improvement on top of technological developments can be obtained due to the "economies-of-scale effect", which also depends on the scale of utilization of a given option (i.e. tonnage being transported with the means of an option). In this model, the economies-of-scale effect is assumed to be reversible. Apart from these structures related to performance change in options, there exists a first-order information delay between the actual and perceived performance of options representing the diffusion of information among users regarding the performance of the options.

In this model no heterogeneity is recognized in the model in terms of user groups or performance dimensions.

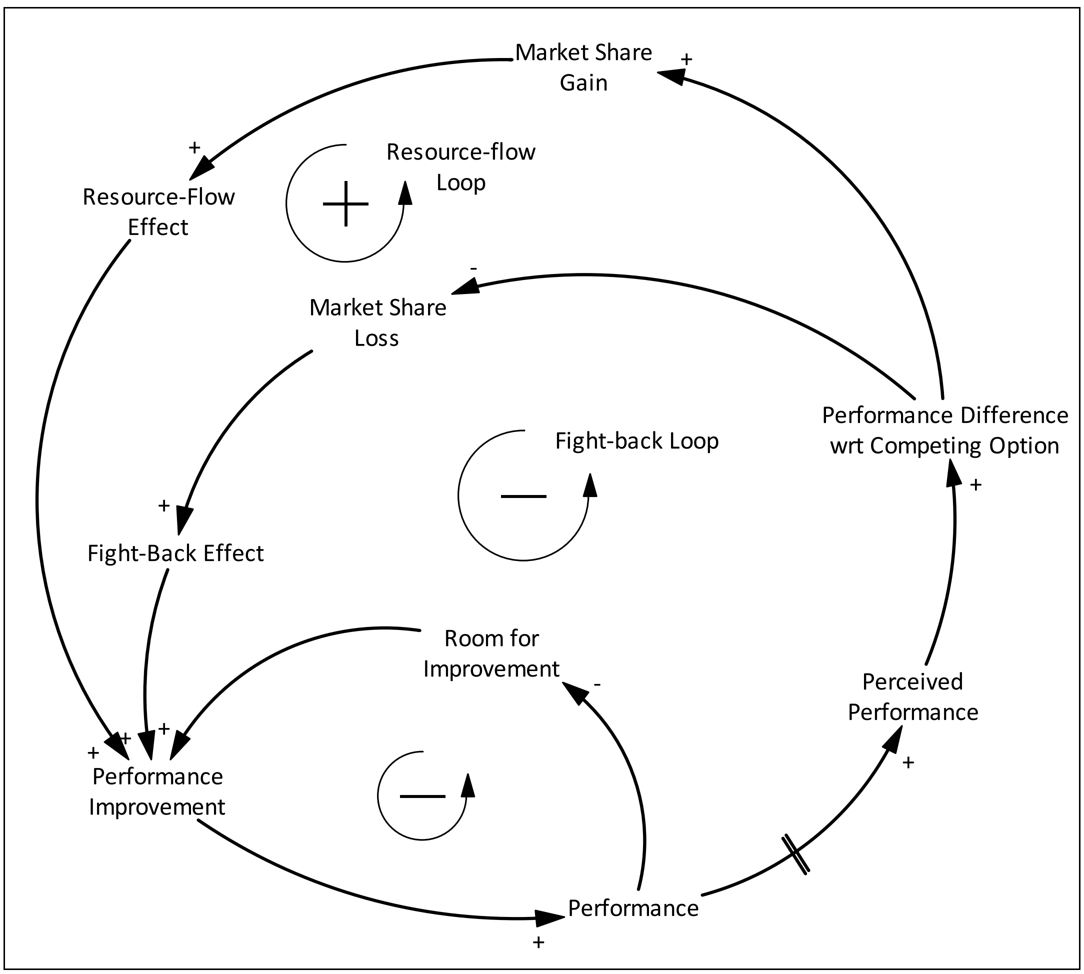

Figure 2: Main mechanisms related to performance development

b. Model 2:

The first level of disaggregation is implemented concerning the type of roles played by different actors in the given transition case. Actor-role concept is discussed in the context of transitions regarding the multi-actor aspect of the process. According to this, discriminating the actors based on the nature of impact caused by their decisions on the socio-technical system under study is very important [1, 10, 19]. Among the four roles proposed by Yucel and Meza (i.e. provider, practitioner, regulator, supporter) [10], we have recognized two of them in this case; practitioners and providers. Apart from that, it is also possible to see discrimination among the practitioners, who are the actors that directly utilize available options for their transportation needs. It is possible to recognize seven different types of practitioners based on their differing needs and preferences regarding naval transportation. These actor types with their priorities are given in the following table[1];

Table 1: Priorities of the practitioer-actors

	Consistency in travel times	Speed	Cost	Range
Long distance, Low Value Freight	Low	Low	High	High
Long distance, High value freight	High	High	Medium	High
Short distance, Low Value Freight	Low	Low	Medium	Low
Short distance, High Value Freight	High	Medium	Low	Low
Mail	High	High	Low	High
Luxury Passengers	High	High	Low	High
Emigrants	Low	Low	High	High

On the provider side, i.e. the actors responsible for the provision of capacity and related infrastructure, it is also possible to recognize sub-types; individual ship owners and large shipping companies. These two provider types as well as their preferences are given in the following table. As can be seen, the major difference between these two provider types is their sensitivity to high investment costs. Additionally, they also differ with respect to the capital investment resources they control.

Table 2: Priorities of the provier-actors

	Investment Cost	Demand
Individual Owners	High	High
Large Shipping Companies	Medium	High

The major difference from Model 1 is the separation of the practitioners, who are willing to utilize the options (i.e. demand-side), and the providers, who are responsible for the provision (i.e. supply-side). So market share of an option is not just dependent on the demand for that type of ship, but also on the availability of these ships and required infrastructure. This enables us to obtain differing dynamics on the demand and supply sides. The second difference is the introduction of different actor types with differing

[1] Entries in the table cells represent how important is an aspect of the option to the actor. High indicates a high priority and means that the actor will be weighting that aspect of the options more in his/her evaluation.

preferences. This also necessitated the disaggregation of the performance indicators of the options. Hence, instead of a single aggregate performance indicator, in this version of the model six different performance indicators (i.e. regularity, speed, operating cost, range, investment cost, and demand[2]) are included in the model.

