Modeling the Diffusiondynamics of a new Renovation Concept

Matthias Müller[a]
matthias.mueller@ikaoe.unibe.ch

Dr. Silvia Ulli-Beer[a,b]
silvia.ulli-beer@psi.ch

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[a]University of Berne
Interdisciplinary Centre for General Ecology (IKAÖ)
Schanzeneckstr. 1, 3001 Berne, Switzerland
p: +41(0)31 631 3940

[b]Paul Scherrer Institut (PSI)
Dynamics of Innovative Systems
OVGA 105, 5232 Villigen PSI, Switzerland
p: +41(0)56 310 2723

Abstract

This paper reports on a preliminary version of a System Dynamics model of the diffusion dynamics of an innovative retrofit concept in the residential construction sector. The diffusion process is conceptualized as depending on the actions of two types of agents and the results of their interactions. The focus of the paper is on the positive feedback processes fueling the diffusion across the two groups of agents and on the negative feedback processes capable of shutting the diffusion process down. After exploration of the model's feedback mechanisms, the results of three simulation scenarios are presented and discussed in view of societal policies and business strategies in support of the innovation's diffusion.

Keywords

Construction industry, innovation, residential housing, energy.

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1 Introduction

The implementation of ecological innovations is an obvious way to transform the current, unsustainable practices in advanced industrial economies. Presently, the CCEM-CH “Advanced Retrofit” research network develops such an innovation for the residential housing sector. This paper reports preliminary modeling results from the project "diffusion dynamics of energy-efficient renovations (DeeR)" carried out within the context of the aforementioned research network. It aims to explain according to what processes the innovation will diffuse into society.

The bulk of Switzerland’s residential buildings were constructed before the year 1990 and have none or insufficient thermal insulation. While energy-standards for new buildings have tightened considerably in the past few years, old buildings are only seldom refurbished with thermal insulation (Gerheuser 2007, 54). If this trend were to continue, it would take several decades until the residential housing sector’s demand for energy services reached a sustainable level as characterized by the vision of the 2000-Watt-Society (Jochem 2004). Presently about 1600 Watt (per capita) of Switzerland’s gross energy demand of roughly 5100 Watt per capita can be attributed to residential housing (Koschenz & Pfeiffer 2005, 8). Because of its significant share of gross energy demand and the widespread lack of insulation, the residential housing sector offers a large potential to reduce Switzerland’s demand for energy services. Since most energy resources in the residential housing sector are of fossil origin, widespread insulation would significantly reduce Switzerland emission of $C0_2$.

Several studies [1] show that energy-efficiency enhancing investments often are economically profitable at current energy prices. However, there exist a number of barriers that prevent building owners from refurbishing and insulating their buildings. Among those barriers the complexity of the renovation process is an important one.[2]

The innovative renovation concept under development by the research network aims to reduce such barriers by providing a simplified renovation process. In a nutshell, the envisioned application of the renovation concept can be described as follows: Apartment houses in need of renovation are scanned with a laser in order to obtain a 3D-model of the building. Based on the exact model, architects can customize standard modules of façade elements and order them from module manufacturers. There,

[1] Examples are Jakob, Jochem & Christen (2002), Jakob (2006).

[2] See Jakob (2007) for a full discussion.

highly efficient prefabrication processes already used in the construction of new buildings can be employed to manufacture the elements. The resulting elements are then checked for quality, shipped to the construction site and installed in a quick and efficient process.

Minsch, Eberle, Meier & Schneidewind (1996) argue that 'sustainable development by means of ecological innovations' has the biggest chance, if the interactions between politics, companies and actor-networks are understood. This is the purpose of the DeeR study. It aims to contribute to a successful diffusion of the renovation concept by developing a System Dynamics simulation model (Forrester 1961, Sterman 2000) that represents the actors, actions and interactions that will control the diffusion process.

Since this is an ex-ante study, the model strongly relies on theory and expert judgment rather then on historical (statistical) data. In consequence, the epistemological position of the model should be considered to be closer to theory than to experience. This closely fits the notion of "theory-building with System Dynamics" as presented in Schwaninger & Hamann (2005). The benefit of developing a formal simulation model is seen to lie in the fact that it helps to ensure internal logical consistency and forces the researchers to be very explicit about the assumptions underlying the emerging theory.

