Master Thesis

Strategic pathways to eradicate two infectious diseases:

An experimental study on dynamic decision making

in resource allocation task

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"For the things we have to learn before we can do them, we learn by doing them."

Aristotle

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Abstract

In such areas like infectious diseases management, resource allocation strategies are crucial, as they determine the livelihoods of people both in the short-term and in the long-term. Often, a specific geographic area is affected by several diseases that create a heavy burden on the society. As resources are usually limited, allocating resources, for example, to fund vaccination activities, becomes highly important and full of trade-offs. With managing infectious diseases there are multiple decisions that need to take place, the results of which will affect the situation in the future. Being demanding in general, dynamic decision making in such a domain becomes even more complex as there are people's lives at stake. Arriving at the understanding of how people will behave in such situations through field experiments is not only costly but also unethical. System dynamics-based simulators proved to be fruitful in the experimental research in dynamic decision making. The novelty of this research is in its application of a system dynamics-based simulator in an experimental setting to investigate the general strategic choices people make when they need to eradicate two competing diseases with a limited financial resource. In addition, the research strives to shed light on the possible reasons to why people do not pursue eradication strategy. The results provide an empirical evidence on the four general clusters of allocation strategies, with the majority of subjects who did not pursue eradication. One of the explanations for such performance is that even in the sparing conditions of the game, the context of the problem was too demanding for the subjects to correctly infer the results of their actions, use the provided information and based on that infer which strategy would lead to eradication. Further research should concentrate on assessing subjects' understanding of the underlying system and its effect on their decisions as well as testing a broader range of dynamic decisions in the simulator.

Key words: dynamic decision making, system dynamics, simulators, gaming, resource allocation, infectious diseases, epidemiology, strategy

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Introduction

Background Information

Fields such as systems and cognitive neuroscience, psychology, operations management, behavioral economics, and system dynamics focus on understanding decision making in socio-economic, environmental, industrial, financial and other domains. Dynamic decision making (DDM) occurs when decisions are made in an environment which changes continuously while a decision maker collects information about it (Gonzalez & Vrbin, 2007). These changes can be related to previous actions of a decision maker and to an endogenous dynamics of a system beyond a decision maker's control. Because dynamic decision making requires multiple adaptive decisions, high uncertainty, possible trade-offs, different alternatives, and constraints make this type of decision making more complicated and demanding compared to a single, one-time decision. The research into DDM includes observations on how people make decisions in a dynamic environment and what type of experience they use to formulate their actions.

Decision making in a dynamic environment is a challenging task, not so much due to people's inherent inability to process information and use it, but more due to the limited cognitive capacity humans posses (Sweller, Van Merrienboer, & Paas, 1998). The human brain can only keep 3-5 elements in its working memory (Gerjets, Scheiter, & Catrambone, 2004). This well-documented limitation does not allow people to take all information into consideration and perform complex manipulations with it. As people acquire knowledge, they create schemas that facilitate the application of known tools to unknown problems. The more experienced one is, the more schemas there are in one's long-term memory. In dynamic decision making there are several features that can be demanding for the decision maker: the interdependencies of the decisions, the changing environment that may or may not depend on the decision maker and the fact that the decision has to be made in real time (Gonzalez, Vanyukov, & Martin, 2005). Thus, in order to act, a decision maker needs to keep several elements in mind as well as take into consideration the effect of his or her previous actions.

Some decisions are successful, others are not. Although there are many factors that contribute to a certain decision's success or failure, understanding how people make decisions can help develop tools that support the decision-making process and make it less demanding for humans. As Forrester noted, people store most information in mental models (Forrester, 1992). Identifying the decision-making rules that people store in their minds sheds light on this complex process and allows the decisions to be improved. Since 1990 researchers have been actively engaged in studying dynamic decision making. Evolving technology has provided us with sophisticated software that captures the complexity of systems and of the decision rules that people apply. More recently, the use of computer simulations, or *microworlds*, (Gerjets et al., 2004) has played a big role in developing the field that investigates the DDM process. As Gonzales states, referring to Brehmer and Dorner, "microworlds have been hailed to bridge the gap between the laboratory and field research". These computer simulations control the characteristics of DDM tasks while still providing the context of the problem under investigation (Gonzalez et al., 2005). For the past 20 years, researchers have been using microworlds for different DDM domains: supply chain management with a classic example of the "Beer Game" (Sterman, 1989), fire management and the "Fire Chief" (Omodei & Wearing, 1995), ecosystem de-

velopment and the "Reindeer experiment" (Moxnes, 2000), peacebuilding and the "Peace Maker" (Gonzalez & Czlonka, 2010). These few examples examine strategic choices in resource management in different settings. The health care sector is another domain where allocating resources is a challenging task. Complexity and the internal dynamics of many health-related projects require dynamic decision making. Due to the fact that the health sector by definition is related to human lives and health, it is crucial that decisions made in this sector are successful.

Problem Formulation and Research Objective

There are several types of resources that a project requires, i.e., money, time, labor force, infrastructure, knowledge, and expertise. Monetary resources are one of the prerequisites for a project's success. Without thoughtful and timely investment, projects face a higher risk of failure. Already demanding, allocating resources becomes even more complicated when it is not sufficient to achieve a certain goal and when the context of a problem brings additional complexity and uncertainty. In the healthcare sector, infectious disease management represents a cluster of this type of problems. Its contextual complexity is formed by the non-linear relationships of infection transmission, delays in the development of a disease, as well as in detecting, reporting and responding to it. Often, a specific geographic area is affected by several diseases that create a heavy burden on society. As resources are usually limited, allocating resources when making decisions regarding infectious diseases becomes highly important and full of trade-offs. Among such trade-offs are ethical, socio-economic, cost-effectiveness and short-term versus long-term consequences.

Historically, the human race has proven to be committed to "winning the war" with infectious diseases, however, the only example of full victory to this date is smallpox. There are multiple factors and reasons why eradication programs have not been as successful as expected. The history of different projects related to infectious diseases and their results are a valuable resource of information on how decisions were made and what could be improved. However, to prevent the history of unsuccessful eradication repeating itself, it is important to understand how people behave when they need to allocate a scarce resource to fund, for example, vaccination activities. Arriving at such understanding through field experiments is not just very costly but also unethical, because experimental activities in this domain have real lives at stake. In addition, the problem with infectious diseases is that if financial support for vaccination is withdrawn before the threshold for safe cessation is reached, there is still a reservoir of infection that will lead to a new outbreak of the disease after a certain amount of time passes, risking that all the previous efforts would have been in vain. This suggests a demanding environment and the resource allocation decisions become dynamic.