In this version, each practitioner allocates its freight to available options. The distribution of this allocation of a practitioner type changes based on the comparison of the options based on the performance indicators relevant to that specific actor type.

As a direct consequence of having the providers responsible for capacity provision (e.g. number of ships of a particular type), a new mechanism is needed for capacity management. Providers are assumed to be in control of a certain amount of capital investment resources and they allocate these among available options, mainly based on the demand/supply balance in the market.

c. Model 3:

Going further down in the aggregation scale, it can be claimed that - apart from having different actor-types - having variety of actors under each actor category is very important in capturing some interesting transition dynamics. So in this third model, a random in-group heterogeneity is introduced for each actor type. Multiple actors –in the range of 50-100- are defined under each actor category, and they are initialized randomly being consistent with the average values of the actor-group that the actor belongs.

Since there exist many providers for a given practitioner to choose from in allocating its freight, an additional freight-allocation mechanism was needed. For this purpose a very simple procedure is implemented. Practitioners give priority to the providers that they worked with recently, which forms the primary provider list. A practitioner randomly selects a provider from the primary provider list and tries to allocate its freight. This goes on until no provider is left in the list and there is more freight left. Then the same procedure is repeated using the secondary provider list, which is the list of providers who are not in the primary list. Apart from this mechanism and random initialization of the individual actors, the model structure is identical to the Model-2.

4. Implementation of the Models

It is also important to mention technical differences among these models in terms of implementation. The first model is a pure SD model implemented using standard SD software. Although information update, performance improvement and allocation shift mechanisms are all pure differential equation based ones, due to some discrete operations - such as provider selection- a different implementation platform is needed for the last two models. Therefore, these models are implemented using Java programming language and

[2] Although "demand" does not qualify as a traditional technological performance indicator, since it is an aspect of the options that is used in the comparison of them by providers, it is assumed to be acceptable to classify it as a performance indicator monitored by the providers (i.e. higher the demand for an option, better it performs as an investment opportunity).

simulated with the help of RePast[3]. Additionally, another advantage of using the latter platform was related to the inclusion of multiple actors in the model. Once the structure representing a single actor is developed, it is quite straight forward to duplicate this structure for as many actors as required. With a higher level structure that defines how these individual structures (i.e. actors) are interrelated the model is easily constructed. In this way, the 2nd and 3rd models can be characterized as multi-actor SD models in fact.

5. Model Output:

In this section we aim to explore the variety of dynamic behavior that can be generated by the models. In doing so, Model-1, which is calibrated based on the historical case, is used as the base case.

In the case of other two models, i.e. Model-2 and Model-3, we aim to explore possible alterations in the base dynamics generated by Model-1 as a consequence of the introduced heterogeneity regarding actors, and if possible find different behavior patterns that have the introduced heterogeneity as an underlying cause. During this process the properties of the options (i.e. sail-ship and steam-ship) are kept the same, which means the initial performance gap between them and the room for development defined in the models were not the aspects of the model we experimented with. In short, the exploration with Model-2 and Model-3 summarized in the following sections is done to seek alternative courses of development in the system regarding the utilization of options with given properties[4].

a. Model-1:

The model is initialized and calibrated in order to reproduce the historical data about the selected transition. According to this initialization, the steam-ship is defined as an option initially inferior to the sail-ship, but it has a considerable large room for performance improvement. Additionally, the room for further development is defined to be restricted for the dominant option sail-ships. As it can be seen in Figure 3, the model replicates the S-Shaped growth in the market share of the steam-ships successfully. The change is initiated by the gradual performance improvement, and then this change triggers two reinforcing mechanisms. First, the shift towards steam-ships represents more resources flowing into this direction, and hence allows faster performance improvement. On the other hand, the option also benefits from economies-of-scale as a consequence of growing market share. As a result, the steam-ship outperforms the formerly dominant option, and takes the dominant position in the market.

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[3] Refer to http://repast.sourceforge.net/repast_3/index.html for further information about RePast

[4] Although the properties (e.g. initial state, room for development, etc) are given an fixed, the dynamics of change/development in these properties are dependent on the dynamics of the whole system due to mechanisms like economies-of-scale, for example.

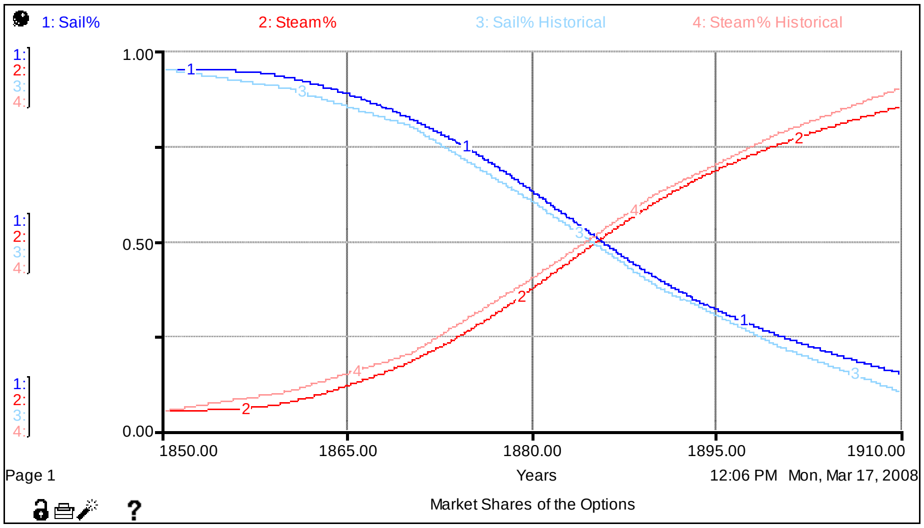

Figure 3: Base run with Model-1

Based on this base behavior pattern, we will be exploring what difference it makes in terms of behavior pattern, if we keep the model structure the same as much as possible, but just introduce some sort of heterogeneity into the model. In the following two sub-sections, we will be dealing with that.

b. Model 2:

As briefly mentioned before, there are two fundamental differences in Model-2 compared to Model-1;

- Separation of demand and supply for different ship types
- Introduction of different actor types with differing priorities

Base-run of this model, as well as the reference behavior from Model-1, is given in Figure 4. The minor effects of the separation of demand and supply can even be seen in this base-run output. The diversion from the smooth S-curve behavior in the first quarter of the run (marked with a dashed rectangle) is found to be due to the lack of sufficient steam-ship capacity compared to increasing demand. In order to reveal possible changes in behavior, the response dynamics of the supply side is furthered changed via modifying the perception and capacity adjustment delays of the 'provider' actors.