The research process is as follows: Previously, a small number of unstructured, issue-centered interviews (Flick 2005, 134) with experts from the research network were conducted and a workshop with the same experts was held. The interviews served to gather the experts' perception of the emerging innovation and gain a preliminary understanding of relevant groups of actors: Building owners, architects, module manufacturers, construction suppliers and tenants were identified as the groups of actors that are affected directly by the diffusion of the renovation concept and have the ability to influence its diffusion outcome. Based on theories of the diffusion of innovations (Rogers 2003, Stoneman 2002), general economic theory and the results from the interviews, a first version of the simulation model was developed. Recently, a workshop with some of the experts that were interviewed took place. There, the benefits, costs and risks that the renovation concept brings to the relevant groups of actors were discussed and consolidated. In the future, the model will be further refined and possibly a small number of focus group discussions with selected experts representing the system's agents will be carried out.

The structure of the paper is as follows: The dynamic hypothesis guiding the modeling endeavor is presented in section 2. Section 3 introduces the general setup of the model. Section 4 first presents the positive feedback loops driving the diffusion process of the RC among module manufacturers and building owners. It then explains how negative feedback loops shut the diffusion process down once the fraction of failed renovations exceeds the tolerance level (the tipping point) of building owners or module manufacturers. In section 5 the results of three simulation runs are reported and discussed in view of their implications for societal policy and business strategy. Section 6 offers preliminary conclusions and identifies challenges the preliminary model needs to overcome in future versions.

Throughout the paper, <text in brackets> refers to variables. In order to keep variable names short, the following frequently used terms were abbreviated (see brackets for abbreviation): *Renovation concept* (RC), *building owner* (BO), *module manufacturer* (MM).

2 Dynamic Hypothesis

The following dynamic hypothesis guided the development of the model described in this paper:

Modul manufacturers (MM) gain knowledge of the renovation concept's (RC) existence and with a delay of several months they evaluate if they should adopt it or not. The attractiveness of the renovation concept for module manufacturers determines how many of them adopt the renovation concept and invest in it's marketing. The lower the attractiveness is, the more module manufacturers decide to delay adoption until the renovation concept becomes very attractive.

The more module manufacturers adopt the renovation concept and invest into its marketing, the more it gets known among module manufacturers and building owners (BO). In addition, a lot of marketing causes the building owners to gain trust in the new technology, thus increasing its attractiveness. This increases the probability that building owners are convinced by the renovation concept and implement it. Increasing implementations of the renovation concept cause more and more building owners to be aware of the innovation, causes the technology to mature and decreases prices - all ultimately further increasing renovation rates.

However, the lower the initial level of technological maturity the renovation concept has at the moment it is put on the market, the higher the number of failed renovations that are delivered. Once the ratio of total failed renovations to total renovations reaches a tipping point, it undermines the confidence both building owners and module manufacturers hold in the technology, causing a sharp drop in the rate of renovations. Further, module manufacturers start to discontinue the adoption of the renovation concept, with module manufacturers abandoning the renovation concept creating bad word of mouth which decreases the attractiveness of the renovation concept.

3 General Setup of the Model

3.1 Temporal Dimension

The model runs over a time of 10 years, with one timestep representing one month.

3.2 Reference Mode

The **number of RC renovations implemented per month** is the reference mode of this model. In the base scenario of a successful diffusion it is expected to increase according to the typical s-shaped diffusion-path and converge towards a steady state. In the case of a failed diffusion scenario the reference mode is first expected to rise until failed renovations have risen over the level of tolerance for both the building owners and module manufacturers and the rate sharply drops and converges towards zero.

3.3 Agents of the System

Modul manufacturers and building owners are the two types of agents represented in the model. The successful diffusion of the renovation concept relies on its adoption by both types of agents.