Using computer simulators in order to observe what strategies people apply and what factors determine their preference towards one or another strategic decision can help in understanding why eradication programs might still fail, keeping other factors, such as infection resistance to a vaccine, budget volatility, external civil disturbance, certain and fixed. Computer-based simulation games have proven to be a valuable source for DDM research. Professors Thompson and Duintjer Tebbens have conducted a thorough study in the infectious diseases sphere, mainly focusing on poliomyelitis, but also exploring the general dynamics of infectious diseases and various managerial decision rules that focus

on disease eradication and control activities. However, there is scarce empirical evidence on how dynamic resource allocation tasks perform in the domain of infectious disease management. This research aims to provide empirical evidence for the general trends in dynamic resource allocation decision rules that people apply when faced with a task to eradicate two competing diseases with limited resources. In addition, the research strives to shed light on what information factors might drive certain decisions.

Literature Review

Eradication versus Control: Trends in Infectious Diseases Management

In 1993, the International Task Force for Disease Eradication announced over 80 infectious diseases as potential candidates for eradication, among which 6 were determined eradicable. In 1997, on the Dahlem Workshop on the Eradication of Infectious Diseases, participants gathered to discuss questions such as the definition of eradication and its biological, societal and political criteria; estimation of eradication costs and benefits; the time and the approach to implementing eradication programs (Dowdle, 1998). According to the results of that workshop, as Dowdle reports, the definition for *eradication* is the following: "Permanent reduction to zero of the worldwide incidence of infection caused by a specific agent as a result of deliberate efforts: intervention measures are no longer needed". Among other terms *control* is defined as "the reduction of disease incidence, prevalence, morbidity or mortality to a locally acceptable level as a result of deliberate efforts; continued intervention measures are required to maintain the reduction" (Dowdle, 1998).

As noted by these authorities, theoretically with the right measures all infectious diseases could be eradicated, however, in reality, some of them are more likely to be eradicated than others. Eradication programs usually come together with general health and non-health related projects. All of them require human and monetary resources. Given that resources are limited, making a certain decision is not always an easy choice. Besides biological feasibility, eradication programs need to meet several economic, social and political criteria. Eradication programs differ from ongoing health interventions and other projects in their urgency and sustained interventions, which if interrupted can undermine all previous efforts. That is why they are also defined by higher risks of failure and its consequences and higher short-term costs. They can fail when the resources are diverted due to a war, or another health problem (eradicable or not) (Dowdle, 1998).

These limitations pose a high need for thorough consideration on whether to commit to an eradication program. However, the benefits cannot be underestimated: improvements in public health and long-term cost-effectiveness, as after eradication is reached, activities can be ceased with no need for further surveillance. Eradication programs establish "high standards for logistics, surveillance performance, and administrative support" and as a result can attract potential sources of funding (Dowdle, 1998). Such programs also contribute to improving the expertise of medical staff and strengthening collaboration among partners and countries involved. In addition, setting future generations free of the fear and horror of the eradicated disease is an objective that we can strive for.

Despite enormous effort invested in eradication programs and high commitment among

stakeholders, only smallpox has been successfully eradicated (Fenner, Henderson, Arita, Jezek, & Ladnyi, 1988). Several eradication programs were launched but later abandoned. Although eradication was not achieved in these programs, they serve as a source of valuable information for better understanding of the complexity of achieving eradication goals (Dowdle, 1998). Recent initiatives prove that there is still the commitment to achieve a disease-free world.

Smallpox - the only story of success

Fighting infectious diseases in ongoing since the development of medicine and epidemiology as a specified field. Currently, only one disease is considered to be eradicated: smallpox. By 1959, there were 63 countries who reported the incidence of smallpox to the World Health Organization (WHO). After a year of reports revision, the incidence increased by 1.2%. The numbers were, however, considered to be incomplete due to the unknown degree of underreporting (Fenner et al., 1988). During the 12th World Health Assembly in 1959, the Director General of the WHO proposed an eradication program for smallpox. However, it took a considerable amount of time for the program to become active. Also, between 1966 and 1969, the program to pursue smallpox eradication was not sustained at full strength. Among the factors that contributed to the delay between the initiation and the actual implementation was that WHO focused on malaria eradication programs, thus the investments in smallpox eradication were occasional. Information available on the incidence of smallpox cases was scarce and not representative enough for the WHO to shift its priorities, and little effort was made to get more valuable information on the situation with the disease. Reports from different countries on activities undertaken were inconsistent in the quantity and quality of information provided. In the case of the People's Republic of China, it became a member of the Organization in 1973 and only reported on the situation 5 years later. From the incomplete reports it was anticipated that smallpox was under control in that area but was only proven by the WHO's team visit in 1978. In South and North America the regional programs did not stop; however, they also did not get much support from the WHO, which led to the resurgence of smallpox in 1963 in Peru. For most African countries, smallpox had less attention and focus compared to other health concerns, at least until the epidemic would break out. In general, even without sustained and continuous support, countries worldwide achieved impressive results in combating the disease. Once again, this information could have been underreported to the WHO, which made the reports more pessimistic than the reality providing a push for an intensive eradication program (Fenner et al., 1988).

Eventually, after seven years of preparation, the smallpox eradication program was launched in 1967. Despite the fact that smallpox was a good candidate for eradication, there were several reasons for the inertia towards commitment to the eradication program. As with many eradication programs, its roots are in the vector control programs, as is the case with malaria, and these are the most costly projects undertaken and abandoned. There was also insecurity about the success of the program in African countries due to inadequate infrastructure. The emphasis on malaria drove the WHO's lack of interest and concern about smallpox. However, the sustained effort and attention towards smallpox from the USSR provided a solid motivation to pursue the eradication program. The USA has also contributed to strengthening idea by its commitment. Despite all this,

the Director-General of the WHO was rather skeptical about the success of the program, believing it to be impossible to achieve.

