Webs of Innovation and Value Chains of Additive Manufacturing under Consideration of RRI

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D5.2 Simulation Results

Collection of all scenarios and assumptions, model input data, simulations results, including calibration of the model and summary of the main insights coming from the simulations

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Abstract: The deliverable contains the collection of all scenarios and assumptions, model input data, simulations results, including calibration of the model and summary of the main insights coming from the simulations; first results from gaming simulations are shown

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List of Abbreviations

ABM&S	Agent-Based Modelling & Simulation
AM	Additive Manufacturing
HW	Hardware
ID	Identification Number
IH	Innovation Hypothesis
IVC	Innovation Value Chain
NGO	Non-Governmental Organisation
OEM	Original Equipment Manufacturer
RRI	Responsible Research and Innovation
SKIN	Simulating Knowledge Dynamics in Innovation Networks
SME	Small-Medium Enterprise
SW	Software
WP	Work Package

1. DELIVERABLE SUMMARY AND INTRODUCTION

The deliverable D5.2 contains the collection of all scenarios and assumptions, model input data, simulations results, including calibration of the model and summary of the main insights coming from the simulations.

The deliverable represents a natural consequence of the deliverable D5.1, in which we have reported the followed verification steps, the relative experiments, and the refinements implemented with respect to the first version of the model presented in the deliverable D3.3 (v0.1).

The deliverable collects the simulation results that come from 2 sequential analyses conducted in the development phase of the model, which have distinguished the evolution from version 1 (v0.1) of the IAMRRI AB model (based on SKIN - IAMRRI SKIN model), to version 2 (v0.2).

The first simulation analysis was aimed at a general revision, without any verticalization or in-depth analysis on particular or detailed research questions, it is the one that led to the first version of the model. On this analysis, and on this version of the model, a verification of the functioning and compliance of the model was carried out through simulations, to assess, mainly that this was not self-referential, but that it was able to describe the dynamics of innovation and diffusion of RRI practices, as seen in the use cases (real and retrospective).

In the 2nd version of the model, the analysis (more verticalized) focused more on the impact of RRI keys, not only through the introduction of an additional breed of agents, the NGOs (CSOs), but also through the addition of an additional RRI key (not considered in the first[t] version), that relating to gender equality.

This transition to a verticalized analysis was mainly due to the way in which we conducted the model validation phase, which you will find described in this deliverable D5.2 (section 3), a phase that is generally done or using series of empirical historical data (taken from databases existing) to compare with the data of the simulations, or (as happened in our case, lacking these series of empirical data on RRI), approaching the literature.

In the validation section, after the presentation of the different validation methodologies, a review of the literature related to the impact of RRI keys is presented, that anticipates the experiments design and execution results presented later.

The verification results have demonstrated the rigor of the model implemented with respect to the conceptual model, giving useful insights into the role of regulatory bodies in the diffusion of RRI practices and the number of agents undertaking a process of innovation.

So, after the calibration/grounding section, a section with the capitalization insights and conclusions is reported, briefly presenting the main insights/impacts coming from the simulations carried out using the IAMRRI SKIN model at four different levels: RRI, strategic, economic, and societal.

The related impacts of RRI diffusivity, of RRI cost and of NGOs attendance are briefly reported and analysed.

2. VALIDATION

2.1 Methodology

Validation is the process of determining how well the implemented model corresponds to reality. Validation has always played an essential role in modelling issues (Conway et al., 1959), especially computational models (Carley, 1996; Garcia et al., 2007). We could say that the biggest problem related to validation is that there is no universally accepted approach. In the literature, there are many validation techniques and the principles on which they are based are different, so it would be too expensive to use all the possible methods (Xiang et al., 2005).

Schlesinger et al. (1979) claim that validation is a "substantiation that a computerized model within its domain of applicability possesses a satisfactory range of accuracy consistent with the intended application of the model." This means that validation depends on the purpose and type of system/phenomenon to be studied.

Furthermore, the validation process requires a clear understanding of the purpose of the model and what it is trying to explain. The crucial aspect is to demonstrate that individual agents' behaviour, or the model as a whole, is compatible with evidence gathered from outside the model. The better the evidence, the more credible the model (Ormerod & Rosewell, 2009).

Different validation levels depend on the availability of data and the purpose of the model and the researchers. As Carley (1996) suggested, illustrative-theoretical models usually require a reduced level of validation, while case-based models require a higher level of validation because usually these models are used to give practical advice on some specific aspects.

Different levels of validation identified by Carley are:

- face validity;
- parameter validity;
- pattern validity;
- process validity;
- point validity;
- distribution validity;
- value validity.

The first three-four levels are more related to theoretical or illustrative models, and the others are more concerned with emulative models of reality. The IAMRRI SKIN model is not a purely theoretical (illustrative) model, but it is not a case-based model. Consequently, we expect to reach an intermediate level of validation.

The choice of the validation level (low level as face validity or higher level as distributional or point validity) has to be inspired by the identification of the right balance (determined by the researchers involved, based on the availability of data and the simulation purpose) between the simplicity of the computational model (the capability of the model to be used as a generative machine of hypothesis on a group of cases sharing some stylized behaviours) and the veridically, the adherence to the real.

Rand (2011) divides the validation levels identified by Carley into four basic categories: *Micro-face Validation*, *Macro-face Validation*, *Empirical input Validation*, and *Empirical output Validation*.

Micro-face Validation is the process that allows us to verify that the mechanisms that govern the model correspond "on face" to the real world. For example, do modelled firms follow processes that can be found in reality?

Macro-face Validation in which the aggregate patterns of the model "on face" correspond to real-world patterns (North & Macal, 2007). The dynamics that guide the model are found in the real world?

Empirical input Validation is the process through which it is verified that the data introduced in the model are accurate and have one correspondence with the real world. In this case, it is crucial to demonstrate how the data are collected and to which model inputs they correspond. For example, the percentage of large firms within the model (big-firm-percent) could be based on the presence of multinationals within the European market.

Empirical output Validation demonstrates that the output of the implemented model corresponds to the real way. This represents a test key for the Validation of a model.

In *Micro-face Validation* and *Macro-face Validation*, there is no comparison between data and model (Rand & Rust, 2011), while the focus is on showing that the general patterns and attributes have an acceptable correspondence to the real-world.

The IAMRRI SKIN model aims to reach a high level of validation, demonstrating its rigor, through methodologies that involve the use of empirical data (*Empirical input Validation - Empirical output Validation*). At the moment, some data on additive manufacturing in the European market are available, thanks to the presence of industrial partners in the IAMRRI project; however, to reach very high levels of validation, time series of data covering large markets and longer timeframes are required.

For these reasons, we can only achieve an intermediate level of validation at this stage of the project.

2.2 Experiments design and execution results

Following the lead of Sargent (2005) and Law et al. (2007), there are several ways to achieve the intermediate levels of rigor that approximate validation:

- using existing theory or studies;
- modeller experience and intuition;
- conversations with subject-matter experts during development/face validity;
- observing macro-level effects.

All the approaches just listed have been used to approximate the validation process. This deliverable focuses primarily on the correspondence between existing RRI literature and the IAMRRI SKIN model's emerging behaviours. Obviously, in the early stages of the IAMRRI project, a careful review of the literature regarding the development of RRI practices was conducted, but that, unfortunately, did not include the study of the impact of RRI practices on the entire industry. Therefore, a literature review was conducted focusing on the impact of RRI practices in innovative contexts.

Finding a correspondence in the literature on how RRI practices impact innovations is not an easy task since "the impact appears to be elusive and difficult to measure" (Pansera et al., 2020). In fact, "the RRI cannot be used as an evaluation tool since it does not have the material metrics to measure how responsible or positive or negative the impacts of innovation are, but is a normative framework designed to influence the process of innovation" (Postal et al., 2020). Thus, we can say that the RRI intervenes in the innovation process as a whole and indirectly on that process's product.

Some authors measure the performance of organizations that adopt RRI practices from a financial point of view (measuring, for example, the level of sales growth; the level of return on equity; ROA; market share; the level of productivity), while others focus on a non-financial point of view, such as an increase in the knowledge base. Finally, long-term benefits are observed mainly of an internal nature, such as "the development of new resources and capabilities" (Gonzales-Gemio et al., 2020) and an increase in knowledge that leads to more excellent responsiveness on the identification of potential innovations (Fitjar et al., 2019).

Another aspect reported in the literature is that RRI practices ensure greater inclusiveness and heterogeneity of working groups (Fitjar et al., 2019; Kupper et al., 2015; Van den Hoven, 2013) to reach better decisions (Stahl, 2013) and to ensure richer discussion (Flipse et al., 2013).

We can conclude that the introduction of RRI practices influences the innovation process and the actors involved in two ways:

- increased heterogeneity of actors involved in the innovation projects;
- increased knowledge base.

Having identified the impact of adopting RRI practices in innovation processes through the literature review, three experiments were conducted to validate the correspondence between the arguments reported in the literature and the IAMRRI SKIN model's behaviour.

For the first two experiments we ask then, "if agents give more importance to RRI practices, select their partners considering RRI principles, will we observe an increase in the heterogeneity of actors involved in networks? Will the knowledge base also increase at the end of the simulation?"

As can be guessed, the variable of interest is the weight given to RRI values during partner selection (RRI-attractiveness), while the outputs are:

- *Average Heterogeneity of Networks*, where Network Heterogeneity is measured as the ratio of the number of different breeds (typologies of classes to which agents in the network belong) within the network to the total number of members.

$$Heterogeneity = \frac{\sum_{breed \in Network} breed}{number\ of\ partners} \quad (1)$$

- *Average Knowledge of Agent*. Starting from the Kene, the knowledge (k_i) of the agent was modelled considering the length of the Capabilities vector. We could not use the expression for knowledge of the i-th agent used by Ahrweiler et al. (2011, p. 227):

$$k_i = \sqrt{\sum_{j \in \{C\}_i} A_{ij} E_{ij}} \quad (2)$$

Since in the IAMRRI SKIN model the Abilities of the agents do not belong to an ordinal scale but represent the label of the Capability in the broader knowledge domain. To be clearer, in IAMRRI SKIN, Ability 9 is not "better" than Ability 2. Finally, the Average Knowledge of the agents participating in an innovative project can be represented as:

$$\bar{k} = \frac{1}{nFirms} \sum_{i \in \{partnering\ Firms\}} ki \quad (3)$$

Furthermore, the study conducted by Ahrweiler et al. (2019) shows that NGOs (identified as CSOs in the study) are not included in the innovation project to disseminate the ethical practices of RRI. However, they are considered essential partners because of their specific expertise (their knowledge base) and the dataset they have at their disposal that other partners cannot access. Thus, NGOs do not have the central and dominant role in the diffusion of ethical RRI practices, but they are considered essential in research and innovation consortia. The study also finds that in 47% of cases, NGOs contribute to open access publishing, thus playing a role as disseminators of this RRI practice.