Modul manufacturers are conceptualized as construction companies which have all the industrial facilities to implement the renovation concept, including architects and a network of suppliers. It is assumed that the number of module manufacturers is finite. At time = 0, it is assumed that the module manufacturers are identical. As the diffusion process unfolds, the module manufacturers are distinguished only by the state they are in (see figure 1):

- <MM without knowledge of the RC> contains all the module manufacturers before they know of the renovation concept.
- Once module manufacturers hear of the renovation concept, they enter the state <MM evaluating the RC>.
- <MMs adopting the RC> contains module manufacturers that offer the renovation concept on the market and invest into technological maturing and marketing of the technology.
- <MMs not adopting the RC> contains the module manufacturers that do not offer the renovation concept. However, this state need not be definitive; once the renovation concept's attractiveness is very high, module manufacturers in this state can reconsider their decision and become adopters too.
- <MM having abandoned the RC> contains module manufacturers that have discontinued the use of the renovation concept because of bad experiences. Instead of pushing the diffusion by marketing activities, they actually will undermine its reputation by spreading bad word of mouth.

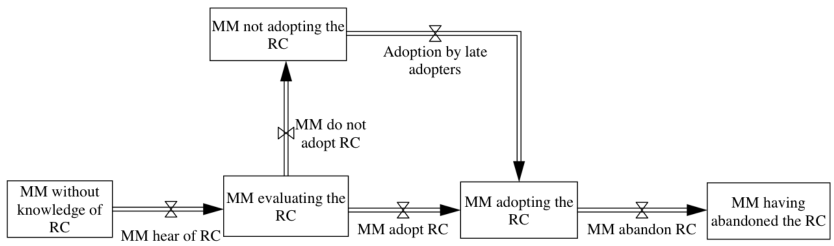

Figure 1: Stock and flow representation of the various states module manufacturers can be in.

Building owners are conceptualized as individuals with a building in need of renovation. In the model it is assumed that each building owner is responsible for one building and that each timestep a constant number of building owners enter the system. building owners exit the system after going through the first or both of the following two states (see figure 2):

- <Number of BO with need of renovation> contains the building owners entering the system at each timestep. building owners that do not become aware of the renovation concept exit the system by satisfying their demand for renovation by conventional approaches.

- building owners that become aware of the renovation concept enter the state <number of BO with need of renovation aware of the RC>. Building owners that get convinced by the renovation concept, will increase the number of renovations by one before exiting the system; the building owners not convinced by the renovation concept exit the system without any effects.

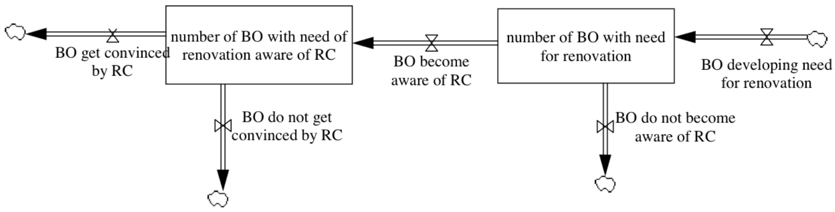

Figure 2: Stock and flow representation of the various states building owners can be in.

4 Important Feedback Loops

In the following subsections, the focus is on developing an understanding of important feedback loops - not the whole model. Therefore, often variables which are important for the model as a whole, but not for the feedback loop were omitted. However, figure 7 on page 18 shows a stock and flow diagram of the whole model. There, the causal structure of the whole model can be seen.

4.1 Reinforcing loops driving the diffusion process among module manufacturers

The two reinforcing loops seen in figure 3 drive the diffusion of the renovation concept among module manufacturers by moving them from the state of not knowing the renovation concept into evaluating and eventually adopting it.

At t=0, <Total number of renovations> already contains a small number of renovations, which are research and demonstration (R&D) projects undertaken before the renovation concept became regularly available on the market. R&D too causes <visibility of the RC for MM> to be above zero at t=0, thus avoiding start-up problems.

As the model unfolds, increasing <visibility of the RC for MMs> causes more and more module manufacturers to evaluate the renovation concept, which - all other variables constant - leads to higher numbers of adopters (loop R2). The positive links between <MMs adopting the RC>, <marketing activities> and <visibility of the RC for MMs> expresses the ideas that while adopting module manufacturers communicate the renovation concept primarily to their customers, the knowledge about the renovation concept increasingly reaches other module manufacturers by way of word of mouth.