Notwithstanding the slow process, up to now, the smallpox eradication program is the only successful one. Among the factors that contributed to its success, four are distinct. There was the authority of the World Health Organization that governed the collective implementation and sustained commitment (in terms of budget and willingness to pursue the program), even when the strategy seemed to be less optimum for some countries. There was a well-developed, inexpensive, simple, but comprehensive plan, that governed the program, which focused more on the principles and methodologies than directives, giving autonomy to individual areas to develop their own implementation plans. Lastly, but not least, the well-trained staff and the ongoing research contributed to combating the disease (Fenner et al., 1988).

As a result, it can be noted that despite the problems including an irregular or insufficient budget, delays in reporting, civil and natural disturbances, and the initial lack of necessary attention, the smallpox eradication program was a success due to sustained efforts and commitment.

Malaria, yaws, poliomyelitis - the many stories of continuous battles

Malaria

Carter and Mendis report on the history of the fight against malaria (Carter & Mendis, 2002). In Europe and North America, the improvement in general health care and the infrastructure reduced contact between humans and vector mosquitoes, which eventually caused a decline in incidence and by the 1960s these parts were cleared to be malaria-free by the WHO. Asia, the Western Pacific, and Africa carried a higher burden. In the case of Asia, great effort during the national campaigns of the 1940s - 1950s brought the incidence down to very low levels, almost impossible to detect. However, these were not the overarching results for all countries in these geographical areas. For many countries the costs posed by the eradication program were unsustainable, so the program was abandoned. The situation was worsened by the resistance that mosquitoes developed towards the treatment. This led to the resurgence of malaria to previous instance rates. In Africa, this problem differed from all the other areas in both human and biological terms (Carter & Mendis, 2002). There was a substantive scepticism that an eradication program would work in that area due to the size of territory that had to be covered. Another concern was the waning immunity of the elderly generation, which put the whole effort at risk of disappearing. Nevertheless, the goal of eradication of malaria remained sound up until 1996, when it was eventually abandoned in Africa as well as in other malaria-endemic regions. Despite enormous efforts and successful results in some countries, there are still those left with the burden of malaria, which means that the goal of global malaria eradication was never reached. Several reasons point out what could have been the causes of failure. One of them is the general vertical approach of eradication programs. In countries on the African continent, administration activities characterized by this approach, especially in remote areas, were constrained by the large areas that had to be covered coupled with poor environments in terms of resources. Moreover, it disrupted the delivery of general health care. Malaria is referred to as the disease of poverty (Carter & Mendis, 2002). And this becomes a trap in itself: a country cannot reach prosperity without eradicating

the disease, however unless it has the necessary resources it will not be able to win this fight. As of today, the situation at hand is such that countries in Asia, South America and Africa are left with the burden of malaria under control programs.

Yaws

Another example of a control and eradication program that was initiated but did not reach the ultimate goal is the fight against yaws. The first attempts of control policies regarding yaws were proposed during the "First International Symposium on Yaws Control" in 1952 (Antal & Causse, 1985). After the first national campaigns in Haiti, Mexico, and the former Yugoslavia, mass treatments were available in 46 countries. With support from the World Health Organization (WHO) and the United Nations Children Fund (UNICEF) the initial goal of the program was formulated as a control policy: to reduce the prevalence of the disease to a level that will stop it from being a threat to public health. A rather rapid decline in incidence became an encouraging incentive for the control policy to shift to eradication. Yaws eradication was another example of a vertical disease-specific program, and soon enough it was clear that such an effort could not be sustained, which meant that activities for yaws eradication were to be transformed into general health care services. The plans included the development of the infrastructure in rural areas for control and surveillance of incidence to reduce the disease level. However, the continuous surveys lost their priority. At the onset of the campaign, total mass treatments were the prevalent policy, no matter what the prevalence of the disease, which brought the level of incidence down dramatically (Antal & Causse, 1985).

Success stories were not immediate for all regions, as in the case of Togo where treatments had to be repeated due to the low initial coverage. But overall results were so impressive that initial plans for rural development got less attention as part of the final steps of the eradication program. It was thought that improvements in socio-economic conditions and hygiene (which did not appear according to expectations) would help with reducing the disease incidence. The rather ignorant notion regarding latent cases among children, who constituted a reservoir of the disease, also contributed to the resurgence of yaws in later years. In 1965, mobile teams responsible for treatment and surveillance were pulled back and resources were diverted to other campaigns (like malaria and cholera). As the development of the infrastructure in rural areas for regular surveillance and treatment was never brought to life, the necessary control over the situation with the disease was limited. The failed hope for environmental, hygienic and socio-economic improvements to contribute to finishing yaws, coupled with the diverted focus of resources to the management of other diseases, the failure in implementing the continued control activities and the remaining pool of infection in populations, caused yaws to reemerge and spread into areas where eradication was previously achieved.

Such was a case in Ghana (Agadzi, Aboagye-Atta, Nelson, Hopkins, & Perine, 1985) where the resurgence of the disease forced the government to initiate and implement a set of new mass treatments between 1981 and 1983 together with campaigns against yellow fever (Agadzi, Aboagye-Atta, Nelson, Perine, & Hopkins, 1983). As noted by Antal and Gausse, "most of the cases occurred in very remote areas, exactly the places where the continuous activities for treatment and surveillance were not satisfactory and most of the cases accumulating during the time when eradication was considered to be reached and the intensity of treatments were at their lowest level" (Antal & Causse, 1985). The resurgence of the disease has been reported in Sierra Leone, Central African Republic,

Gabon, Ghana, Senegal. And even though reporting on the incidence might not be 100% reliable, "governments are usually aware of the problem". This fact brought the focus back to yaws control activities in the form of resolution WHA 38.51 to the WHO for support. The example of yaws management in countries that experienced the resurgence and were forced to repeat efforts can be an example of wavering (shifting the resources) and as a consequence, failure to eradicate. With the remaining pool of infection, previous efforts were in vain, calling for new programs to bring the incidence of yaws back to acceptable levels.