Therefore, the question we try to answer with the third experiment is: "*does a greater number of NGOs undertaking an innovative process imply a greater tendency towards open access publishing?*"

2.2.1 Experiment 1

As mentioned, we use RRI-attractiveness as the input variable; all other independent variables were considered control variables and reported in **Fehler! Verweisquelle konnte nicht gefunden werden.**

Table 1 Control Variables Experiment 1

Numbers of Agents [value]		**Firm's Variable [value]**		**Environmental Variable [value]**	
nAM-tech	[200]	Attractiveness-threshold	[0.5]	Standard Organization	[5]
nSupplier	[200]	RRI-start-up-trigger	[0.5]	Funding	[50]
nResearch-inst.	[200]			Funding-RRI	[0.5]
		Publish-open-access		Funding-quality	[5]
nOEM	[200]	Economic-threshold	[50]	RRI-cost	[30]
nCustomer	[200]	RRI-open-access-thres.	[0.5]	Big-firm-percent	[10]
				Regulator	[0.5]

The input variable RRI-attractiveness, which expresses the weight given to RRI values in the partner selection process, has been divided into three ranges: *low* [0 0.3], *medium* [0.4 0.6], and *high* [0.7 1]. The value 1 indicates that the partner selection process is based exclusively on the compatibility of RRI values, while a value of 0 indicates that the selection of partners is based exclusively on the complementarity of the knowledge base.

The combination of variables used to conduct the experiment is systematized in Table 2.

Table 2 Experiment 1 simulation set-up

Control Variables	Run	ticks	input	output
See Table 1	300	30	RRI-attractiveness [0.2 0.5 0.8]	Average Heterogeneity of Networks

EXPERIMENT 1 RESULTS

To investigate the issues outlined above, we first made use of some descriptive statistics concerning the average heterogeneity of the networks when varying the RRI-attractiveness factor. The results reported in Table 4 to the 30-th tick of the simulation. For each level of RRI-attractiveness [0.2, 0.5, 0.8], 300 runs were performed to assure the robustness of results.

Table 3 Descriptive Statistics of Experiment 1

Descriptive Statistics								
RRI-attractiveness	Run	Mean	Std. Dev.	Std. Error	95% Confidence Interval for Mean		Min	Max
					Lower Bound	Upper Bound		
0.2	300	0.6553	0.02982	0.00172	0.6519	0.6587	0.57	0.74
0.5	300	0.6758	0.03027	0.00175	0.6724	0.6793	0.57	0.76
0.8	300	0.6909	0.03017	0.00174	0.6875	0.6944	0.60	0.77
Total	900	0.6740	0.03342	0.00111	0.6718	0.6762	0.57	0.77

The literature shows that an increase in the diffusion and importance of RRI practices corresponds to an increase in heterogeneity within innovation systems. Observation of the scatter plot in Figure 1 shows that the IAMRRI SKIN model behaves as predicted by the literature (Fitjar et al., 2019; Kupper et al., 2015; Van den Hoven, 2013).

However, to consider the effect of the RRI-attractiveness factor on the dependent variable heterogeneity significant, a *One-way* ANOVA was used, the results of which are summarised in Table 4.

Table 4 Results of ANOVA for Experiment 1**.**

ANOVA					
	Sum of Squares	df	Mean Square	F	Sig.
Between Groups	.192	2	.096	106.027	0.000*
Within Groups	.812	897	.001		
Total	1.004	899			

*The test is significant for p-value < 0.05

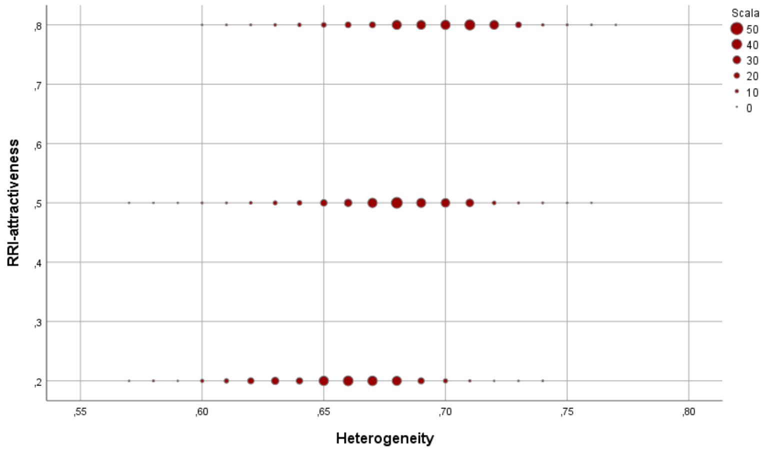


Figure 1 Scatter Plot of Experiment 1

As shown from the Table 4, we can reject the null hypothesis H_0 by accepting a risk first kind $\alpha = 0.05$. Thus, we can consider the influence of the RRI-attractiveness factor on network heterogeneity as significant.

In order to further deepen the analysis, Post-hoc tests (Tukey's HSD) were performed following the significance of the ANOVA, whose results are reported in Table 5.

Table 5 HSD of Experiment 1

	(I) RRI attractiveness	(J) RRI attractiveness	Mean Difference (I-J)	Std. Error	Sig.	95% Confidence Interval	
						Lower Bound	Upper Bound
Tukey HSD	,2	,5	-0.02053*	0.0024	0.000	-0.0263	-0.0148
		,8	-0.03563*	0.0024	0.000	-0.0414	-0.0299
	,5	,2	0.02053*	0.0024	0.000	0.0148	0.0263
		,8	-0.01510*	0.0024	0.000	-0.0209	-0.0093
	,8	,2	0.03563*	0.0024	0.000	0.0299	0.0414
		,5	0.01510*	0.0024	0.000	0.0093	0.0209

These tests, performed two by two, offer us experimental evidence that the averages' difference is statistically significant. Therefore, observing that all three levels of RRI-attractiveness produce statistically significant effects, we can consider that this first subdivision into three ranges (low, medium, high) is acceptable.

Although there are still disagreements between academia and administration on the RRI definition (Gianni, 2021), it seems clear that societal involvement plays an essential role among the purposes of RRI practices (Gianni, 2021; Owen et al., 2012; Von Schomberg, 2013). Kupper et al. (2015) translate this concept by formulating the process requirement of diversity and inclusion, measured in our model through the variable heterogeneity. Stakeholder heterogeneity, the presence of diverse viewpoints, are critical features in adaptive innovation processes (Stirling, 2007) to achieve better decisions (Stahl, 2013) and ensure a richer discussion (Flipse et al., 2013). Ultimately, an innovative project guided by RRI principles must be characterized by a more significant heterogeneity of the working group. The conclusion is closely related to the concept of inclusion, a cornerstone of RRI practices (Stilgoe et al., 2013).

Our model demonstrates emergent behaviour in total alignment with the principles just described while also showing that the conceptual model on which it is based is correct. As Kupper et al. (2015) suggest, heterogeneity must permeate all phases of the RRI process, starting with the initial stages. In the IAMRRI SKIN model, this aspect is emphasized by the importance (greater or lesser, depending on the parameters chosen for the simulation) given to the RRI values of potential partners during the search and selection phase. As shown by the ANOVA results of the post-hoc multiple comparisons (Table 4 and Table 5), higher importance given to RRI values during partner selection corresponds to an increase in network heterogeneity. In this way, diversity, the inclusion of different types of stakeholders becomes intrinsic to the importance given to RRI values modelled as exogenous agent variables. Ultimately, a selection process that also considers agents' RRI values, not just the type of knowledge base and financial resources of potential partners, implies a significant increase in network heterogeneity.

2.2.2 Experiment 2

The second experiment aims to investigate the effect of partner selection strategies based on their inclination to RRI practices. Therefore, the input variable remains RRI-attractiveness, while the output variable is represented by the average knowledge reported by the Formula (3). We seek to determine whether an increase in this variable corresponds to an increase in the diffusion of knowledge base among agents participating in an innovative network. The combination of variables used to conduct the experiment is systematized in Table 6

Table 6 Experiment 2 simulation set-up

Control Variables	Run	ticks	input	output
See Table 1	300	30	RRI-attractiveness [0.2 0.5 0.8]	Average Knowledge of the agents

As mentioned, the existing literature on RRI indicates that an increase in RRI practices should be matched by an increase in the knowledge base of agents. To test this hypothesis, a One-way ANOVA was used, setting the parameters as described above. As can be seen from the following Table 7, there is no experimental evidence to suggest that the effect of RRI-attractiveness input on agents' knowledge is significant.

Table 7 Results of ANOVA for Experiment 2

ANOVA					
	Sum of Squares	**df**	**Mean Square**	**F**	**Sig.**
Between Groups	0.006	2	0.003	1.448	0.236
Within Groups	1.754	897	0.002		
Total	1.760	899			

The test is significant for p-value < 0.05

At this point, the investigation did not stop. First, the code was modified so that the advertisements (each agent makes public its knowledge base through an advertisement) were formed only by the IH's Capabilities, as in SKIN (Pyka et al., 2007). This modifies the mechanism of partners selection and learning. However, even in this case, the ANOVA was not significant (p-value=0.236).

Some authors measure the performance of organizations that adopt RRI practices from a financial point of view (for instance, measuring the level of sales growth; level of return on equity; ROA; market share; level of productivity), while others focus on a non-financial point of view, such as increasing the knowledge base. Finally, we observe long-term benefits that are mainly internal, such as "the development of new resources and capabilities" (Gonzales-Gemio et al., 2020, p. 17) and an increase in knowledge that leads to more excellent responsiveness on the identification of potential innovations (Fitjar et al., 2019).

In our model, agents have a particular knowledge base depending on the *breed* to which they belong, resulting from the analysis of various use cases provided by the IAMRRI project partners. This knowledge is disseminated and exchanged among the various network members during the simulation.

The results of the one-way ANOVA reported in Table 7 lead us to believe that the increased importance of RRI values in partner selection is not significant. The literature mismatch can be explained by the small number of Capabilities in the system (18 in total). Therefore, an agent most likely already possesses its partner's Capability, making learning unnecessary. Future developments may first address the identification of a more significant number of Capabilities present in the AM industry through collaboration with the industrial partners of the IAMRRI project.

In addition, a way forward could lead to a different codification of knowledge in which Abilities and Expertise play a more prominent role. Thus, the refinements made have extended the number of Abilities to 72: hopefully a number high enough to observe significant learning among agents.