While loop R2 drives the diffusion of knowledge and causes module manufacturers to evaluate the renovation concept, loop R1 determines the fraction of evaluating module manufacturers actually adopting the renovation concept. The <trust MMs have in the RC> depends on the number of <MMs adopting the RC>. Increasing <trust MMs have in the RC> increases the <fraction of MMs adopting the RC>, which in turn again increases <MM adopting the RC>.

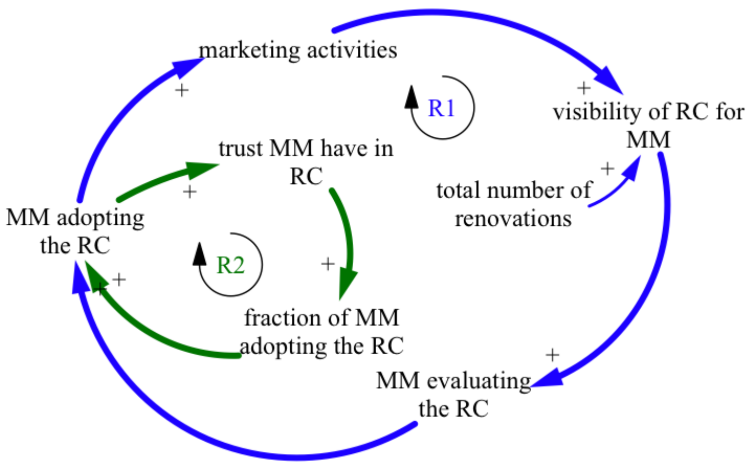

Figure 3: Reinforcing loops driving the diffusion process among module manufacturers.

4.2 Reinforcing Loops driving the diffusion process among building owners

As in the case for module manufacturers, a positive value of <total number of renovations> due to R&D avoids start-up-problems.

As the diffusion process unfolds, increasing <total numbers of renovations> increases <visibility of the RC for BO>. This ultimately translates into higher values for <total number of renovations>, by way of increasing the <probability that BO's become aware of the RC> and increasing the <number of BO's with need of renovation aware of RC> (loop R3).

While loop R3 can be said to create the potential of building owners aware of the renovation concept, loop R4 drives the fraction of building owners effectively implementing the renovation concept: Increasing <numbers of renovations> drive down <costs of the RC>, as learning effects and economies of scale allow for increasingly efficient production. Decreasing <costs of the RC> increase the <attractiveness of the RC for BOs>, thus leading to more renovations. The reason that <technological evaluation of the RC by BO> is modeled as a distinct variable, rather than lumped together with the variable <attractiveness of the RC for BOs> is because they represent very different concepts: While the result of <technological evaluations of the RC by BOs> strongly influences the <attractiveness of the RC for BOs>, the <cost of the RC> is not important when evaluating if the renovation concept technologically works or not. <Cost of the RC> however is an important component of the <attractiveness of the RC for BOs>.

At this point it is important to justify why the <technological evaluation of the RC> relies on the <attractiveness of the RC for MM>: This is because building owners have much less technological know-how and no experiences with the renovation concept. They have to rely heavily on the module manufacturer's opinion. Therefore, the more attractive the renovation concept is for module manufacturers, the more will they influence building owners towards a positive evaluation of the renovation concept. Additionally, the more marketing activities are carried out in the system, the more likely building owners are to get the information they require, thus increasing the evaluation of the renovation concept technology.

4.3 Balancing loops

The reinforcing loops described in the previous two subsections together with the fact that the number of module manufacturers is finite and the number of building owners entering and exiting the system is constant, can explain the case of a successful diffusion of the renovation concept. Figure 5 shows two balancing feedback loops (thick arrows) capable of shutting the diffusion process down. The feedback loops in thin and dotted lines