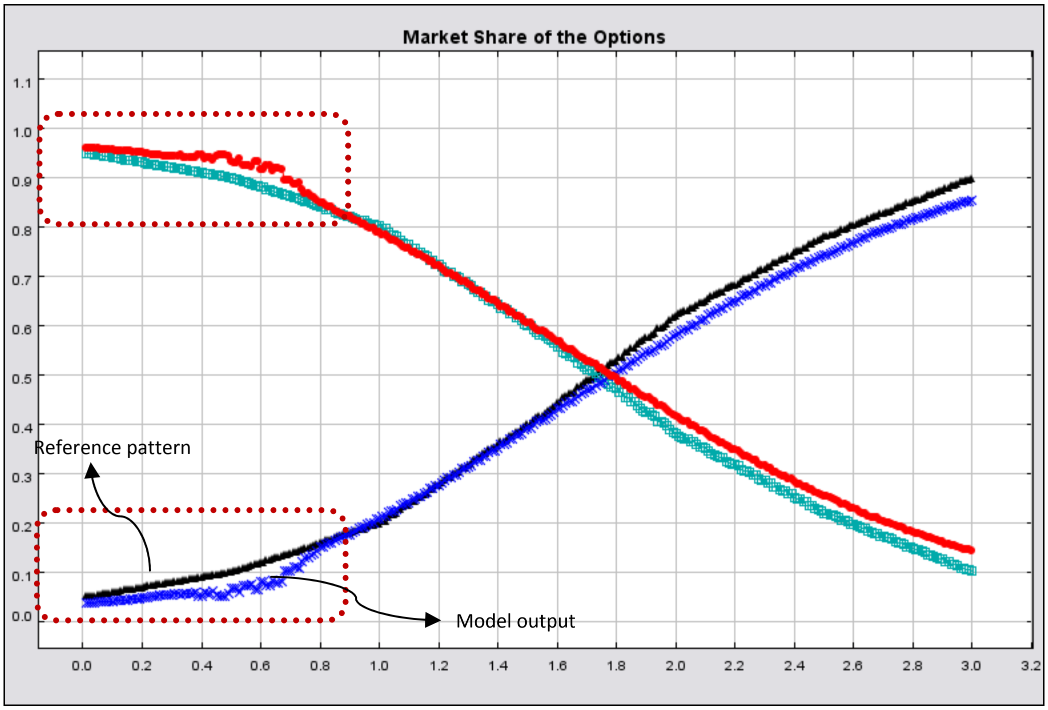

Figure 4: Base-run with Model-2

The output from Model-2 with 'providers' slower in perceiving market signals and also slower in responding to these signals is given in Figure 5. In order to avoid confusion, only the steam-ship side of the behavior is plotted. The first of the series plotted is the actual market share of the steam option, whereas the second one is the desired market share (i.e. total market share of the actors willing to use steam-ships). The third line is the reference pattern. As can be seen, the actual market share of the steam-ship is significantly different from the base-run. Although there is a growing demand for the option, due to lack of sufficient capacity provision, the market share of the option does not change for a considerable amount of time. Since the level of utilization is much lower compared to the base-run, the performance improvement due to economies of scale is also less. Hence, in the time horizon of the run, the steam-ship cannot reach the performance level attained in the base-run and attracts less market share due to this (see the diversion of desired market share from the reference behavior in the second half of the run).

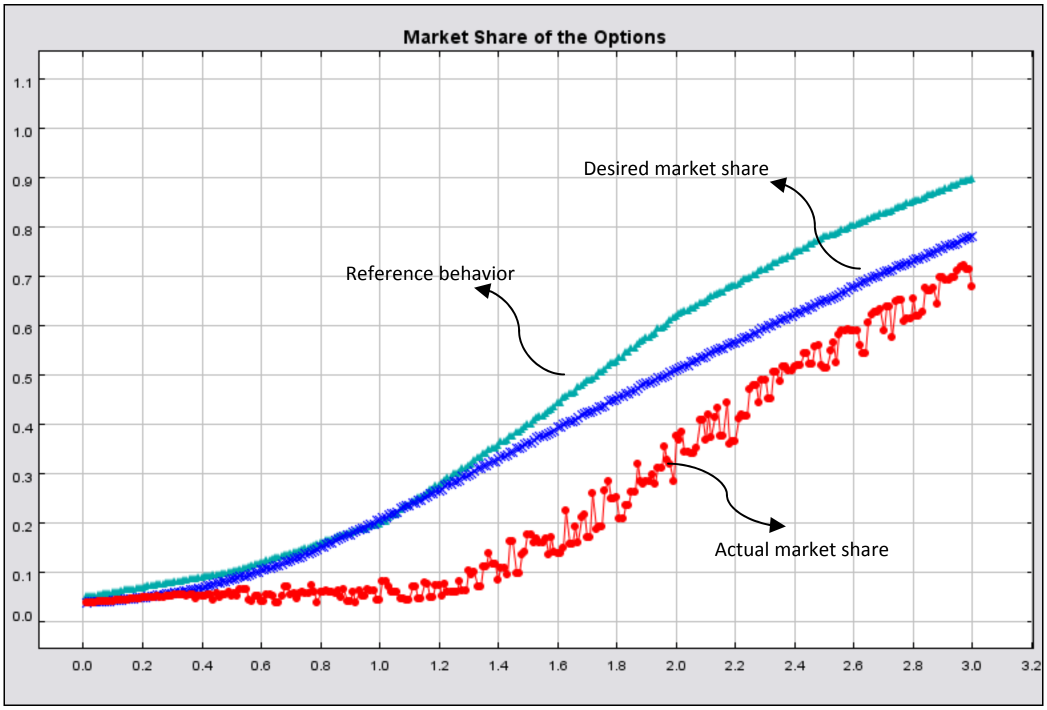

Figure 5: Behavior with slow providers in Model-2

Despite these differences, it can easily be seen that there is no fundamental change in the dynamics; if the model is run for a longer period we can see the successful transition to steam-ships, which starts later and follows a slightly steeper S-shaped market share behavior. So concerning the numerical fit to the historical data, the change in the provider behavior makes a difference, but if the objective is to study the underlying causes of the S-shaped development, it can be claimed that separation of the supply and demand sides did not make much of a difference.