2.2.3 Experiment 3

The literature claims that NGOs play a central role in RRI practices, incentivizing public engagement and open access publications. Therefore, we wonder if also in our model, a greater presence of NGOs in networks leads to a greater number of open access publications (the impact on public engagement is considered in the refinement of the original model as an internal mechanism). The presence of NGOs in networks depends on the variable we have called "ngo-attendance" compared with the average RRI key of the network. Therefore, we expect the number of publications to decrease as the number of NGOs within the Networks decreases, depending on the ngo-attendance as reported in D5.1 (Section 3.1.1). The combination of variables used to conduct the experiment is systematized in Table 8.

Table 8 Experiment 8 simulation set-up

Control Variables	Run	ticks	input	output
See Table 1	300	30	ngo-attendance [0,3 0,6 1]	Numb of open access publication

In order to consider the effect of the ngo-attendance factor on the Number of open access publications (dependent variable) as significant, a One-Way ANOVA was used, the results of which are summarised in Table 9.

Table 9 Results of ANOVA for Experiment 3

ANOVA					
	Sum of Squares	**df**	**Mean Square**	**F**	**Sig.**
Between Groups	71352174,907	2	35676087,453	365,401	,000
Within Groups	87578982,133	897	97635,432		
Total	158931157,040	899			

The test is significant for p-value < 0.05

As shown from the Table, we can reject the null hypothesis H_0 by accepting a risk first kind $\alpha = 0.05$., we can consider the influence of the ngo-attendance factor on number of open access publications as significant.

In order to further deepen the analysis, Post-hoc tests (Tukey's HSD) were performed following the significance of the ANOVA, whose results are reported in Table 10.

Table 10 HSD of Experiment 3

	(I) RRI attractiveness	**(J) RRI attractiveness**	**Mean Difference (I-J)**	**Std. Error**	**Sig.**	**95% Confidence Interval** Lower Bound	Upper Bound
Tukey HSD	,3	,6	77,313*	25,513	,007	17,42	137,21
		1,0	632,187*	25,513	,000	572,29	692,08
	,6	,3	-77,313*	25,513	,007	-137,21	-17,42
		1,0	554,873*	25,513	,000	494,98	614,77
	1,0	,3	-632,187*	25,513	,000	-692,08	-572,29
		,6	-554,873*	25,513	,000	-614,77	-494,98

Following the statistical analysis conducted, we can consider the behaviour of the IAMRRI SKIN model to be in line with the evidence reported in the literature by Ahrweiler et al. (2019). Therefore, NGOs support networks in publishing open access, and a reduction of networks with NGOs as partners corresponds to a reduction of open access publications. Thus, although NGOs are not the main disseminators of knowledge for ethical keys such as ethical-thinking and gender-equality, they turn out to be essential agents in the role of knowledge dissemination, and thus in the dissemination of open access practice. Recall that when an agent publishes open access in the model, it has a slight increase in its value.

At this point, we consider the intermediate validation phase to be complete. In the next section, we will briefly explain which calibration process we will carry out, repeating the experiments with the calibrated model.

3. CALIBRATION/GROUNDING

There are various levels of model validation – as said earlier. This is since for a model to be considered "valid" it often takes years and several researchers to work on it. Due to lack of data, we will carry out a type of Validation that will not be considered "total", but in a sense "partial". According to Carley (1996), it is possible to identify several validation techniques that fall into these categories:

- **Verifying**, verification is a series of techniques to determine the validity of the predictions of a computational model against a set of real data. It is sometimes done on uncalibrated models. During verification, the focus is on validating the results of the model, not on its inner workings. In addition, the level of detail needed in the real data for verification is less than the level of detail needed for calibration.
- **Grounding**, "involves establishing the reasonableness of a computational model" (Carley, 1996, p.6). we will explain this procedure in more detail later.
- **Calibrating**, is the process of developing a model to fit real data. It is a multi-step and often iterative process in which model processes are modified so that the model predictions fit, within a reasonable tolerance, to a real-world data set. This approach is generally used to establish the feasibility of the computational model; that is, to demonstrate that it is possible for the model to generate results that match real data. Calibrating a model may require the researcher both to set and reset parameters and to modify the programming of the computational model. In order to validate the functioning of the model and its results, it is necessary to have both real input data with which to start the calibration and real output data with which to compare the model's results. In terms of results, the calibration can stop at any level - model, point, distribution or value. We will not go into the details of this process, as we do not have any real output data with which to compare the results of the model.
- **Harmonising**, "is a set of techniques for determining the theoretical adequacy of a verified computational model with respect to a linear model and a non-computational data set" (Carley, 1996, p.11). The objective of this process is to demonstrate that the theoretical assumptions underlying the computational model are well-founded, or in harmony with the real world. The process involves multi-step validation and two real-world data sets. First, the computational model is calibrated with detailed data and then verified with the first set of real data. Then the model is verified again with a second set of real data. Next, a linear model is estimated on the first set of real data. The linear model is used to generate robust results that are not constrained by the theoretical assumptions underlying the computational model. The next step is cross-validation, which involves the use of the first set of real data, the estimation of parameters for a simple linear model on that data and then, given those parameters, the prediction of the behaviour of a second set of real data. The final step involves statistically contrasting the predictions of the computational model with the predictions of the linear model for the second set of real data. Again, we will not go into detail here, as this process will not be studied.

In our case, even if the objective of the IAMRRI SKIN model is to reach a high level of validation, through methodologies that foresee the use of empirical data (Empirical input Validation - Empirical output Validation), this could not be totally done due to the lack of complete data sets. For this reason, we will focus on the techniques proposed in the Grounding process, which do not require either a high degree of accuracy of the actual input data or a high number of variables to be calibrated.

As already mentioned, grounding consists of establishing the plausibility of a computational model. “The fundamental objective of grounding is to determine that the simplifications made in designing the model do not seriously reduce its credibility and the likelihood that it will provide important insights”, (Carley, 1996, p. 6).

Grouding is usually used to ascertain the face validity of a model and sometimes its parameter or process validity. The use of this approach implies the use of:

- storytelling, the author makes a claim as to why the proposed model is reasonable. This step we have already performed in the Verification phase with the relevant experiments
- initialisation, it concerns the process of setting the initial or starting parameters or procedures for the model. This technique is typically used with stochastic, parameterized and Monte Carlo models. In this case, the various parameters must be set so that they correspond to the actual data.
- evaluation techniques, in this case performance evaluation. "Simple performance evaluation is the process of determining whether the computational model generates the stylised results or the expected behaviour of the underlying processes" (Carley, 1996, p. 7). To do this first the researcher identifies one or more stereotypical facts or stylised behaviours, which can be thought of as general empirical regularities that have been repeatedly observed with real data, then the researcher demonstrates that the proposed model generates data or exhibits behaviour consistent with the stereotypical fact or stylised behaviour. This step was partially carried out in the Validation phase.

The nextsSection we report, the data that was provided to us by the project partners, in what format it was received, and the data mining carried out.

3.1 Input data

The input data we were provided with came from different project partners. Although we have done data mining of all of them, not all the data could be used because of the way the code was implemented. We report this data as a starting point for future developments of the model implementation.

Open Access data

Open access data refer to open access publications. With the values derived from these data, we will calibrate the variable called “open-access.” We recall that this variable is one of the four variables representing the RRI keys in our model.

We worked on two datasets that were provided to us by the project partners AIT/MUL.

Open Access Publications			
2018	**2019**	**2020**	**TOT**
1348	885	685	**2918**

The first set is a database of 2918 open access publications in the field of Additive Manufacturing, extract from Scopus[1]. The keyword used was “additive manufacturing”, limiting the research to papers published in open access in the EU-27 countries in the fields of engineering, material science and medicine. Each publication has been divided by year (2018-2019-2020), the scope of publication (materials, technological, product, process, etc.), and the entity that made the publication, authors, funders (or projects that funded and made the publication possible). These data showed a decrease in publication over the years.

[1] https://www.scopus.com. Scopus is an international database of bibliographic references and citations from the Elsevier company, of peer review literature and quality web content, with tools for monitoring, analysis and visualization of research.

In a second step we asked the partner to draw a sample from these 2918 publications. A sample of 284 publications was representative. The sample of 284 publications was selected under one criterium only: that the publications were published in 2018, which was the year with higher number of open access publications among the years 2018, 2019 and 2020. Other that, the selection was made randomly. The results emerging from this sample are shown in Table below (11).

Table 11 Open Access Publications

Open Access Publication by firm	Number of publication Open Access	% of Publication Open Access
Research Institution	239	84,15
Customer	15	5,28
Supplier	13	4,58
AM Tech	12	4,23
OEM	3	1,06
Other consultancy	2	0,7

The second set of data was provided to us in reports; the data collected are not yet usable in our model. They include statistics on which country publishes the most in open access, the percentage of open access publications in AM in Europe, and the total number of publications by the individual company. Here again, it is reported that universities and research institutes publish the most in open access with a percentage of almost 90%.

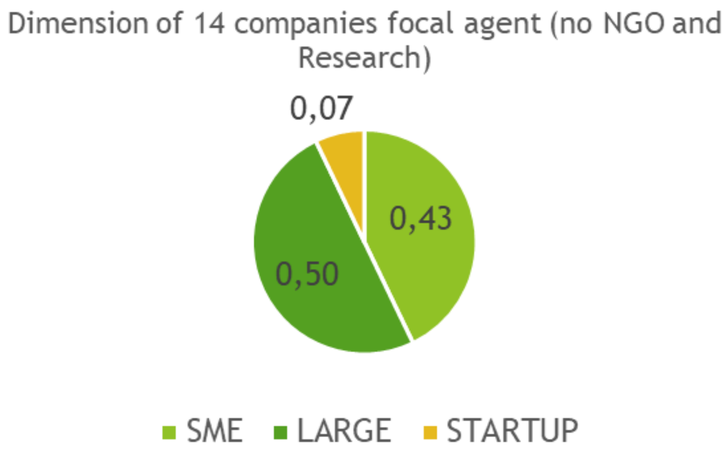
For this reason, we will set the values of the open-access variable in a pointwise manner for the agents on which we have data (Am-techs, Suppliers, Customers, Research-insts, and OEMs) and randomly in a range between 0 and 0.1 for NGOs, in order to remain as faithful as possible to the data obtained from the project partners.

Focal Agent data

The other input relates to the possibility of being a focal-agent and therefore of starting a project and setting up a network. In this field, data was obtained by considering some data related to the Materalia cluster, one of the clusters used in the project's use-cases.

The data was provided using a spreadsheet file and a transcribed interview in doc format.