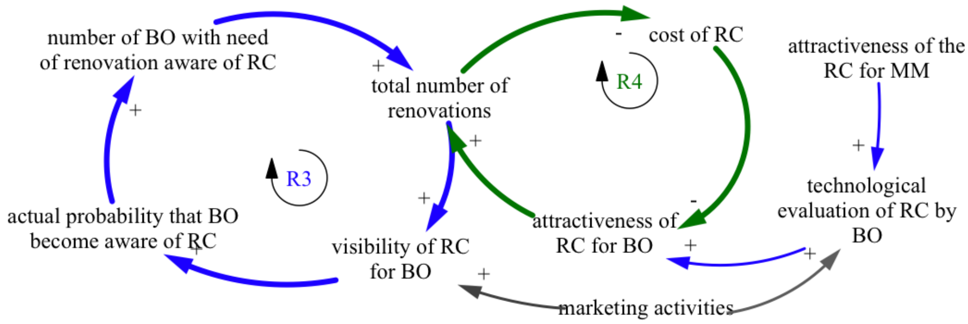

Figure 4: Reinforcing loops driving the diffusion process among building owners.

show additional loops that work in the background, increasing the shut-down-effect, that occurs once loops B1 and B2 kick in.

If the <fraction of renovations failed> exceeds the <tipping level of the BOs> (loop B1), the renovation concept is evaluated as an unfit technology, causing the <attractiveness of the RC for BOs> to drop, thus undermining the possibility for technological maturing, and "freezing" the <fraction of renovations failed> above the tipping level.

Loop B2 shows that once the <fraction of renovations failed> surpasses the <MMs tipping point>, module manufacturers start to abandon the renovation concept's adoption and reduce the <attractiveness of the RC> by creating <bad word of mouth>. This should strengthen the impact of B1, because it further undermines the <technological evaluation of the RC by BO>.

5 Selected Scenarios and their Implications

In the following, simulation results from three different scenarios are presented and discussed in view of their implications of the governance of the renovation concept's diffusion (see figure 6 for the phase plots of key variables). All the scenarios were derived from the same model, with only one or two differences in parameters. The three scenarios are:

- **Base model**: This first scenario shows a successful diffusion of the renovation concept across the two agents of the system.

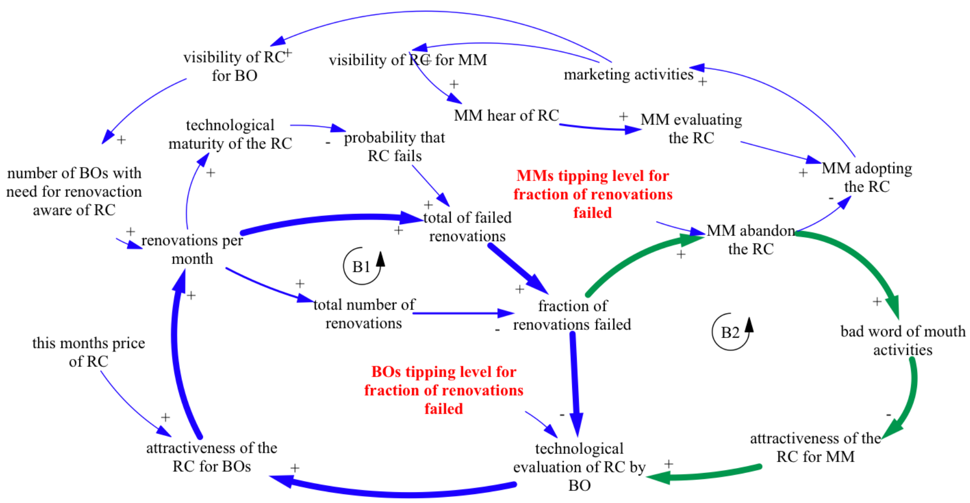

Figure 5: Balancing loops capable of shutting the diffusion process down.

- **Too early**: The second scenario shows a failed diffusion. The only difference from the first scenario is that the initial value of the variable <technological maturity of the RC> is reduced from 0.75 to 0.5.
- **Strong marketing**: The third scenario shows an even worse failure of the diffusion process. The difference to the second scenario is that the variable <average number of communications per MM per month> is increased from 25 to 50.

The message derived by comparing the scenario "base model" with the scenario "too early" is straightforward: If the renovation concept is put prematurely on the market, the number of failed renovations may exceed the tolerable amount and causes the system's agents to loose trust in the renovation concept. In that case, the negative feedback loops effectively shut the diffusion process down.