Poliomyelitis

In 1985, regional programs in South and North America initiated the effort for polio eradication (Arita, Nakane, & Fenner, 2006). Peru reported the last case in 1991 and three years later the WHO certified regional eradication programs. Four years later, the success with these programs incentivized launching the global polio eradication program setting the year 2000 as a target for the last case, which was achieved in the Western Pacific. However, for other regions, the goal was far from being fulfilled. For the territories of India, Middle East, and Africa there were "still 23 nations reporting cases" (Arita et al., 2006). After efforts were intensified, by 2005, the number was reduced by 7, leaving 16 countries still experiencing incidence of polio. As Arita et al. report, there were four main differences compared to smallpox for why eradicating polio became more difficult and was not achieved. The difference in biological characteristics in sub-clinical cases of polio does not have a typical clinical picture once someone is infected, making these cases "invisible" for detection and treatment. The vaccine-derived polio infection was less contagious but still added an additional threat to the success of the program. Socio-economic changes added up due to increased population (compared to what was present globally during the times of the smallpox program). As with malaria, the polio burden is mostly borne by poor nations. As an eradication program requires a substantial effort, the administration and assistance costs are simply unsustainable for poor nations. The global commitment during smallpox was supported by the two world super-powers (USA and USSR), however, the vaccination against polio was seen to be ineffective and was thus abandoned in Sub-Saharan Africa and Indonesia (Arita et al., 2006).

Arita et al. advocated that the policy for managing poliomyelitis shift from eradication to control. Among the reasons provided are the prolonged time horizon required for eradication (it took 10 years in total for smallpox, but is already more than 20 of the ongoing effort for polio eradication). The belief was that eradication was an unrealistic goal and the diverted resources could have been used for financing other health-related projects e.g., general health services or investments into programs against other threatening diseases such as AIDS and malaria. However other scholars believe in the global benefits of polio eradication (Thompson & Tebbens, 2007), (Barrett, 2004), (Sangrujee, Duintjer Tebbens, Cáceres, & Thompson, 2003). There are multiple research articles investigating the pros and cons of eradication, as well as possible financial and health burden posed by the disease in different scenarios under control and eradication strategies. As Thompson and Duintjer Tebbens (Thompson & Tebbens, 2008), (Duintjer Tebbens et al., 2005), (Tebbens & Thompson, 2009) explore, long-term focus proves eradication to be optimal in terms of cumulative cases and total costs constituted by a certain policy. Barret (Barrett, 2004) and Sangrujee et al. (Sangrujee et al., 2003) explore the economic tradeoffs and the decision options for the years following eradication, in case it is achieved.

Current initiatives and possibilities for the future

Current research does not give up on infectious diseases and numerous foundations are investing in activities aimed at combatting infectious diseases. A few examples are the Bill and Melinda Gates Foundation (`https://www.gatesfoundation.org/`) together with the Medicine for Malaria Venture (MMV; `https://www.mmv.org/`) are committed to continuous efforts to eradicate malaria; the Global Polio Eradication Initiative (GPEI; `http://polioeradication.org/`) focuses on polio eradication in the three endemic countries: Pakistan, Afghanistan and Nigeria. which focuses on polio eradication in the three endemic countries: Pakistan, Afghanistan and Nigeria. Ongoing research into vaccines and more innovative measures, sustainability of efforts, the economic and health burden posed on society, the trade-offs and realisticity of eradication versus control, is in constant progress. Decisions made today affect the situation that unfolds in the future. In the presence of limited resources, competing alternatives and uncertainties, it is never easy to make a decision and act. However, understanding why a certain sub-optimal policy might be preferred by a decision maker may shed light on the factors that influence peoples' choices when it comes to managing infectious diseases. From the historical point of view, such factors can be identified that affect the decision making process: goal formulation and the commitment to this goal, reporting on incidence and prevalence of the disease, feasibility of eradication, socio-economic and hygienic conditions, available resources, time span required for a certain program, competing alternatives (be those other infectious diseases, general health care services, or even nor health-related projects), and/or other events that can disturb sustained efforts, such as lack of infrastructure to pursue an intensive campaign, wars or other civil disturbances..

In the experiment, I seek to identify general trends in resource allocation strategies that people apply and potentially what factors influence their decision to attempt eradication or to favor other strategic options. I adopt the model developed by Duintjer Tebbens and Thompson (Tebbens & Thompson, 2009) and their hypothetical setting with two equal infectious diseases, a fixed budget, and a constant population size. The two diseases are good candidates for eradication, however, the available budget is insufficient to achieve parallel eradication. The limited budget represents one of the constraints discussed in the literature. As resources are usually limited, it is difficult that every project gets the required funding. The two infectious diseases represent the possible trade-offs which can affect the commitment towards one or another strategy as discussed in the literature. As the authors of the original model mentioned, having two diseases that are identical is a rather artificial assumption, however, it is suitable for a generic investigation on the decision rules people choose and eliminates possible emotional bias or preference towards a certain specific disease. Moreover, every disease can be considered hypothetically equally important, as they all affect human lives. Commitment to a certain strategy is also discussed in the literature as a factor for success. In the experimental setting, the budget constraint requires a player to commit to an eradication strategy long enough and aggressively enough to achieve it. The way a goal is formulated also affects the type of effort that is performed and is therefore used as one of the variable factors in the experimental setting. Despite the fact that cost-effectiveness plays a big role in investment decisions, I did not wish to complicate the decision-making process and aimed to keep the control variables to the minimum level. This would help test whether the factors examined have a significant effect on decision-makers, but also increases the validity of the analysis; more variables bring more instability and inconsistency into the experimental results, which

would not be feasible to properly analyze in the scope of this research.

Understanding the Dynamic Decision Making

As defined by Größler there are basically two purposes for using computer-based simulators (games): teaching and experimentation (Größler, 2004). The former one is better represented by the Interactive Learning Environments (ILE) where the overarching goal is to improve subjects performance by providing different sources of guidance. The belief is that certain activities and different ways of presenting the information, as well as different types of information, can enhance the problem understanding, and as a consequence lead to better results when interacting with the game on a dynamic decision task. The later, on the contrary, use the game to explore the decision rules that people apply and possibly provide with some kind of explanation for certain choices that people make. Both research streams are equally important, however teaching for something, or against something has to be built upon empirical evidence of a certain level of performance in the task under investigation. As dynamic decision making (DDM) is an inevitable component in many fields, empirical exploration of the decisions made by people in different settings provides with a solid platform for suggestions on what might be the causes of sub-optimal decisions and how to improve the process of DDM in complex tasks.