These data showed that out of 33 AM-related projects, the percentage of focal agents is: 51.52% for Research-insts, 18.18% for Am-techs, 18.18% for Suppliers, 6.06% for NGOs and OEMs. It turns out that Customer's agents are never focal-agents, so in the code, we have removed the possibility of being focal agents for this type of agent. These data were brought back into the model by changing the number of agents who can start a project, thus the variable n_start_project.



From the data provided, it was also possible to analyse the percentages of the size of the focal companies. This data is currently not usable in the model but may relate to future developments.

On the latter data set we also calculated the conditional probability that a Focal OEM, Supplier or Am-techs agent is SME, Large or Start-up. Please note that these are not usable because the model currently in the setup only considers big or SMEs.

- $\Pr\{SME|Amtech\} = 66{,}67\%$; $\Pr\{Large|Amtech\} = 16{,}67\%$; $\Pr\{Startup|Amtech\} = 16{,}67\%$

- $\Pr\{Large|Supplier\} = 83{,}33\%;\ \Pr\{SME|Supplier\} = 16{,}67\%$
- $\Pr\{Large|OEM\} = 50\%; \Pr\{SME|OEM\} = 50\%$

Gender Equality Data

Gender equality is an RRI key that serves as a proxy for the RRI key ethical thinking in the model. The data was obtained independently through a report called THE STATE OF 3D PRINTING REPORT: 2021 EDITION (Sculpteo, 2021).

Unfortunately, in this case, the data is minimal. Therefore, it is only possible to set the value of this variable for three agents in the model. In particular, the data shows that for Research-insts gender equality is 39%, while for AM-techs and OMEs firms gender equality is 81%. Therefore, the data were reported by setting the gender-equality variable as follows: 0.32 for Research-insts and 0.81 for AM-techs and OEMs.

In the absence of data on the other agents, we preferred to keep the variable setting randomly between 0 and 1. We then repeated the experiments done in the Validation phase with the model calibrated with the following values of variables for the agents.

Table 12 Calibrated Input Data

INPUT DATA	AM-techs	OEMs	Suppliers	Customers	NGOs	Research-insts
Open-access	0.0423	0.0106	0.0458	0.0528	Random between [0 1]	0.8415
Gender-equality	0.81	0.81	Random between [0 1]	Random between [0 1]	Random between [0 1]	0.32
n_start_project	(18.18* nAM-tech) / 100	(6.06*nOEMs) / 100	(18.18* nSuppliers) / 100	0	(6.06*nNGOs) / 100	(51.52*nResearch-insts) / 100

It was interesting to note that the running time for each experiment was drastically reduced. With the uncalibrated model each experiment took about 150 minutes, with the calibrated model, as in Table 12, each experiment takes at most 45 minutes.

3.2 Experiment with calibrated data

After the Calibration procedure, all experiments were repeated. We observed better performance in computational times. Experiments 1 and 3, reported in Section 3, already fit the empirical evidence reported in the literature, so we do not report them in this section. Whereas the results of Experiment 2 intimated to us a non-significance of the RRI-attractiveness variable (weight given to RRI keys during the selection of potential partners) on the diffusion of knowledge among (measured according to Formula 3). However, using the calibrated data reported in Table 12 and still setting up the experiment according to Table 6, the effect of the RRI-attractiveness variable on knowledge diffusion turns out to be significant ($F(2,897)=3.742; p=0.024$).

In conclusion, although finding some correspondence on how RRI practices impact innovative processes is not a simple task since "the impact appears to be elusive and difficult to measure" (Pansera et al., 2020, p. 402), we were able to validate the correspondence of the behavior of the IAMRRI SKIN model with all the empirical evidence found in the literature, thanks also to the calibration process. Indeed, as Gonzales-Gemio et al. (2020, p.17) suggest, the effect of adopting RRI practices is measurable in the long run, such as "the development of new resources and capabilities" that leads to more excellent responsiveness on the identification of potential innovations and an increase in knowledge (Fitjar et al., 2019). As the results of the experiments suggest, this dynamic is also represented by the IAMRRI SKIN model, demonstrating its validity in the stylized representation of reality. Therefore, following the example of the experiments reported in the present Deliverable, the model is usable for developing useful insights and suggestions in the management and understanding of IVCs.

4. CAPITALISATION ON SIMULATION RESULTS AND CONCLUSIONS

IAMRRI SKIN model constitutes a first attempt to create an auxiliary tool for institutional bodies and policymakers, assisting them in defining strategic guidelines for disseminating and encouraging RRI best practices. By modifying some model parameters, it is possible to investigate the impact of incentives on RRI practices and innovative performance regulation. It is possible to set endogenous parameters adapting the simulation to different business and industrial contexts.

The model is easily adaptable to other contexts or industries, in which cooperation between the various participants within the network also has an ethical component. After identifying the actors of the new context and having catalogued/labelled their knowledge, it is possible to proceed to the extension/integration of the code.

The rigor of the model developed within the IAMRRI project has been tested through various experiments demonstrating the adherence with the empirical reality reported in the literature. Furthermore, the proposed experiments demonstrate the model's use of the types of research questions that can be developed in the future and how to answer them.

Briefly presenting the more interesting results, and the related insights coming from the experiments executed, we can divide these insights on the base of the perspectives analysed: RRI, strategical, economic, and social.

These perspectives were deeply analysed by the means of 3 main experiments, briefly reported below, in their main insights: Regulator simulation, RRI-cost simulation, NGO simulation.

4.1 Regulator and its impact on RRI spreading

The research question aiming the Regulator experiment (detailing described in the deliverable D5.1) was that to assess the societal effect of the Regulators and what might be a better policy to adopt for spreading RRI practices. The research questions at the base of this experiment were the following:

What happens if the selection of innovation ideas, based on the network's RRI values, becomes more stringent?

Will RRI values spread more rapidly? How will this affect agents?

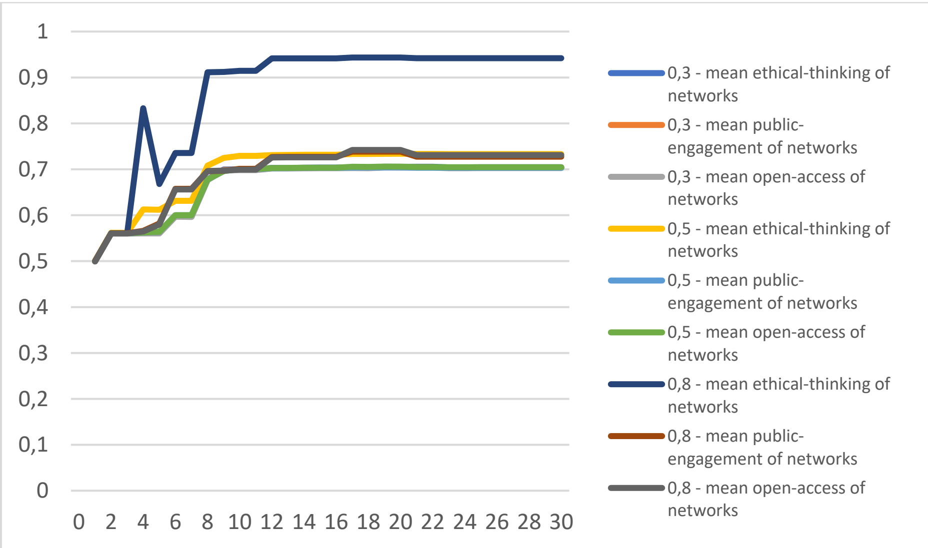


Figure 2 Diffusivity of RRI-values: increasing of ethical-thinking push the other RRI values to increase

As can be observed in Figure 2, stricter regulation on a single RRI key (ethical-thinking) incentives the increase of the remaining keys. As consequence of this we asked if "would it then be sufficient to increase regulatory bodies' constraints to achieve a spread of RRI practices?"

The answer was: of course not. What was observed in this simulation was that with regulation increases, the number of innovative networks drops dramatically, reaching values close to zero.

As some actors advocate to "give innovators a bit more breathing room" or, "do not rush to regulate", we should keep in mind the possible social cost of under-regulation as well as the possible cost of over-regulation. At this point, the next steps to be taken should concern "when to regulate" and "how to regulate" (Eggers et al., 2018).

4.2 The RRI-cost impact

After having tested agents' performance from a social perspective (average of the RRI values) and a strategic perspectives (number of agents involved in innovation projects and number of networks established - see deliverable D5.1, for more details), we focused on testing the model from the point of view of economic performance, so evaluating the networks' average capital, which was chosen as output, studying the effect of the cost necessary to support responsible research: RRI-cost.

Efforts to support RRI represent an investment that agents make for the innovative project's benefit, so this investment is tracked in the capital invested in the project, so increasing the RRI-cost variable should also increase the value of the average capital invested in innovation projects, but:

What happens to the number of agents participating in such projects?

Do they decrease?

Should increase investment in RRI be preferred at the expense of increased participation?

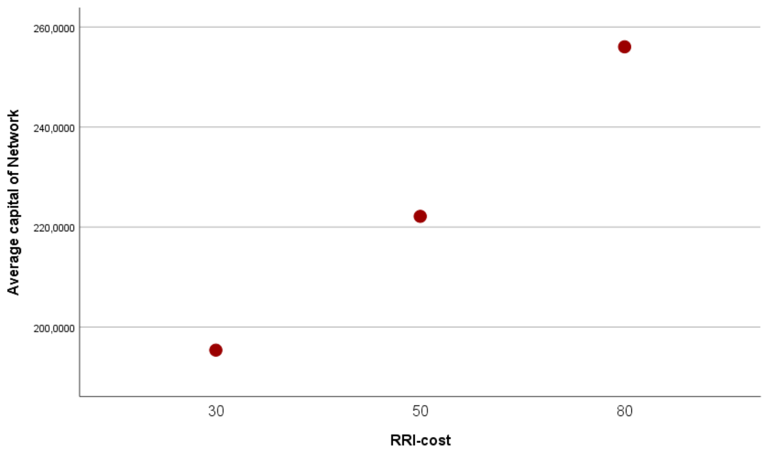


Figure 3 Average capital of the network increasing with the increase of RRI-cost

Since the cost of undertaking RRI projects (RRI-cost) is to be considered an investment, as we expected, the simulation showed that an increase in the RRI-cost leads to an increase in the average capital invested, as shown in the graph of Figure 3.

Besides, we asked whether the change in the cost of upholding RRI values has any significant effect on the number of agents undertaking innovative projects. The results of the simulation showed that an increase in the independent variable RRI-cost corresponds to a decrease in the number of agents involved in networks, as shown in the graph of Figure 4.