By looking at the phase plots for the "strong marketing" scenario it can be seen, that increased marketing activities in the case of unmatured technology just worsens things: Increased marketing activities for unmatured technology may just speed up its failure on the market, possibly adding increased marketing costs to the sunk costs of the failed diffusion.

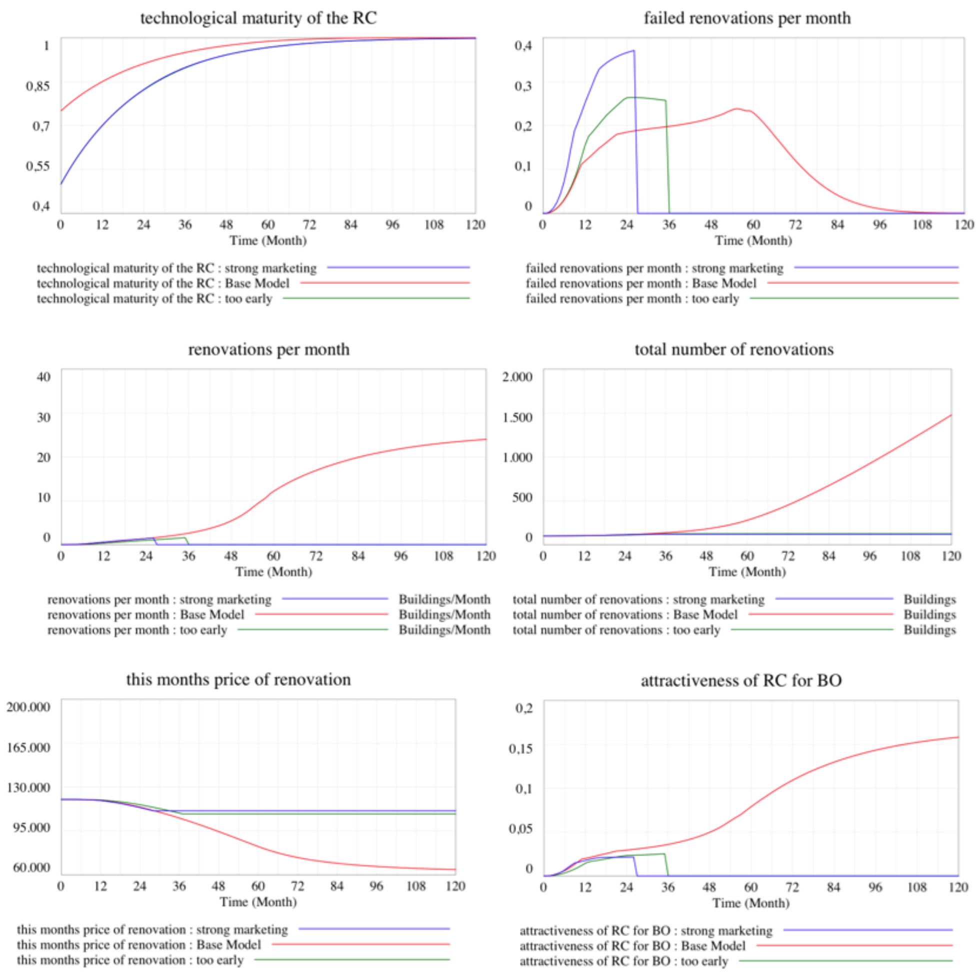

Figure 6: Phase plots of important variables' behaviour within the three scenarios.

6 Conclusions

This preliminary model of the renovation concept's diffusion dynamics was capable of producing behavior in line with expectations and produced two fundamental insights toward the governance of the renovation concept's diffusion: Bringing an innovation to the market before it has satisfactory levels of technological maturity risks destroying the innovation's credibility by producing too high levels of failed implementations. Increasing marketing efforts in such a case actually proves counterproductive, as it just speeds up the accumulation of bad implementations.

However, at its present state, the model is far from perfect. For example, including competition with conventional renovation technologies might prove insightful. Too, some causal links in the model should be made more explicit in the future, for example modeling in greater detail how increasing numbers of renovations lead to reduced costs by economies of scale. Calibration of the whole model and the functional form of soft variables such as "attractiveness" or "visibility" too needs further work. In addition, further work with experts representing the agents of the system needs to be carried out in order to increase the usefulness of the model.