The Beer Distribution Game (BDG) represents a classic example of dynamic decision making and problems associated with it. Pioneered and motivated by Sterman (Sterman, 1989) a lot of research has been focused on investigating the causes behind a robust "bull-whip effect" (amplification of orders upwards the supply chain). Computer-based simulations of the classic Beer Distribution Game were used to study the dynamic decision making. Among the many various examples, Yan Wu and Katok explored the effect of learning and communication. For their experimental setting, they used 3 x 2 design with three types of training and two types of communication possibilities. After analyzing the results of the game performance the authors concluded that besides the commonly known operational and behavioral causes for the bull-whip effect, partial influence might come from the "insufficient coordination between the supply chain partners" (Wu & Katok, 2006). Croson et al. provide empirical evidence for another possible explanation of such phenomena in the supply chain distribution - the coordination risk (Croson, Donohue, Katok, & Sterman, 2014). Oliva and Gonçalves investigate further into behavioral aspects of the bull-whip effect and also use computer-based BDG to empirically support overreaction to backlogs as a reason, "previously ignored" in the literature (Oliva & Gonçalves, 2007).

Computer simulations and games are also widely used in studying dynamic decision making in the humanitarian setting and peacebuilding. The current work in progress of Paulo Gonçalves focuses on the implications of competition for the scarce resource in the emergency response. A computer-based game "Humanitarian Aid" places the players in a situation of a continuous decision-making process, where they have to decide on allocating the resources between the more versus less approachable sites. Gonzales and Czlonka explore the decision making in a dynamic task of finding the solution for international conflict and building peace (Gonzalez & Czlonka, 2010). The "Peace Maker" is an online game "inspired by the Israeli-Palestinian conflict" (Gonzalez & Czlonka, 2010). In the game, the players need to decide on certain policies in order to achieve the satisfaction of both

sides. The treatments differ in the initial role a subject plays: starting as the Israeli Prime Minister or as the Palestinian President. The inquiry pursued by the authors focuses on acquiring the empirical evidence "to build theoretical models of the socio-psychological variables that influence DDM". The variables under control are the personal characteristics of the participants as well as the initial setting of the game on the diversity of actions performed and it's overall effect on performance. Using a computer-based game proved to be a fruitful tool to provide the researchers with interesting results.

Ordering behavior and inventory management is another classic example of DDM illustrated through a newsvendor and the newsstand problems. Several research articles dove into the problem of decision making for ordering different items under various settings in order to explain the general underperformance of subjects in this type of tasks. The results of the experiments from Castaneda and Gonçalves shed light on behavioral aspects of inventory management problem (Castañeda & Gonçalves, 2018); Villa and Gonçalves investigate the importance of delays in ordering behavior (Villa, Gonçalves, & Arango, 2015) and Davis investigates on the behavioral models in the pull contracts in supply chain management (Davis, 2015). These few examples also use computer-based games for their experimental setting.

Another domain that involves DDM tasks is the management of the environmental resources and sustainability of the ecosystems. The classic example in this setting is the problem of common pool resource management. A pioneer in this setting is the "Fish banks" - a simulation game developed by Dennis Meadows, John Sterman, and Andrew King. The game provides an exploratory platform for learning about the complexity of marine ecosystems and their vulnerability under unsustainable managerial strategies. The most common application of this game is however for teaching and learning purposes. Moxnes develops several experiments in different contextual settings in the domain of sustainable development and managing common pool resources. For his experiments, he uses computer-based games for fishery and reindeer stocks management. His endeavor focuses on the misperceptions of stocks, flows and the non-linearities in the "renewable resource management" (Moxnes, 2000).

The few examples above demonstrate that using simulation games in experimental research can provide a flexible tool for almost any type of inquiry when it comes to studying DDM by keeping desired factors constant and allowing for others to vary. The contextual setting defines the control variables for each research, be those technical parameters of the underlying model (delays or the complexity of feedback), the difficulty of a task that for the subjects, or the behavioral aspects that are governed by human cognitive decision-making processes. In each and every case, however, it is a question of choosing a narrow set of variables, that are hypothesized to have an effect on a certain outcome and a suitable experimental design to support the inquiry.

Simulators in the Medical Setting

Healthcare represents an enormous sector of application of System Dynamics models and simulators. The variety of topics covered ranges from understanding the dynamics of a specific disease to understanding the dynamics of the whole health care system; microworlds are also used for policy experimentation, testing, and assessment; to encourage

learning and enhance systems thinking; to bridge the gap between the analysts and the decision-makers.

Among the examples of using system dynamics based simulators in a form of Interactive Learning Environments (ILE's) are the famous models created by Gary Hirsch, Jack Homer, and their colleagues. The most common application of the simulators in a medical setting is, what Größler (Größler, 2004) and Davidsen (Davidsen, 2000) define, for learning purposes and exploration. However, to my knowledge, there is less empirical research done with the use of simulators in this field for investigating the decision making processes.

Homer has developed a simulation game "By prescription only" (Homer, 1985) which focuses on the decisions about the availability of a new clinical product and it's exposure. This game can be one of the first applications of system dynamics models in a medical setting in a form of a game. The experiments he conducted were, in part, for identifying the necessary improvements to the game. Another objective was to develop a user-friendly tool, that would allow policy testing for the decision makers who do not have the technical knowledge of system dynamics. The experiments with the game provided the author with some insights. For example, the high complexity of health policy can be rather demanding, and, if not only, understandable to just a limited number of people. This brings to the light the need for research into the factors that impact decisions that people make in the healthcare sector. Another example of using an ILE is the "Heath Bound" simulator developed for integrated policy testing for the US health system (Milstein, Homer, & Hirsch, 2009). Once again, the gaming interface aims at providing an accessible tool for experimenting with different policy options in order to improve the "troubled" health care system in the country. The players can apply different sets of policies and are encouraged to learn from their actions based on the output feedback provided in the simulator. The application is learning-oriented and there is not a way of inferring the reasonings for one or another policy choice from the players. Another application of the aforementioned model version was used to construct a student competition for the best health policy option developed by a collaboration of Network of Schools of Public Policy, Affairs and Administration (NASPAA) and the Rippel Foundation (McFarland et al., 2015). LeClair et al. developed their simulator as a decision-support tool for controlling the infectious disease outbreaks. This particular example uses an infectious disease as a lens for policy exploration. The overall structure of the underlying model combines the full complexity of the dynamics of an infectious disease as well as the critical infrastructures that are interdependent with the problem of managing an infectious disease outbreak (LeClaire et al., 2007).