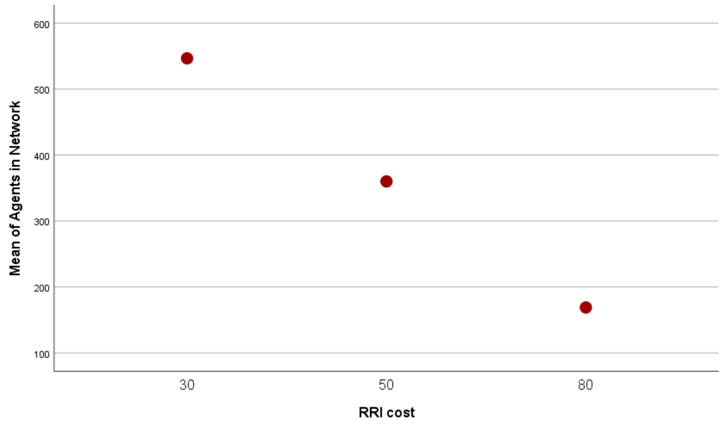


Figure 4 Decrease of the number of agents in the networks, with the increase of the RRI-cost

4.3 NGO Impact

Since literature claims that NGOs play a central role in RRI practices, incentivizing public engagement and open access publications, we wondered if also in our model, a greater presence of NGOs in networks leads to a greater number of open access publications.

Table 13 The influence of the presence of NGO in the innovation networks (first column), vs. the number of open access publications of the innovation networks

					95% Confidence Interval for Mean			
	N	Mean	Std. Deviation	Std. Error	Lower Bound	Upper Bound	Minimum	Maximum
0,3	0	1486,71	270,875	15,639	1455,94	1517,49	807	2319
0,6	300	1409,40	248,691	14,358	1381,14	1437,66	377	2100
1,0	300	854,53	397,097	22,926	809,41	899,64	160	2347
Total	900	1250,21	420,460	14,015	1222,71	1277,72	160	2347

What was observed in the simulations (for more details see the experiment 3, in the section of validation) is that NGOs support networks in publishing open access, and to a reduction of networks with NGOs as partners corresponds a reduction of open access publications. Although NGOs are not the main disseminators of knowledge for social and ethical values, they turn out to be essential agents in the role of knowledge dissemination, and thus in the dissemination of open access best practices.

4.4 Insights from Gaming Simulations

The IAMRRI project aimed to find openings for innovation value chains in AM in order to strengthen RRI practices in the innovation system of the analysed industry. One of the objectives of the AM system research was to understand how innovation networks are formed and evolve in their life cycle of an innovation value chan. The beginnings of AM - which was originally called 3D printing - are difficult to trace today. It is therefore interesting to observe the difference between an early-stage technological innovation and a mature innovation. If differences can be identified from this, recommendations for supporting future RRI-oriented innovations on the case of AM can be derived.

The previous sections (4.2) have already discussed the impact of RRI costs on network heterogeneity. In the following, the influence on the development of innovation networks - characterised by the stability of the networks - is discussed.

For this purpose, hypothetical initial situations for the scenarios (gaming experiments) are defined. Innovation systems in the early phase and in a mature status are determined by the number and typology of actors in the innovation system. In order to learn and understand more about the behaviour of such a complex system, mathematical experiments were conducted with the developed IAMRRI SKIN V1.0 model. Since the model has already been verified, validated and calibrated, these experiments should provide insights into the principle mechanism of network formation and stability in the innovation value chain at different stages of the additive manufacturing life cycle (early stage and mature stage).

These experiments (which are not based on the logic of ABM practice, but on the intuitive use of the model) were conducted by the MUL project team, which has experience and deep knowledge with AM innovation systems. The aim is to gain additional insights for the complex system. This work is referred to as game experiments. Not the absolute numbers are taken for interpretation, more the trends and overserved events as such.

The central research questions were how the characteristics of the innovation networks influence the development of the innovation in the early and mature phases. Parameters such as RRI costs, financing, the participation of large companies are the variables whose mechanisms of action on the innovation networks are to be investigated.

In order to understand the principle mechanism, a minimum number of 20 runs were conducted for each experiment and the development of the network size, the development of network capital and trends in RRI propensities, the stability of the innovation network in the innovation phase of idea generation and product development were observed. In parallel, statistical analyses of at least 500 runs were conducted to quantify more the initial network numbers. Not gates thresholds were set, that why sometime number of open access publication and start-ups rather high.

Figure 5 shows the hierarchy of the performed gaming experiments

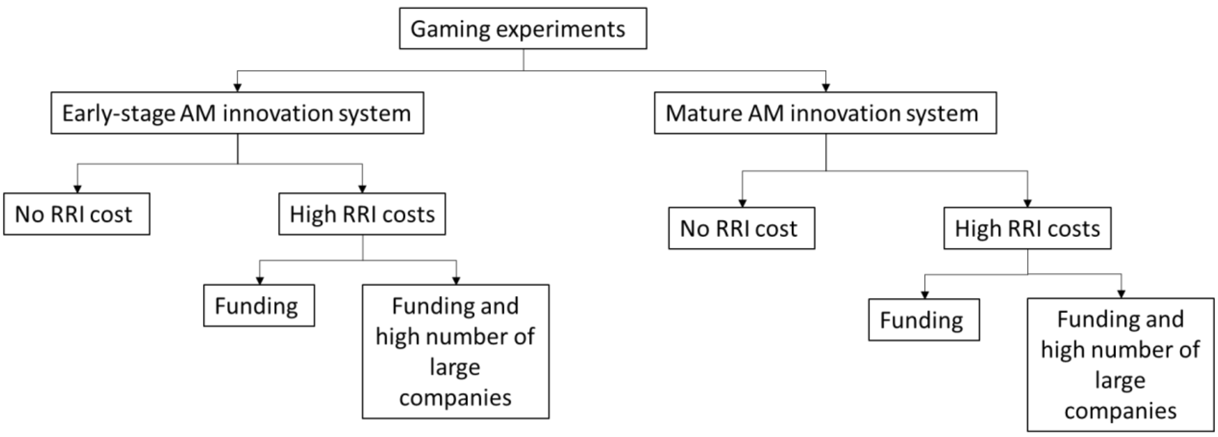


Figure 5 Design of experiment of the gaming experiments

The game simulations were a first attempt to interpret more clearly the mechanism and impact of events on AM's WIVC. The game experiments helped to understand the impact of RRI costs on the AM innovation networks at an early and a mature stage of the innovation system. They also highlighted the opportunities for research and innovation funding and engagement of large financially strong companies in the innovation networks. The introduction of RRI costs was shown to have a strong impact on the survival of innovation networks and their ability to go through all innovation steps from idea generation to market diffusion. Most innovation networks collapsed at high RRI costs in the product development phase, in both the early and mature phases of the AM innovation system. RRI costs showed to have a much stronger impact on the early phase of AM innovation. Funding can somewhat compensate for high RRI costs by supporting the formation of new innovation networks and helping them to survive in the early stage of product development, but funding was not found to be as effective in bringing innovation networks to the market diffusion stage in the simulations. The financial support by research and innovation funding of the innovation system led to a strong increase in RRI inclinations. Events in the formation of new networks and the increase in capital led to a gradual increase in RRI inclinations.

The involvement of large companies brought more resources into the innovation system and saved innovation networks from total collapse in the product development phase and drove most innovation networks to market diffusion. RRI inclinations have also increased, but lags behind the increase initiated by research and innovation funding. The more dynamic behaviour of collapsing and rebuilding an innovation network in the first two phases of the innovation process through funding and RRI costs had a more positive impact on the increase of average RRI inclination in the networks, but the engagement of large companies, which enabled a more "stable" innovation process, led to a higher output of open access publications and start-ups.

Table 14 summarises the observation which were made by the mathematical gaming simulation experiments.

Table 14 Summary of observation in the gaming experiments on early stage and mature AM innovation systems

Changed parameters	Early-stage AM innovations	Mature AM technology innovations
Low number of actors	In average lower number of networks; networks depend on contribution of actors – more research - customer networks, not so a strong diversity in the networks typology	Higher number of innovation networks; networks are built with partners having various competence in network, higher heterogeneity of actors in the networks, higher number of networks
Impact on innovation	Lower possibility of successful innovation ideas passing the market phase	Higher likelihood for reaching a higher number of successful innovations which passes the transition to market diffusion
High number of SME	Low average capital in the innovation networks	Higher number of capital in the innovation system can be reached, but networks are not so very successful in reaching market phase
Funding and high RRI costs	Increase stability of some networks in the product development phase; but funding cannot prevent from collapse of most of the networks, leads to the formation of new networks in the idea generations phase; funding can compensate high RRI cost to some extent, higher RRI inclination can be reached	Increase the stability of the innovation networks, so that some networks can proceed directly to market diffusion phase, but contributes also to the formation of new networks, can compensate high RRI cost to some extend; higher RRI inclination can be reached
High RRI cost	Can stop nearly almost all innovation networks in the product development phase depending on the number of networks which exist in the product development phase	Can stop most of the innovation networks in the product development phase, but a bit milder than in system with low number of actors, innovation systems with higher number of networks tend to collapse completely
Influence of large companies' contribution	SME oriented networks are less stable, many cannot reach the market diffusion phase; low capital in the networks; some large companies lead already to a higher average capital of networks, more impact than funding, increase of average	Large companies-oriented innovation system have high probability of survival of all innovation networks, but a low number of new generated innovation networks in the idea creation phase, high capital of networks, more open access publications and more

	RRI inclination of a network is not so strong	start-up as output, medium average RRI inclination because of limited capital and high number of networks.
Output of innovation networks	Low number of open access publications, low number of start-up because of low average capital	Higher number of open publications and start-up per networks because of high average capital

The detailed results and visualisation of the experiments are in Appendix 5.

The gaming experiments help to show mechanisms and tendencies of influencing implications on the innovation system consisting of web of innovation value chain and will open up the option to build up the understanding of complex innovation systems as WIWVC are. A more in-depth view to mechanism and the interrelation of input- and output parameters will help to increase the learnings and the building up of understanding on innovation system. For users which are not familiar with the programming of "netlogo code" a further improvement of a user friendly interface will contribute to the spreading of usage of these kind of simulations.

4.5 Future improvements of the IAMRRI SKIN model

Future efforts may focus on adapting the model to other innovative or more established contexts, leveraging the amount of data available to achieve an even greater level of calibration. In addition, it would be interesting to introduce additional RRI keys and investigate their effect not only in the early stages of the innovation process, but also in the market diffusion phase.