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B Graphical representation of the whole model

Figure 7 shows the stock and flow diagram of the model in Vensim. In order to simplify the diagram, parameters that were modeled explicitly as variables were hidden.

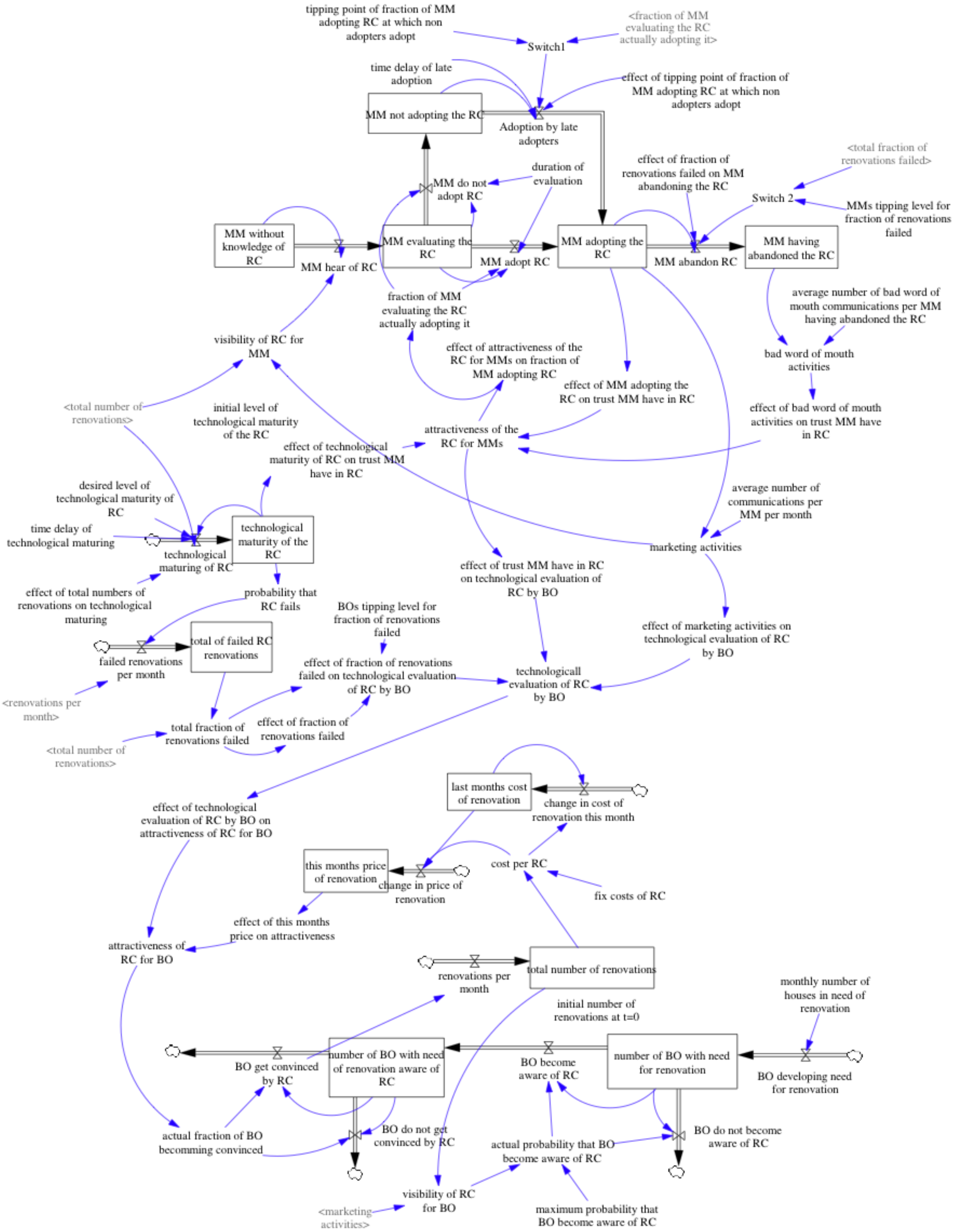

Figure 7: Stock and flow diagram of the model in Vensim.