In the sector of healthcare, there is a broad variety for dynamic decisions: management of a new drug or vaccine development; testing and launching; policy setting for combating infectious and chronic diseases; prevention versus treatment trade-offs; allocation of limited resources; maximizing benefits and minimizing costs. All these have to be done in an uncertain, dynamic and complex environment with the first and foremost goal in mind - saving people's lives. Decision support tools and ILE's are an essential tool for helping the decision-makers make better choices, bring the various stakeholders together to tackle messy problems and help them find feasible solutions, experiment and learn from their mistakes in a safe environment. However, despite the broad application of simulators to study the dynamic decision making in other fields, the healthcare sector seems to be left behind in this regard. Using simulators and model-based games for research purposes can shed light on the possible reasons for various decision rules. The healthcare sector

represents a fruitful platform for experimentation and investigation on the dynamic decision making and tasks such as resource allocation is as crucial in this sector as in any other. Allocating scarce resources in health-related projects is challenging for a variety of reasons, thus investigating the decision rules that people apply in this setting and the reasons behind a policy choice can bring insights for further research into developing better policies and better decision support tools.

Methodology

Research Strategy & Methodology Choice

The research aims to provide an empirical evidence of the decision rules that people follow when they are faced with the problem of resource allocation in the presence of competing alternatives and limited resources. Moreover, the aim of the research is to investigate what are the factors that influence a certain strategy choice. Thereafter, the research is explorative in its nature. Following the post-positivist philosophy as defined by Creswell, the experimental design supports this research inquiry the best, as it strives to "identify and assess the causes that influence outcomes" (Creswell, 2014). In the domain of immunization activities and budget allocation field experiments are either impossible or very hard to conduct due to various reasons such as, for example, ethical considerations or (and) time span required to observe the results; high costs associated with the resources and infrastructure required for the experimental setting.

As was stated previously, microworlds as Gonzales refers to them are a fruitful tool for studying DDM (Gonzalez & Czlonka, 2010). In the past 15 years "system dynamics-based interactive learning environments (ILEs)" have been widely used and applied for learning and research validation (Davidsen, 2000). As Davidsen explains, using ILE's for validation includes exploring people's mental models that govern their decisions in complex and dynamic environments. In this way, ILE helps to gather evidence on what kind of information people take into consideration and how they use it when making a decision. Ultimately, this process can help a researcher "form a hypothesis on why people fail to succeed when operating in such domains" (Davidsen, 2000). Simulations based on a system dynamics model nowadays provide the opportunity for the user to experiment with parameters that determine the strength of a policy, or explore policy combinations. However, predefined policy sets do not provide the room for genuine experiment. If people have to choose from the options that are provided, it is not always the type of a decision they would make on their own.

According to the taxonomy developed by Maier and Größler (Maier & Größler, 2000), the tool that Gonzales and Davidsen propose for the purpose of studying DDM falls into a category of gaming-oriented simulators. For the purpose of my research, I decided to run an experiment, for which I developed a system dynamics-based gaming-oriented simulator, later referred as a "game" or "Resource Management Simulator". By allowing people to make their own decisions I expect the experiment to shed light on the general decision rules people follow as well as information that they take into consideration.

Experiments based on using a simulator, combine features of the controlled setting and allow the subjects of an experiment to experience the context. As the nature of the

experiment is a human-computer interaction, the costs of conducting it as well as the risks associated with it are minimized. I use a system dynamics-based simulator and a mixed survey with closed-ended and open questions. The two tools help me to collect the data on the actual decisions made while interacting with the simulator and the reasoning behind these decisions.

Data Collection & Analysis

Data collection method

I replicate the model that was developed by Duintjer Tebbens and Thompson (Tebbens & Thompson, 2009) in Stella Architect software (`https://www.iseesystems.com/`) and publish the game on the online server isee Exchange (`https://exchange.iseesystems.com/`). The server allows data collection for each decision entry point, as well as other data points that result from the decisions made by the participants. The game output results are anonymized by the participant's individual number (game ID). The access to the data on the server is restricted to my personal isee account, so no other third party can get access to the data without my permission. I set an experimental setting with 4 different treatment groups, that are discussed in greater detail in the section Experimental Setting The experimental groups should provide with the factors that explain subjects' strategic choices.

I develop a survey using Google Forms (`https://www.google.com/forms/about/`). This program supports the output results in both languages (English and Russian). The responses are anonymized in the same way by using a participant's ID number. The survey contains closed questions regarding general demographic and background information and open-ended questions for the clarification of the reasoning participants had while interacting with the game. The full version of the questionnaire (in English) can be found in the Appendix D and in Russian upon request.

Sampling

I acquired 172 people to participate in this research. I intended the participation in the research to be solely on a voluntary basis and did not include any monetary or non-monetary incentives for the subjects. I recruited the subjects for the experiment through different Internet platforms. The information about the research and the invitation to play the game was posted on 3 social media platforms: Facebook, Instagram, and Vkontakte. The participants were also acquired through a snowball technique via recommendations of people who played the game to the other people they knew would be interested to participate. The data collection lasted from 25th April 2018 to 23rd May 2018. I acquired most of the subjects within the first two weeks of the data collection period. After that, I have experienced a saturation of the pool of potential players. According to the central limit theorem, the minimum sample size equals 30. I stopped recruiting the subject once I reached the number of 30 subjects per treatment, for who there was fully recorded data in the isee server and an associated response in the Google survey. The procedure resulted in making it a total sample size of 120 people with an equal distribution of the

participants between the treatment groups. Due to the time constraints, I have decided to stop recruiting the participants as it would make a feasible sample size.