5. APPENDIX

Gaming experiments with the Model: Insights from Additional Simulations

GAMING EXPERIMENT Early-Stage AM Innovation Networks

This experiment was aimed to do simulations for an AM innovation system which comparable with the early-stage of technology development. Such kind of system was characterized by a high number of research centres and SME company partners. OEM´s which will use the technology for producing new generation of AM produced products are hardly active in the AM system. Special research and funding programmes were not offering financial incentives in the early stage of AM innovation because the potential of AM was not yet recognized. The parameters for the gaming experiment 1 are seen in Table 15. Prime assumption to characterise such a system is that the number of actors in the system is low; research organisation, SME´s, AM Tech- companies, suppliers and customers are present in the innovation system. All company organisations are SME´s. The economic threshold is also low. Ticks (units of time) were varied between 1 and 18. No other thresholds were set

These assumptions on the system were made with members of the AM user group of the IAMRRI project.

Table 15 Input parameters for gaming experiment Early Stage Networks

Number of Research organization	**Number of OEM**	**Number of AM Tech**	**Number of customers**
50	0	14	150
Percentage of Large companies	**Number of Suppliers**	**RRI costs**	**Number of big firms (varied) (%)**
0	8	0	0, maximum
Funding	**Economic threshold**	**Ticks**	
0, maximum	10	1 to 18 (depending on the stability of the system)	

Question 1 *What is the development path of such an early technology innovation system under the assumption research and innovation funding is not established and RRI costs are assumed to be low?*

Results

Table 16 Statistical characterisation of initial built networks in the early-stage AM innovation system for Question 1

Min. Number of networks	**Max number of networks**	**Average number of networks**	**Standard deviation**
10	**166**	**102**	**38**

The networking between customer and research organisation is very dense. These networks moved stable to the first and second phase without any change in network numbers (Figure 6).

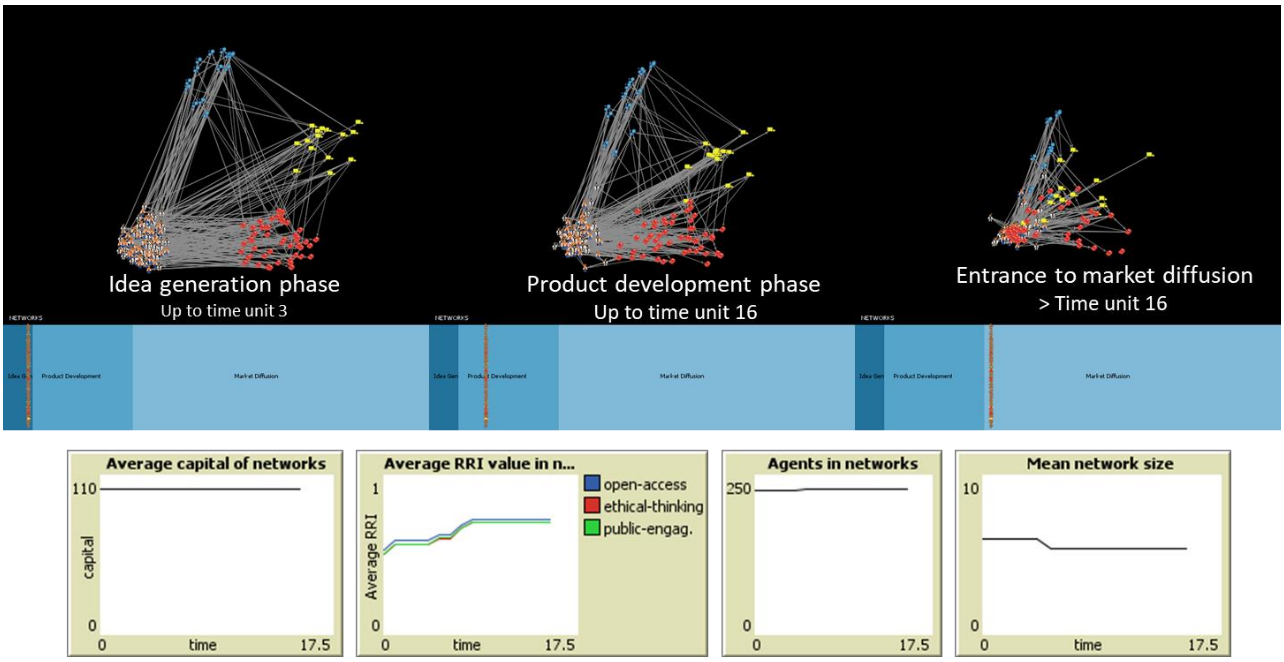


Figure 6 Stages of network development in idea generation phase, product developments phase for early-stage AM innovation with no RRI costs, no funding and no engagement of large companies. Average of network capital, average RRI values, agents in the networks and mean network size are shown in dependence of the innovation time (Question 1).

Question 2 *What is the development path of such an early technology innovation system under the assumption research and innovation funding is not established and RRI costs are assumed to be high?*

Results:

Table 17 Statistical characterisation of initial built networks in the early-stage AM innovation system for Question 2

Min. Number of networks	Max number of networks	Average number of networks	Standard deviation
14	171	101	39

According to the statistical analysis of the initial network in the idea generation phase, it is assumed that they are in the same range.

Again, the networking between customer and research organisation is high (Figure 7) All networks passed the transition from idea generation to product development. At tick number 5 all innovation networks collapsed in the product development phase. Very seldom new networks were formed again in the idea generation phase, when the simulation proceeds to higher ticks. But all networks collapse again in the product development phase. No open access publication or start- up are seen as output. RRI inclination starts at around 0.5 for all keys, and raise up to about 0.75, but shows a stepwise increase depending when a second front of innovations are formed in idea generation phase.

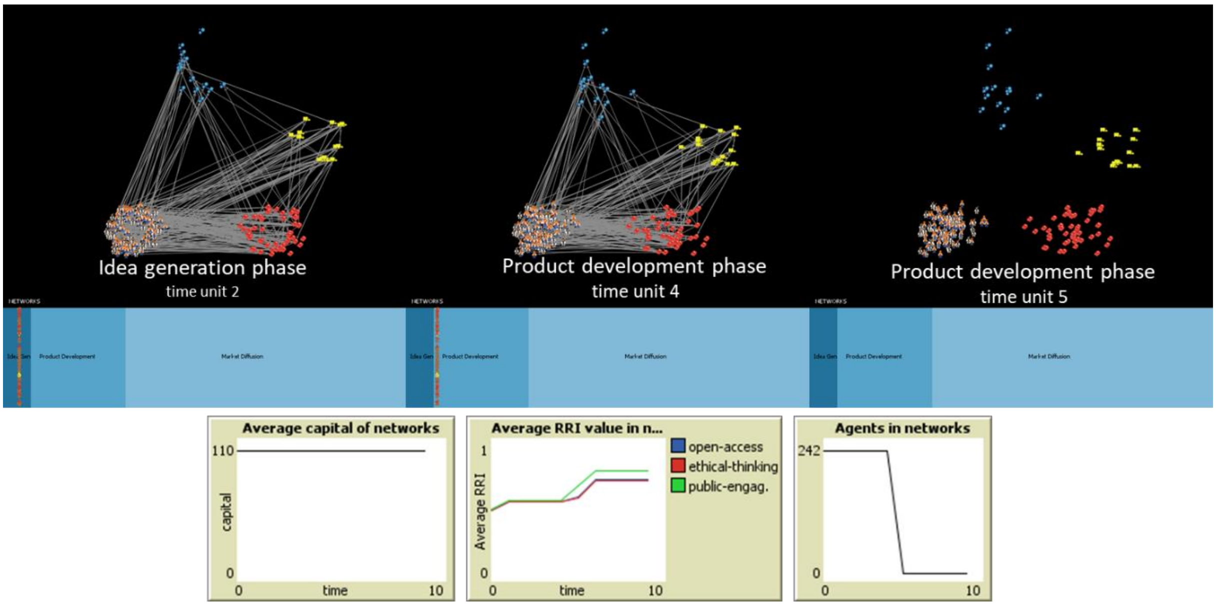


Figure 7 Stages of network development in idea generation phase, product developments phase for early-stage AM innovation with high RRI costs, no funding and no engagement of large companies. Average of network capital, average RRI values, agents in the networks and mean network size are shown in dependence of the innovation time. (Question 2)

Question 3 *What is the development path of such an early technology innovation system under the assumption research and innovation funding is established and RRI costs are assumed to be high?*

Results

Table 18 Statistical characterisation of initial built networks in the early-stage AM innovation system for Question 3

Min. Number of net-works	Max number of net-works	Average number of net-works	Standard deviation
9	172	103	38

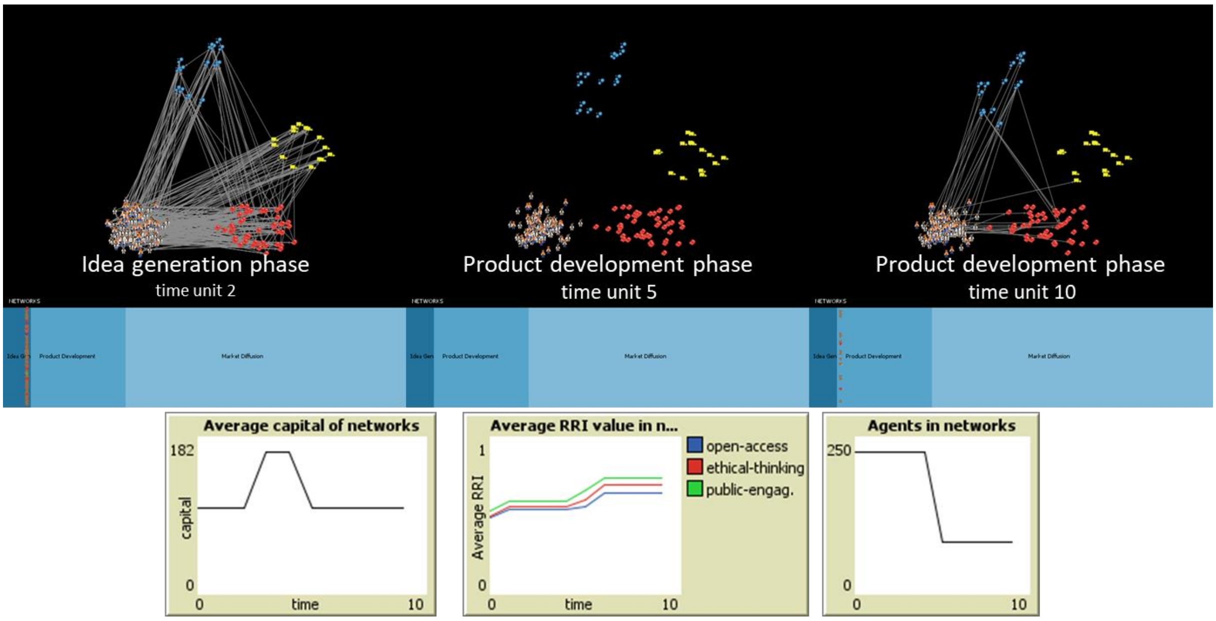


Figure 8 Stages of network development in idea generation phase, product developments phase for early-stage AM innovation with high RRI costs, funding established and no engagement of large companies. Average of network capital, average RRI values, agents in the networks and mean network size are shown in dependence of the innovation time. (Question 3)

The statistical analysis of the initial networks formed in the idea generation phase is similar to the other experiments (Table 18). In the product development phase, a collapse of most of the networks is occurred (Figure 8), but sometimes 5 to 10 networks survived and proceed to market phase. The RRI inclination can go up to values of about 0.8, which is slightly higher than in the other experiments. In most simulation hardly any new innovation- networks are developed. The innovation system produces open access publications compared to experiment of research question number 1. A number of open access publication lower than 10 are publish, no start-up are build.