Going back to case being studied and the conceptualization used to model it, this is a natural consequence. Since the main driver of the providers in capacity investment is the demand in the market, sooner or later they are expected to provide the necessary capacity. On the practitioner side, once they start to see the steam-ship option better their evaluation stays the same and this evaluation is independent of the actions of the providers. In short, they are willing to wait for the desired capacity forever, and a possible prolonged wait does not change their opinion about an option. In this situation, the inclusion of the providers in the model only acts as a delay process between the rise of the desired utilization level for a given option, and the realization of it. It can be claimed that in cases consistent with this conceptualization, introduction of the provider-practitioner heterogeneity does not provide further insights regarding the process. However, it has some impact in terms of numerical sensitivity of the behavior.

In order to explore what could be observed in cases where the situation does not fit our base-conceptualization, we have diverted from the case being studied a bit and assumed that practitioners are sensitive to the demand-supply imbalance in the market. In order to put this into more practical terms, if the available steam-ships are limited, the practitioners willing to use them will form a sort of backlog and they will experience prolonged waiting times before shipments takes place[5]. So, in the modified model, if the practitioners experience a capacity-shortage, their evaluation for the option worsens (i.e. bad reputation of the option regarding waiting times). The result of the run using this modified version of Model-2 is given in Figure 6. The figure includes two additional indicators, which show the average of the perceived performance of the options[6]. Looking at the desired market share behavior, stagnation in the growth and stabilization is observed. The decrease in the perceived performance due to the growing capacity shortage in the early stages of the run, which causes a significant decline in the perceived performance stands as the main cause of such a behavior.

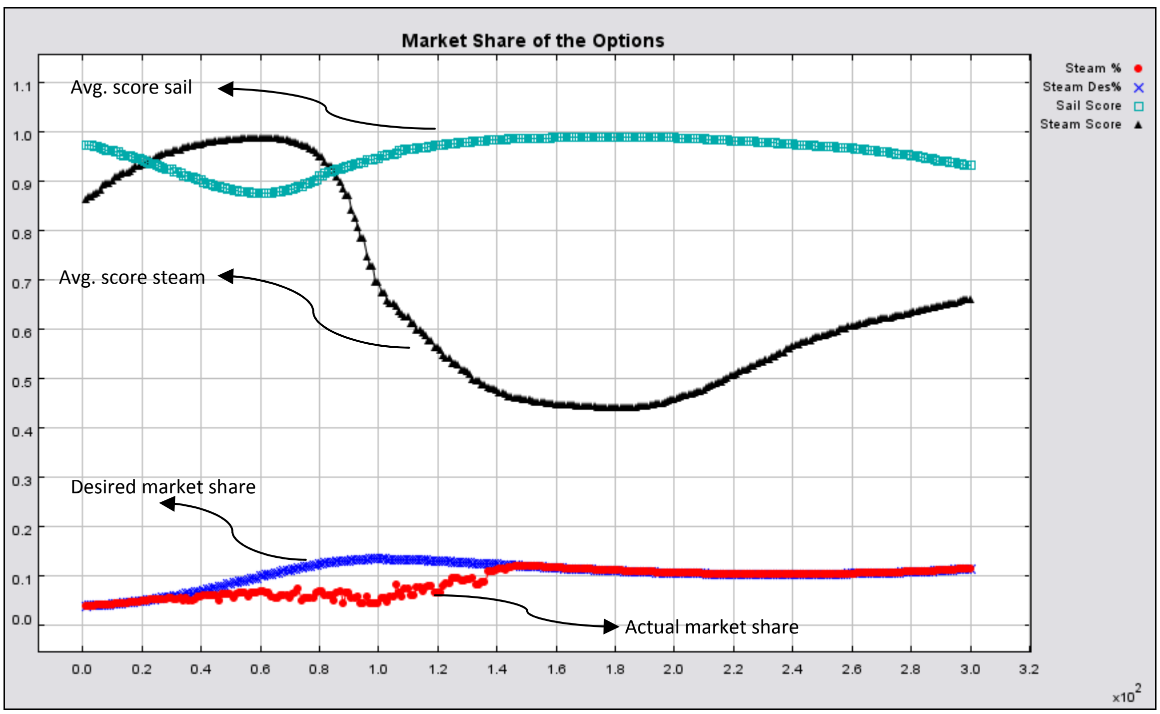

Figure 6: Behavior with practitioners who are sensitive to capacity-shortages (Model-2)

A modified version of the run is given in Figure 7. In this version, it is assumed that practitioners have tendency to forget the bad reputation of an option caused by capacity problems. The impact of the 'forgetting' mechanism can be seen both in average score and in market share plots. After the growth in desired market share stabilizes, the providers catch up with the demand and close the demand-supply gap for the steam-ship option. Benefiting from this closure of the gap and the forgetting mechanism, a fast recovery of the

[5] This is just a hypothetical assumption made for exploring alternatives, which has nothing to do with the historical case being used in this study.

[6] The indicator is a weighted average. The performance levels of options percieved by the actors are averaged using the market share of individual actors as the weight.

average score of the steam-ship option can be seen. This in turn triggers a second period of increasing demand for steam-ships. In this model, the time-lag between the demand increase and capacity provision coupled with the forgetting mechanism is expected to yield a step-by-step transition to steam-ships, which will be composed of recurrent stages of demand growth and demand stabilization.