As I am not testing demographical effects on the outcomes of the decision making, the heterogeneity of the population is not an obstacle for the research. The profile of subjects is diverse: female and male participants with the age range from less than 24 years old to 45 years old. Participants are either English speaking (not necessarily their native language) or Russian speaking (native language). The subjects' background range from those who have high school as their highest completed level of education to those who have obtained a doctorate degree. Current occupation of the subjects ranges including unemployed people, students, and the working population. The knowledge on or the experience with system dynamics and immunization activities also range among the subjects, providing with some participants who had elementary to moderate experience in system dynamics and some who have been involved in vaccination projects. The sample size is a diverse group of individuals, with different backgrounds and experience. In real life, people who have experience in the field are mainly the ones who make the decisions in the domain of vaccination. However, it would be unreasonable to get actual decision-makers to participate in the current research due to monetary and time constraints. Instead, I use a more demographically diverse group to control not for the experience and background knowledge that drives their decisions, but for the general reasoning that people follow when confronted with a specific task. In addition, Frechette reports on the empirical evidence (Frechette, 2015), that the difference in performance between the students and the professionals is small in a variety of tasks. This strengthens my choice of the subjects sample for the experiment.

Data analysis

I adopt sequential data analysis approach (Creswell, 2014) firstly focused on the literature, then the output of the survey and then the game output. The literature analysis provides me with the theoretical framework that I adopt for the experiment. The game output and the survey provide an empirical evidence for the decisions that people performed. I use econometric models to investigate what information had bigger emphasis on the decisions of the subjects and perform several statistical tests to validate my results. I use R open-source software (`https://www.r-project.org/`) for all my calculations.

Research Ethics

The exploratory nature of the research inquiry includes primary data collection and analysis through the interaction with the game and a questionnaire. Denscombe identifies 3 themes shared by all the "codes of research ethics" (Denscombe, 2012). With regard to these themes, I address the question of research ethics as follows.

No harm to participants. The isee Exchange server collects the data from the interaction with the game automatically. All the players need to fill in the questionnaire upon the completion of the game. An individual number (game ID) protects the player's identity and allows matching the game output with the survey results. Using such an ID system allows me to eliminate the possibility for identification of a particular subject of the experiment. There is no physical interaction between the subjects and the experimenter.

The topic of the research can be sensitive, but only to an extent of how each individual perceives the infectious diseases' threat and burden on the society. However, the "safe environment" of the game allows minimizing the risk for participants to develop highly sensitive emotions with regard to the problem. As a result, the threat to the psychological and physical well-being of the respondents is insignificantly minimal.

Voluntary consent. All the data collected during the experiment will be carefully treated with anonymity. Before All the data collected during the experiment will be carefully treated with anonymity. Before completing the questionnaire the participants need to consent for data collection, analysis, and storage for potential future research. I will not distribute the primary data elsewhere, and will only be the only person who is treating the information. Participation in the research was voluntary and the participants were free to withdraw at any point in time if they did not feel comfortable in further participation. In case a participant did not agree for the data collection and treatment, I eliminated the results of that subject from the research analysis.

Scientific integrity. The design of the research aims to achieve the research objective and thus the tools used throughout the research are suitable and valid. All data analysis, manipulation, and provision is done in line with the ethical principles guiding the research, developed by the British Psychological Society: "Ethical Principles for Conducting Research with Human Participants" (Denscombe, 2012) and the research integrity requirements of Radboud University and the University of Bergen on the master thesis.

Model Description

Model from Duintjer Tebbens and Thompson

For the basis of the game, I replicate a model developed by professors Duintjer Tebbens and Thompson (Tebbens & Thompson, 2009). The model is generic and is not tailored to any particular disease, which made it suitable for the current research. Focus on specific diseases would eliminate the generic nature of the research and possibly bias the participants to favor one disease over the other. The effect of such subjective preference based on personal values and experience would be difficult to control in the experimental setting as well as assess later on. Keeping in mind, that no such situation could happen in real life, I still decided to go with the generic model and the hypothetically equal disease, in order to investigate the dynamic decision making with a task of limited resource allocation between two competing diseases.

In their article, Duintjer Tebbens and Thompson focus on the hypothetical model of two infectious diseases and the limited budget that is available to fund the immunization activities. The authors explore the dynamics driven by 5 different decision rules with the aim to explain different policy commitments. Among the decision rules tested, they use 3 control policies and two eradication policies. Among control policies are

- equal resource allocation full term;
- allocation of the full resource to the most pressing disease;
- allocation proportionally according to the prevalence of the disease.

The two eradication policies represent sequential eradication. This is done by allocating the full resources to one disease and then allocating the full resource to the other disease. The difference in the two eradication policies is in the lowest threshold that has to be reached before the immunization activities for a certain disease are ceased. The first eradication policy takes 0 cases per year as a threshold, and the second one has 1 as the threshold below which the disease can be considered eradicated. Duintjer Tebbens and Thompson motivate the second eradication policy to be more realistic as the vaccination can only be ceased after confirmation, which in turn is based on the perceived incidence to reach a "sufficiently low level" (Tebbens & Thompson, 2009). The feature of perceived incidence formulated as an exponential smoothing makes it impossible to reach 0, which as noted by the authors makes the chosen threshold of 1 remain artificial. For their research professors construct a stochastic model and conduct the iterations in Mathematica software.

I replicate the deterministic version of their model using Stella Architect software. The main difference in the behavior of the deterministic and stochastic models, as also reported by the authors, is in the inherent randomness, a feature of a stochastic model missing in the behavior of a deterministic one. Nevertheless, for the purpose of the current analysis, I decided that the deterministic model will be sufficient enough as it represents the main dynamics of an infectious disease. Moreover, there are multiple examples of infectious diseases modeled as a deterministic model (Sterman, 2000).