Question 4 *What is the development path of such an early technology innovation system under the assumption research and innovation funding is established, large companies contribute to the innovation system and RRI costs are assumed to be high?*

Table 19 Statistical characterisation of initial built networks in the early-stage AM innovation system for Question 4

Min. Number of networks	Max number of networks	Average number of networks	Standard deviation
19	164	102	38

Results

The number of formed research networks in the idea generation phase is in the similar range and typology as before. All networks pass the transition to product development and market diffusion. The networks produce open access publication in higher number than all other gaming experiments. The capital of the network is 4 to 5 times higher than in the only funded version (Figure 9). Open access publications are released and start-ups are build.

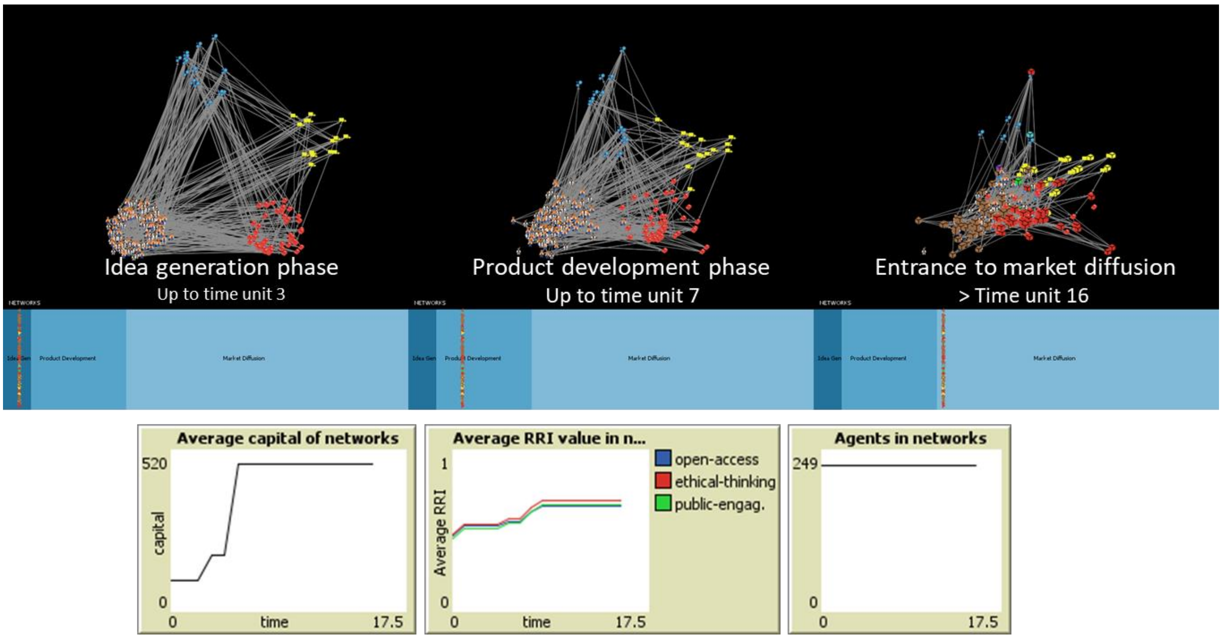


Figure 9 Stages of network development in idea generation phase, product developments phase for early-stage AM innovation with high RRI costs, funding established and engagement of large companies. Average of network capital, average RRI values, agents in the networks and mean network size are shown in dependence of the innovation time. (Question 4)

Interpretation of gaming early stage AM innovation system

The results show that all variations of the parameters had hardly any influence on the formation of networks in the idea generation phase. All formed networks reach the gate to the product development. Since no gate´s thresholds are set, all the networks pass the gate between idea generation and product development phase. In systems with low capital or high RRI costs, the simulation show a significant collapse of innovation networks and in some cases the formation of new networks. When any cost compensating mechanisms for RRI cost are activated, either the innovation networks can run stable to the market diffusion phase, produce open access publication and start-ups or have the power to create new numbers of innovation networks in the idea generation phase. The simulation show that funding stabilizes the network formation in the idea generation phase, whereas large company engagement stabilise the innovation networks in the product development phase and their transition to the market diffusion. The comparison with the real AM world shows that in the last 10 years either large companies get involved in AM or act as investors for start-up.

GAMING EXPERIMENT 1 Mature AM innovation networks

The second gaming experiment concentrates on a more mature innovation system. The actor´s typology and number are different. In the mature AM system, all actor types are active, AM technology, suppliers, customer, research organisation, OEM are active in the system. The fraction of large companies is already higher. The parameters which were selected are shown in Table 20. The starting values of this experiment correspond to a high extent to the real AM world of today.

Table 20 Global input parameter of second gaming experiment mature AM innovation system

Number of Research organization	Number of OEM	Number of AM Tech	Number of customers
300	80	140	300

Number of big firms	Number of Suppliers	Economic threshold	Tick
0% and 100%	15	10	Max to end of product development, transition to market diffusion
Funding	**RRI COST**		
0 and maximum	0 and maximum		

Question 5 *What is the development path of such a mature technology innovation system under the assumption no research and innovation funding is granted and no large companies are active in the network. The RRI cost are assumed to be zero?*

Table 21 statistical characterisation of the reference network of mature AM innovation system, comparison 500 and 1000 runs

Runs	Min. Number of networks	Max number of networks	Average number of networks	Standard deviation
500	102	624	396	88
1000	68	627	399	110

Results

In the initialisation phase approx. 100 to 630 networks are built (Table 21). Higher numbers of agents lead to a higher number of random network formation, so the standard deviation is higher, than in the early stage networks. A reference simulation with about 1000 runs confirmed that result.

The initialisation is like the previous experiments. In the mature AM innovation scenario, a strong networking between research, customer, AM-Tech companies are seen. The network engagement of the OEM is also strong, suppliers are a bit outside. This tendency can be seen in all phases of the networks. In the idea generation phase the RRI inclination increases start at about 0.5 and goes up till the transition to the product development, then the RRI inclination is constant or goes in some cases slightly stepwise upwards. Open access publications are produced in the product development phase to a high extent. In the market dissemination phase the RRI inclination levels at 0,7. No start-ups are generated. Average capital is stable or sometimes a slight increase can be found in the simulation runs.

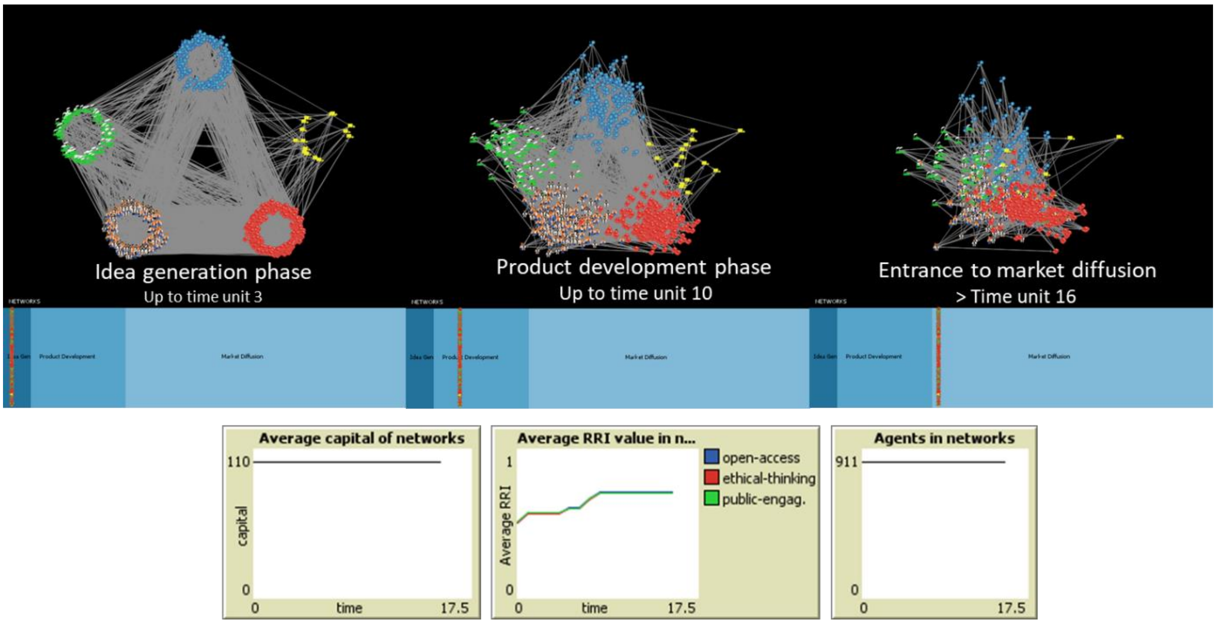


Figure 10 Stages of network development in idea generation phase, product developments phase for mature AM innovation system with no RRI costs, no funding established and no engagement of large companies. Average of network capital, average RRI values and agents in the networks size are shown in dependence of the innovation time. (Question 5)

Question 6 *What is the development path of such a mature technology innovation system under the assumption no research and innovation funding is granted and no large companies are active in the network. The RRI cost are assumed to be high?*