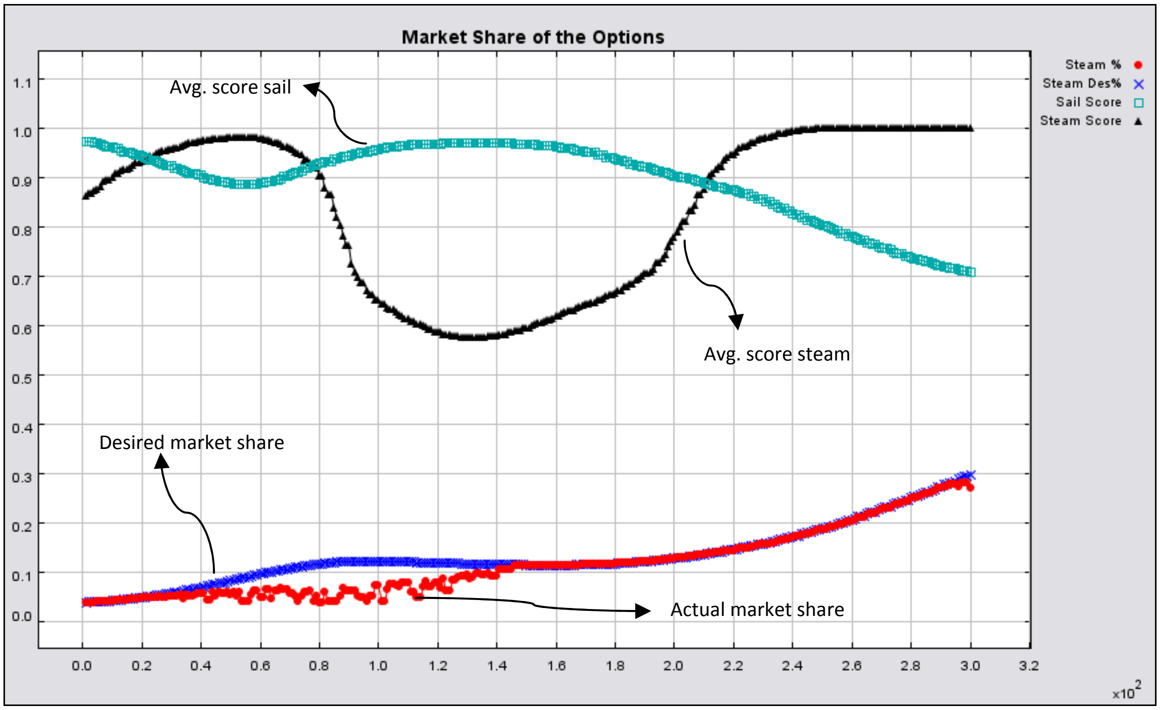

Figure 7: Behavior with 'forgetting' practitioners who are sensitive to capacity-shortages (Model-2)

As can be seen here, such sensitivity to the sufficiency of the capacity on the practitioner side alters the transition dynamics significantly, and yields new dynamics as step-by-step transition or as failure of a potentially superior option. Contrary to the base conceptualization used in this study, the last two runs demonstrate the potential contribution of recognizing the actor-role heterogeneity (i.e. providers, practitioners, etc).

The second stage of the test using Model-2 is related to the second point of difference, i.e. introduction of different actor groups with differing priorities. Instead of having a single practitioner prototype, 7 different practitioners with differing priorities/preferences are introduced on the demand side. As a natural result of this diversity in priorities/preferences, they attribute different scores to the options. Just to remind, in the aggregate version, we were utilizing a single performance score, which was assumed to be representing the performance score averaged over different actors. The point we test in this stage is that it is possible to have very different initial actor compositions –in terms of their share in the market- that gives almost the same aggregate performance scores for the options. So the question is whether this makes a difference and pays back the effort for introducing 7 types of actors instead of a single prototype.

The base-run configuration of the model is used as the reference state. 10 different actor compositions are generated, which give almost the same average initial, as well as best performance scores (i.e. score attributed to an option assuming it reaches its best plausible levels in all performance dimensions). The results of the runs with these 10 different actor compositions are given in Figure 8. As can be seen, the range of numeric diversion from the base-run behavior is significant. However, diversion in terms of behavior pattern is very limited on the other hand. A couple of behaviors (marked on Figure 8) are evaluated to have different characteristics.

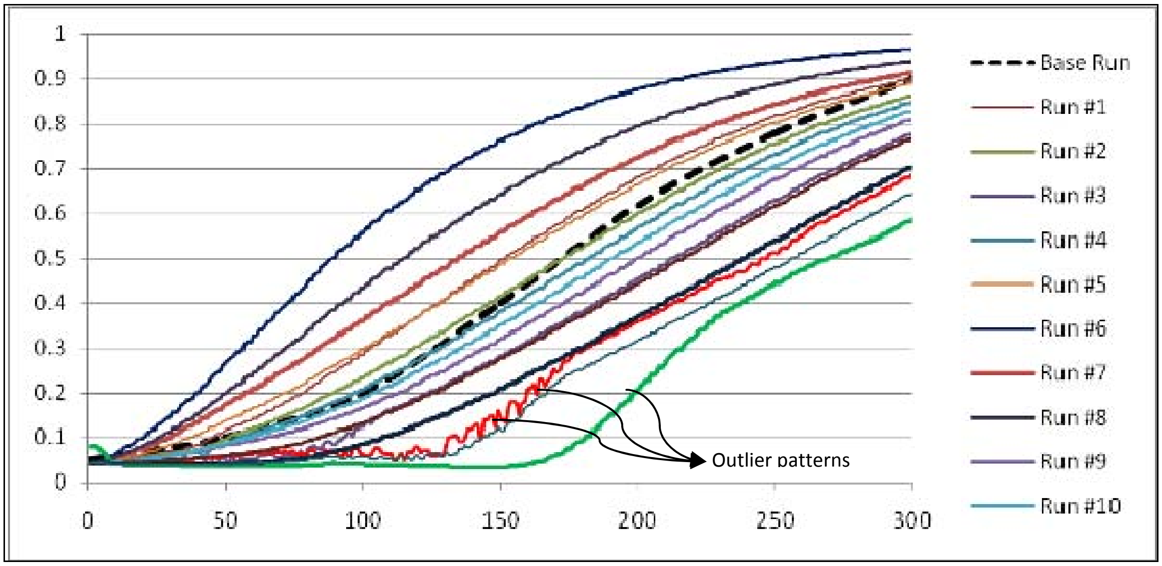

Figure 8: Market share dynamics for steam-ships with different initial actor compositions

Studying those two behaviors mentioned above in detail, we have concluded that such dynamics are observed in cases where there exist significant opinion (i.e. in terms of performance score they attribute to the options) gaps among the actors dominating the market, which can also be translated as not having a continuum of actors' option-scores. This situation can be better understood with the specific example given below in Figure 9.

On purpose, we have initialized the market such that there is a moderate sized group (i.e. group A) who already evaluate the steam-ship as superior at the beginning of the run. There exists a second and bigger group (i.e. group B), which evaluates the steam-option as inferior and in order this group to change its position significant improvements are needed in a couple of dimension (e.g. range and operating cost). A fast increase in the desired utilization level of the option is mainly due to the immediate shift of group A actors to the steam-ship option. However, this shift does not constitute the critical mass that can yield the needed boost in performance improvement via economies-of-scale. Hence, following the complete shift of group A to the steam-ship utilization, stagnation in the demand for the option is observed. Then after a period of slow performance improvements, group B's shift to the steam-ship option is initiated. This starts the second fast increase in the market share. What happens in the marked cases in Figure 8 can also be explained similarly; the shift of an earlier group does not lead to performance improvement enough to initiate the shift of a later group, hence a period of further performance improvement is required, which is the period of slowed-down growth in market share in between fast growth phases. The resulting dynamic can also be labeled as the step-by-step transition.

Figure 9: Step-by-step transition due to special actor composition

As the second part of this analysis demonstrates, the composition of the actors has the potential to alter the pattern of transition process, or at least may speed up or slow down significantly the S-shaped transition pattern. This is valid in the cases where different actor clusters can be recognized in the actor population that has significantly different preferences/priorities, despite having the identical actor-role; *practitioner*. Ignoring this variety and clustering these significantly different clusters into a single aggregate body might lead to loss of interesting dynamics that has the potential for initiating development of new insights about the process. As shown here, two significantly different actor populations, which lead to different dynamics, may correspond to the same aggregate representation. The loss of dynamic richness mentioned above is expected to be negligable when actors belong to a single cluster (i.e. a single actor type sharing similar priorities/preferences).

c. Model-3:

In the previous section, the impact of existence of actor-groups and heterogeneity among them is studied. However, during that process a single aggregate actor is used to represent the whole actor-group. In other words, despite recognizing the existence of different actor groups (i.e. inter-group heterogeneity), the heterogeneity among the members of those groups (i.e. in-group heterogeneity) was ignored. In this stage, the main focus will be on the latter one; in-group actor heterogeneity.

In order to conduct this analysis, average values for key properties of each actor group (i.e. perceived attributes of the options, weights for different attributes representing their priorities, amount of resource they control representing their market share, etc.) are initialized deterministically. Then multiple individual actors are created for each actor group. The properties of these individual actors are initialized stochastically using random number generator sampling from a Normal distribution. The mean of this distribution is defined to be the average value of the actor-group that individual belongs, and the standard deviation is defined as the mean multiplied by a dispersion factor (i.e. *StDev=Mean*DispFactor*). The stochastically defined actor properties, their meaning and the value of corresponding dispersion factors are summarized in Table 3. Number of individual actors created under each actor group is given in Table 4.

Table 3: Stochastically initialized properties of the actors

Actor Property	Explanation	DispFrac
Perceived Attributes	Perceived value of a certain attribute of an option	0.2
Resource Level	Amount of resource controlled by an actor. For a practitioner represents the amount of goods actor has to be shipped.	0.2
Priority	Level of importance of a certain option attribute for the actor	0.2
Support Shift Normal	Normal rate of shift between options for an actor	0.2

Table 4: Number of individual actors in each group

Actor Group	No of Actors
Long distance, Low Value Freight	50
Long distance, High value freight	50
Short distance, Low Value Freight	50
Short distance, High Value Freight	50
Mail	50
Luxury Passengers	50
Emigrants	200
Total Practitioner	**500**
Individual Owners	150
Large Shipping Comp	50
Total Provider	**200**

For each of the properties listed in Table 3, the dispersion factor is set to a high value (i.e. 0.7) and 15 replications are performed using different random seeds. Resulting model outputs are summarized in Figure 10 to Figure 13. As can be seen in those plots, no pattern sensitivity is observed in these 15 runs, and also the observed numerical sensitivity was insignificant. Additionally, we also repeated the procedure after setting the dispersion factor of two properties to high values at the same time. The outcome was no different than the former case of altering single factor. Absence of numerical and pattern sensitivity to intra-group heterogeneity may seem counterintuitive at the first glance, however considering the particular model being used that is not a surprise, in fact. In our model, the interactions of the actors are not direct, but indirect through their influence on the market and on the option attributes. Hence, individual actors are changing their behavior based on their perception of the aggregate market situation and option properties. So what matters for an individual actor is not the distribution of other actors' individual responses, but their aggregate response. Additionally, initialization of large number of individual actors assures that their aggregate statistics converges to the averages of the actor group they belong.

Combining these two factors, it is definitely normal to see minimal differences among the individual runs, and also between the output of Model-2 and Model-3.

The same procedure is repeated with creating very few agents under each actor group, being aware of the fact that the statistics of the resulting actor samples won't be identical with the average of the actor group (see Table 5). The identical procedure is repeated with these numbers of actors, and the resulting model outputs are given in Figure 14 to Figure 17. Apart from the effect of distortion in the averages of the actor-groups caused by the sampling size in the individual actors' creation, no significant change is observed in the behavior patterns.

Table 5: Number of individual actors in each group

Actor Group	No of Actors
Long distance, Low Value Freight	5
Long distance, High value freight	5
Short distance, Low Value Freight	5
Short distance, High Value Freight	5
Mail	5
Luxury Passengers	5
Emigrants	10
Total Practitioner	**40**
Individual Owners	10
Large Shipping Comp	5
Total Provider	**15**

In short, the lack of direct interactions among the individual actors as well as a network structure defining the feasible social space of interaction for the actors, the in-group heterogeneity is observed to lead almost no alteration in the model behavior. It is also important to mention that despite its influence on the model output, the burden of having many individual actors under each actor-group has a significant cost in terms of running times.