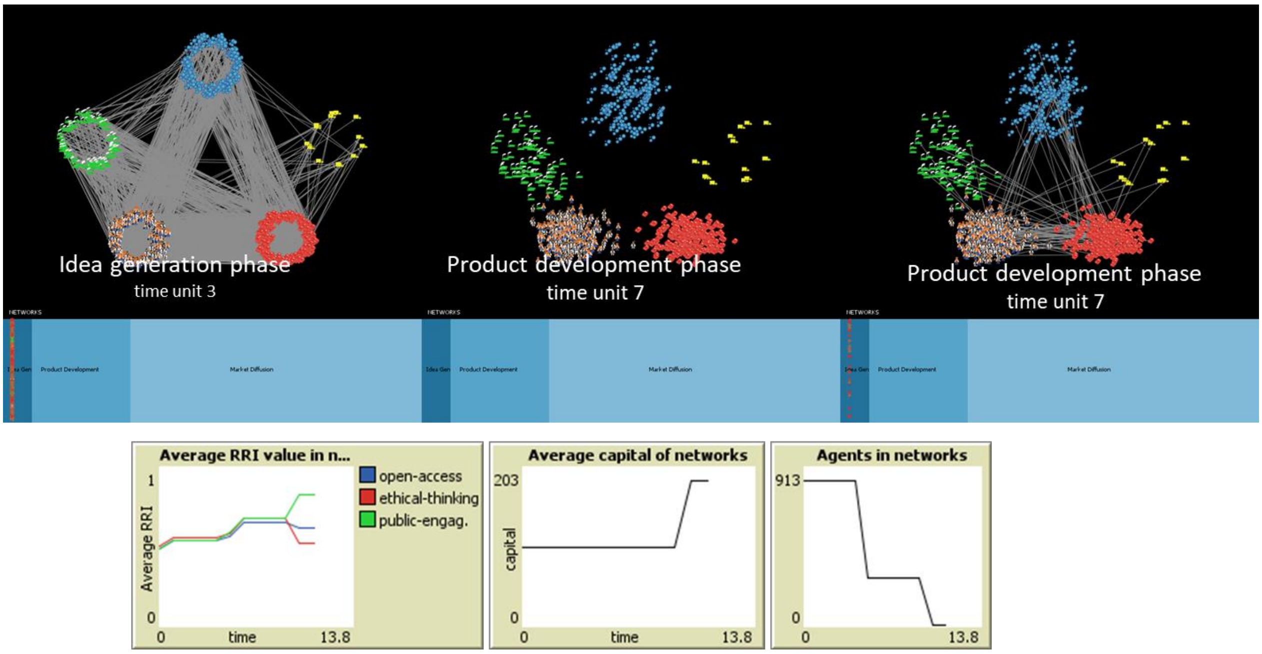


Figure 11 Stages of network development in idea generation phase, product developments phase for mature AM innovation system with RRI costs high, funding established and engagement of large companies. Average of network capital, average RRI values and agents in the networks are shown in dependence of the innovation time. (Question 6)

Results

The development of the innovation networks are shown in (Figure 11). The initialisation is like the previous experiments. In the mature AM innovation scenario such as strong networking between research, customer, AM-Tech companies are seen. The network engagement of the OEM is also strong, suppliers are a bit outside. This tendency can be seen in all phase of the networks. High RRI cost can lead to a completed collapse of the innovation networks. In some cases, especially in lower number of initial networks some are stable and can proceed in innovation process. But in principle these innovation system are not powerful system because hardly any open access publication are created and no start-up are built. The RRI inclination show a stepwise increase, splitting of the RRI key inclination can be overserved.

Question 7 *What is the development path of such a mature technology innovation system under the assumption research and innovation funding is granted and no large companies are active in the network. The RRI cost are assumed to be high?*

Table 22 Statistical analysis of the initial networks for question 7

Min. Number of networks	Max number of networks	Average number of networks	Standard deviation
61	**612**	**403**	**111**

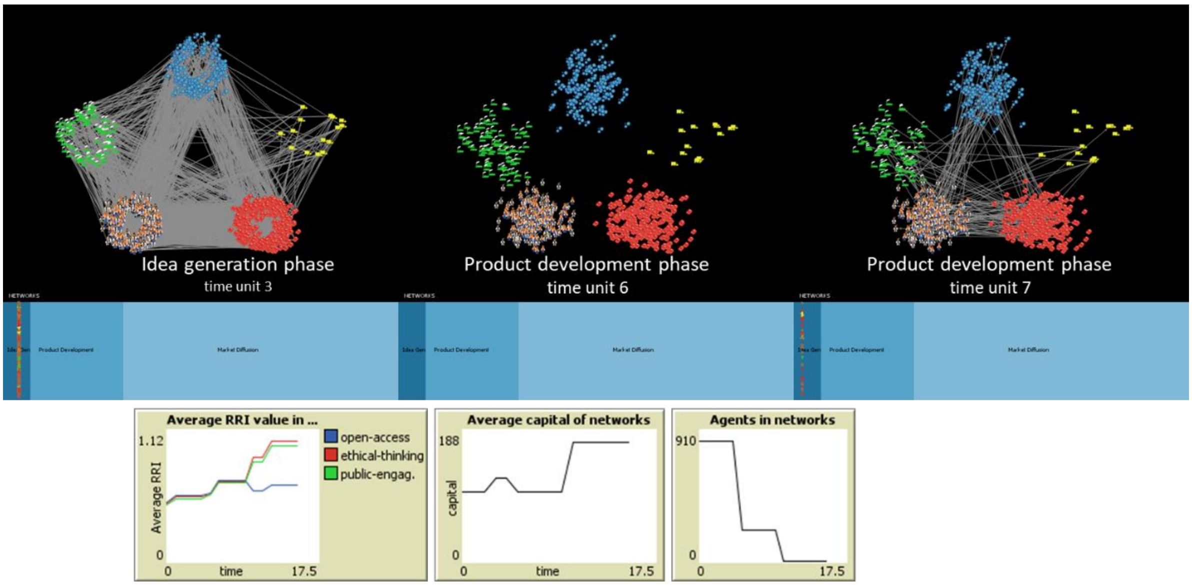


Figure 12 Stages of network development in idea generation phase, product developments phase for mature AM innovation system with RRI costs high, funding established and no engagement of large companies. Average of network capital, average RRI values and agents in the networks are shown in dependence of the innovation time. (Question 7)

Starting network numbers are also between 300 and 600 networks, topology of networking between actors is similar as in the experiments before. In the product development phase, most of the networks break down, sometime a low number can survive and proceed. But main mechanisms is that some ticks after the system collapse it seems to recover in the idea generation phase. These new networks have a higher starting value of average capital. When the innovation systems proceed forward to market diffusion, the average capital is reduced again, which leads to the breakdown of almost all networks of the second wave. (Figure 12.) Funding seems to support the system with addition capital which allows to strengthen the innovation system in creation of new networks, but the resources are not high enough that most all of them cannot overcome the product development phase. The RRI inclination of the remaining networks can become really high.

Question 8 *What is the development path of such a mature technology innovation system under the assumption research and innovation funding is granted and all companies in the innovation system are large firms. The RRI cost are assumed to be high?*

Results

Table 23 Statistical analysis of the initial networks for question 8

Min. Number of networks	Max number of networks	Average number of networks	Standard deviation
72	**574**	**313**	**98**

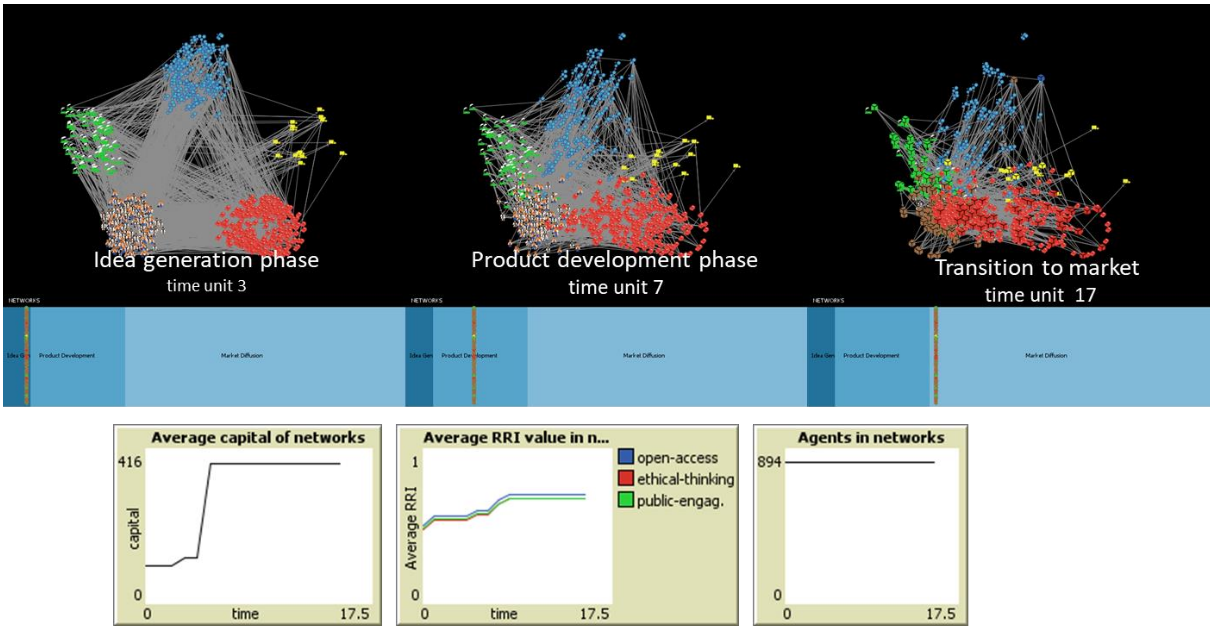


Figure 13 Stages of network development in idea generation phase, product developments phase for mature AM innovation system with RRI costs high, funding established and engagement of large companies. Average of network capital, average RRI values and agents in the networks are shown in dependence of the innovation time. (Question 8)

The initial number of generated networks is comparable to the other values in the scenarios before in mature AM innovation networks. All networks proceed through the product development phase, the average capital of the networks is 4 times higher than the starting value. The transition to the market phase is coupled with a high output of open access publication and start-up companies. Each network produces a start-up. The average capital per network is increased about 4 times. The inclination of RRI show a rather low increase and reach values in the middle of the average RRI value scale.

Interpretation

- High RRI costs can hinder the innovation networks to proceed to the product development phase. In a system with a higher number of starting networks in the initialisation phase leads to networks having a higher chance to survive in develop in the product development phase.

- Increasing the capital in the innovation system by giving funding or large companies’ contribution to the network, drive the innovation networks further to market diffusion.
- Capital given via research and innovation funding, enables more the recreation on new innovation-networks in subsequent phases to the first innovation wave and stabilise the innovation network by creation of new innovation networks in the product development phase.
- Large Companies have another systematic influence on the stability of the innovation systems. Large companies’ financial contribution enables all networks to travel to the innovation process from idea generation to the product development. As results open access publications and start-up formation is seen. Funding cannot give that power to the system.

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