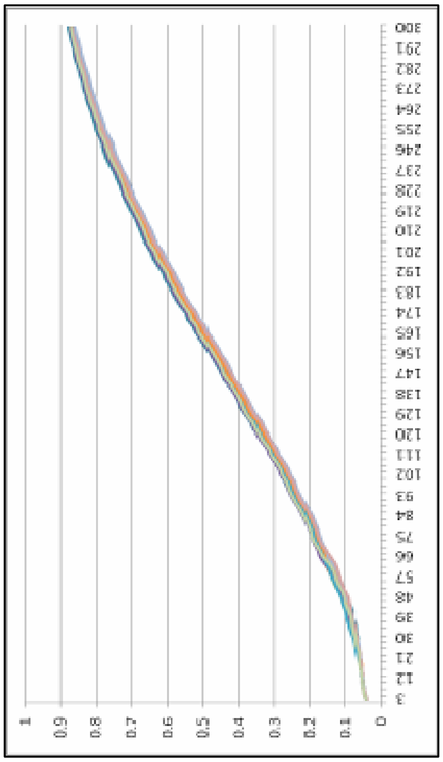

Figure 10: DispFactor for Perceived Attributes=0.7

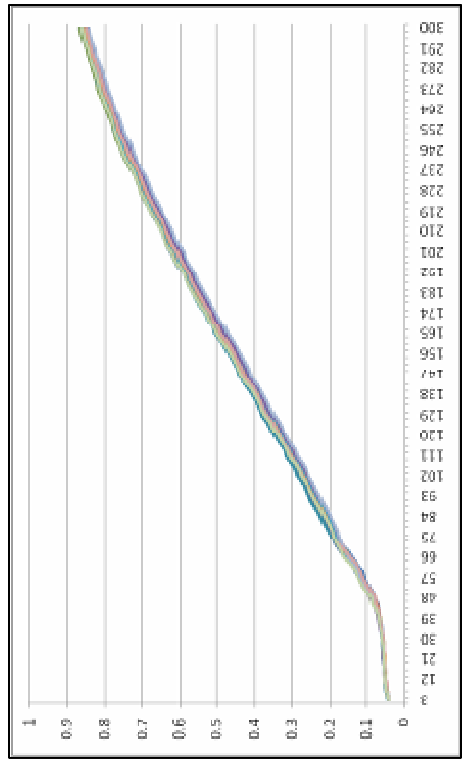

Figure 11: DispFactor for Priority=0.7

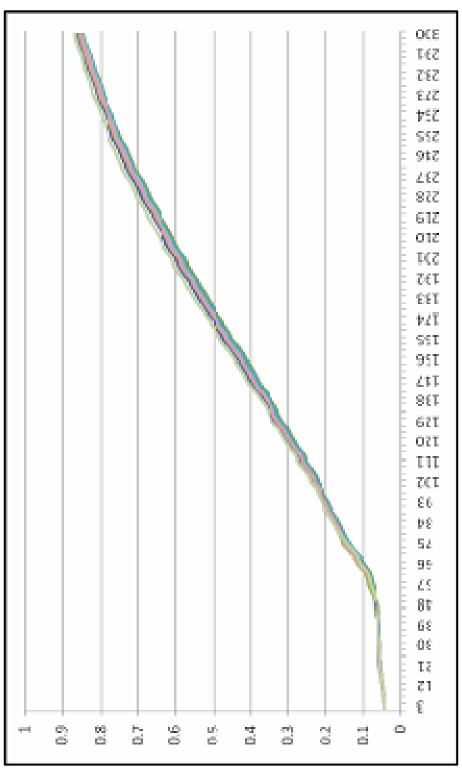

Figure 12: DispFactor for Resource Levels=0.7

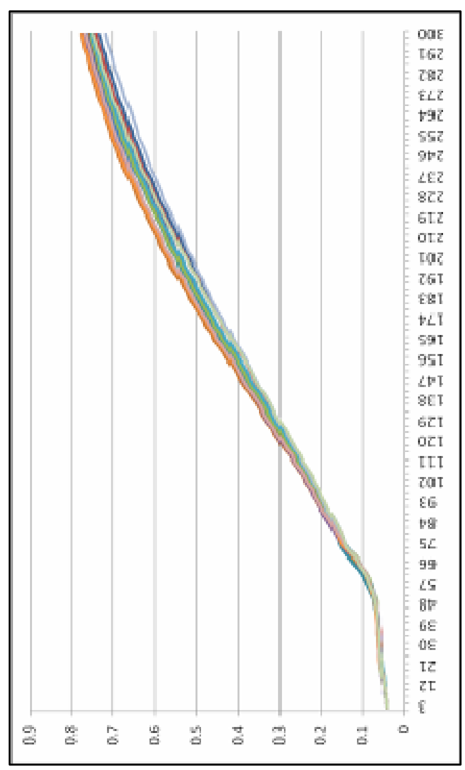

Figure 13: DispFactor for Sup. Shift Normal=0.7

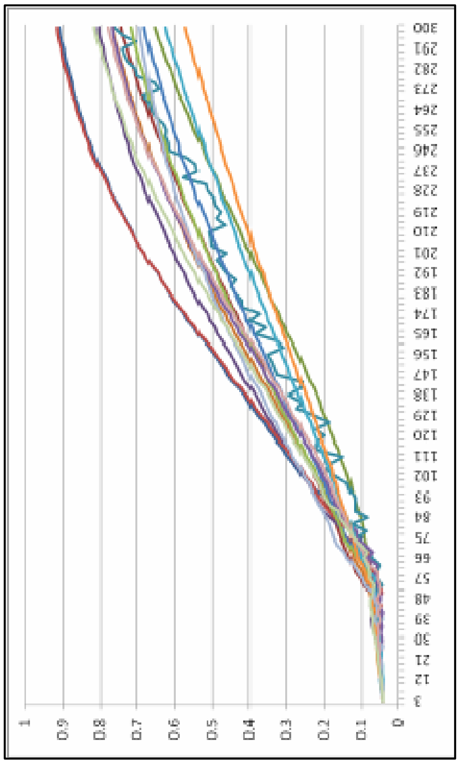

Figure 14: DispFactor for Sup. Shift Normal=0.7

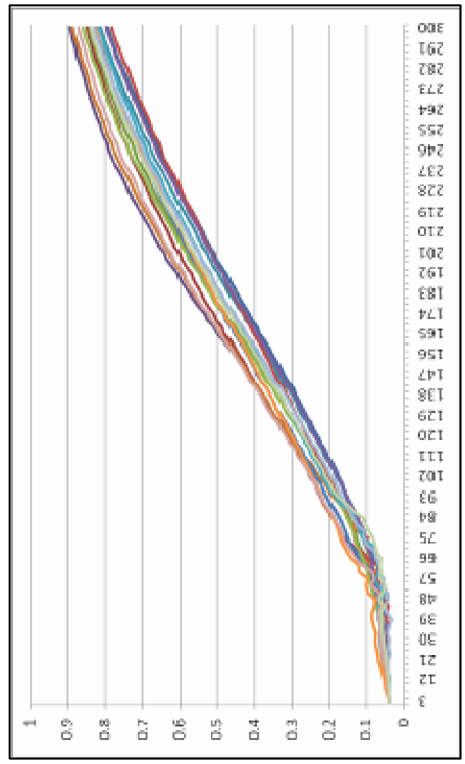

Figure 15: DispFactor for Resource Levels=0.7

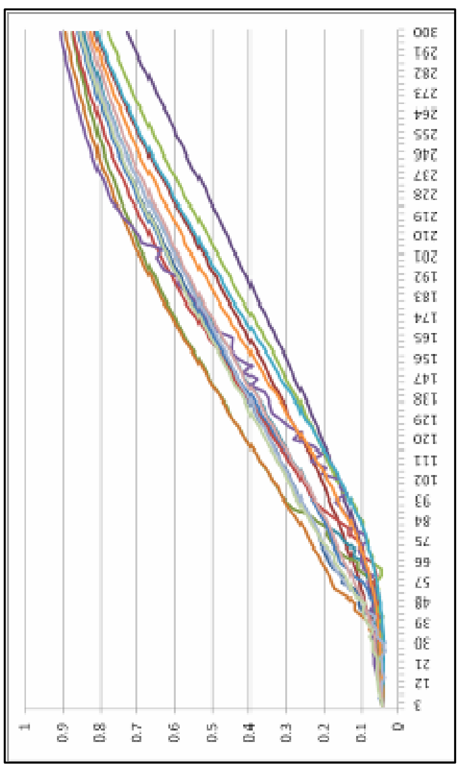

Figure 16: DispFactor for Priority=0.7

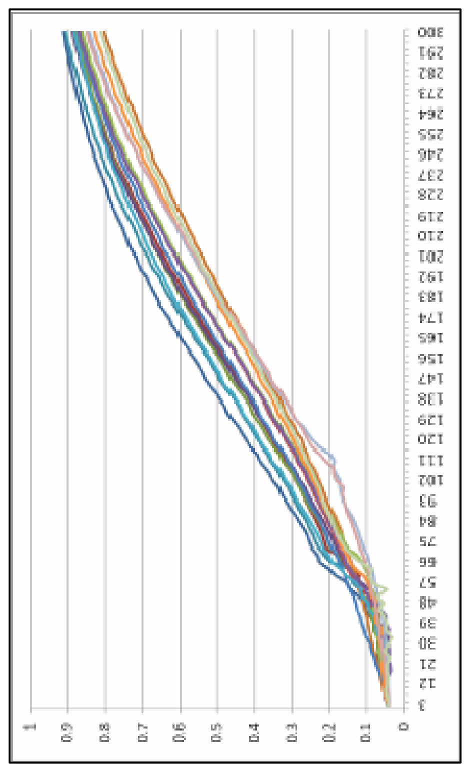

Figure 17: DispFactor for Perceived Attributes=0.7

6. Discussion and Conclusions:

In this experimental study, we attempted to develop some insights about the consequences of recognizing/neglecting actor-level heterogeneity in a socio-technical transition context. This is done with the means of three different models that enables introduction of different sorts of heterogeneity.

In the specific context we have focused, i.e. socio-technical systems, the distinction of the practitioners (e.g. users of an artifact) and providers (e.g. producers, distributers, etc.) seems natural and necessary most of the times. In our limited experimentation, we have identified two cases where it is important to recognize this discrimination in the model. The first of them is the case where providers are slow in perceiving the market conditions and also in reacting according to their perceptions. Although this does not change the overall pattern of transition, if may cause significant delays in the process. The second case is more important since it can yield significant changes in the behavior pattern observed. In cases where the practitioners' assessment of the options depend on the actions of the providers (e.g. their ability to provide enough service), the practitioner-provider heterogeneity stands as a crucial aspect to be included in the model. Additionally, we also observed in Model-3 case that the loss of dynamic richness in the model output due to representation of the actor-groups using a single aggregate actor is negligible, which is consistent with expectations based on elementary statistics. However, this conclusion shall not be taken as a general one, since its validity is specific to the way we have conceptualized the transition process in focus. Hence, impact of this can be quite different in other cases where actors interact directly and there exists a social network structure that shapes these interactions. A more in-depth study about related to this point is done by Hazhir and Sterman [20]. Via the points mentioned above, the study formally supports the former intuitions regarding the degree importance of actor heterogeneity in specific transition contexts.

Focusing on the cost of introducing heterogeneity, it is important to highlight three aspects based on the experience from this and some former modeling research done by the authors. First of them is a technical aspect, which about the computational requirements of the models. Compared to Model-1, the computational load of the Model-3 with 500 actors was significantly higher. However, this is a minor cost that can be compensated with better computers or more patience.

The second aspect is regarding the verification and validation of the models. Based on this experience as modelers who have some former experience with programming, we can state that the possibility of skipping a minor problem, which may lead to completely different output patterns, during model verification stage is extremely high in the cases of Model-2 and Model-3. Hence, the willing to use a multi-actor model comes with a big burden of model verification.

The third aspect is about benefiting from the model and it is vital. It is about the comprehensibility of the model and its behavior. A model even with 30 actors becomes too complicated to analyze its behavior and understand the underlying mechanisms. In cases where the motivation is to link the behavior to the structure this is a vital problem. On the other hand, for someone just seeking some numeric fit and predictive power from his model this is not an issue. We can claim that some modeler, including the authors, would have great difficulty and probably fail to understand what is going on if just Model-3 was used for studying steam-ship transition case. This shall not be interpreted as the superiority of Model-1 over Model-3. It may be the case that a model with heterogeneity in many aspects (i.e. 'big model') fits the purpose better. However, before jumping into a pool of hundreds, if not thousands, of heterogeneous actors, using a simple conceptual model (i.e. 'pocket model') looking at the bigger picture may contribute significantly to the insights to be developed based on the 'big model'.

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