Deterministic Model

The model equations of the deterministic version of the model can be found in the Appendix G. For the game purposes, I disable the decision rules described the Duintjer Tebbens and Thompson in their article which also disables one of the feedback loops that governs a vaccination policy based on the perceived incidence. This, in turn, is represented in the information provided to the participants in order to test whether they base their decision on the provided information. In the deterministic model, the fractional formulation of the flows in the infectious models will always contain a small fraction of infection. Thus, if not forced otherwise, the disease will always be reintroduced into the system driven by this specifics of the model. After a consultation with the authors of the model I decided to follow their advice and for the purpose of the research I formulate the flow of infectivity to remain 0 once it crosses a sufficient threshold < 1. I have conducted sensitivity tests and validated the model against the results reported by Duintjer Tebbens and Thompson. The model proved to behave in a reasonable way, reproducing the expected results with all of the policy rules that are described in the article. The units are consistent and there is no violation of conservation of matter.

Resource Management Simulator

General Description

The Resource Management Simulator" can be found by following this link `https://exchange.iseesystems.com/public/olga-poletaeva/resource-management-simulator`

The Resource Management Simulator is a simulation game based on the system dynamics version of the model described in the previous section (Tebbens & Thompson, 2009). In the game, a player is appointed to serve as the Minister of Health in a hypothetic country named Nayonda. A player has to make annual decisions on the budget allocation, that will fund the immunization activities for the two diseases that are present in the country. There is a limited budget that a player can use and a reporting delay. The budget is set constant and is defined as 75% of the total need in order to achieve parallel eradication, as originally used by the authors. The perception delay varies depending on the treatment group. There are two chances to play the game, each consists of 20 years. The game starts in the equilibrium condition. That is if a player does not allocate any budget to any disease the resulting behavior of the system will be an equilibrium.

Interface Design

I have developed the game in two languages: English and Russian. As Russian is my native language the risk to lose the meaning and create misinterpretations due to translation from English is minimized. The Russian and the English versions of the interface are identical and follow the same sequence of information presentation and activities that a player has to perform. There are 6 main pages in the interface of the game. Sample screen-shots of the interface can be found in the Appendix B.

- **ID Entry Page**

On this page, a player has to enter the personal ID number, with which he or she can then follow to one of the 4 treatment groups. Depending on the personal ID number that each player has, there are 4 buttons that direct the player to a certain treatment group T1, T2, T3, T4. The player knows which treatment group he is assigned to by the last number of his ID.

- **Navigation Menu Page**

This is the central page of the game navigation. From this page a player can choose between three options: read about the historical development, read the instructions, play the game.

- **Historical Development Page**

On this page, a player can read about the so-called historical development of the problem. I artificially created the historical development in order to provide a player with some background information. However, in the original model, the initial conditions are represented by the pre-vaccine equilibrium. I considered that if a player sees a single graph of equilibrium condition, it will most likely be heavily priming. Due to the fact that the two diseases are considered equally important and have the similar pattern of infectivity, as well as the absence of randomness in the deterministic model behavior, the diseases behave the same way. Thus, in order to avoid perception bias towards equal allocation due to historical development presentation, the story told to a player follows an artificial plot. The full description of the historical development can be found in the Appendix C.

- **Instructions Page**

This page presents the player with the short summary of the problem described in the "Historical Development", states the necessary information about the SIR-model concepts, available budget, reporting and responding delay (1 or 2 years) as well as the goal that a player needs to achieve (eradicate both diseases or achieve the lowest total cumulative number of incidence). Which of the delays and goal formulations each player gets, depends on the treatment group. (An example full description of task can be found in the Appendix C).

- **Game Page**

This page represents the main interaction platform where a player makes the decisions and receives immediate outcome feedback. There are instructions about interaction with the decision tools (knobs for allocating the budget proportions), description of the game mechanics (information about notifications upon the completion of the term and the whole game) as well as tips on how to interact with the graphs. In order for the players not to overcome the available budget, I restrict the budget proportion for the disease 2 to be automatically calculated as 1 - Proportion for Disease 1. Otherwise, it follows the budget proportion chosen by the player. The players are notified about this specification in the instructions. On the game page there are:

- 2 knobs for the decisions regarding budget proportions that a player chooses to allocate for each disease;
- a graph that tracks the development of the budget proportions, assigned by a player;
- a combined graph that reports Perceived Incidence for the Disease 1 and the Disease 2;
- A single graph of the Total Cumulative Incidence (that is a sum of cumulative incidence for both diseases);
- a note on the years left to complete the term;
- a note on the chances left before the end of the game;
- a note on the player's ID.

The game is simulated in a ballistic mode. Each year a user has to assign the desired budget proportion for each of the two diseases and proceed by the "Run" button. The game advances one year revealing the results of the decision on the graphs mentioned above. After 20 years, a player receives a notification that his term is over and is invited to play one more time. After the second round is completed a player receives a notification that the game is over and is automatically redirected to the last navigation page.

- **Survey Page**

This is the final page of the interface, which provides a player with the link to the post-survey.

Experimental Setting

Experimental Design

The experiment has a 2x2 between subjects factorial design. The treatment groups are presented in the table below

Table 1: Experimental Setting

	Goal formulation	
	Eradicate both diseases as soon as possible	Achieve the lowest total cumulative number of incidence by the end of 20 year period
Delay	Treatment Groups	
1 year	(T1) Eradicate diseases with 1 year delay	(T3) Achieve the lowest total cumulative number of incidence with 1 year delay
2 years	(T2) Eradicate diseases with 2 years delay	(T4) Achieve the lowest total cumulative number of incidence with 2 years delay

Previous research that was done in the field of infectious diseases, as well as human-computer interaction, proved that goal formulation affects the way people approach the task. Größler points out that ambiguity or contradiction in the goal setting may play a crucial part in subjects performance in experiments (Größler, 2004). I chose the two different goal formulations as experimental treatments to check whether it affects the performance of the subjects and their strategies. Stating eradication explicitly (as in T1 and T2) is in line with the formulation of the goals for eradication programs such as WHA 64.16 resolution on dracunculiasis, WHO on smallpox eradication, GPEI and Bill and Melinda Gates initiatives for polio. In control policies, the aim is to keep the incidence low on a certain level. Having that in mind I decided to check whether there will be an effect of "Control Policy" formulation on subjects considering and performing eradication strategy. The second goal formulation (T3 and T4) still implies the need for the long-term focus, as the only way to stop the cumulative incidence from growing is to eradicate the diseases. In their article Duintjer Tebbens and Thompson (Tebbens & Thompson, 2009) base their assessment on the total cumulative incidence that results after simulating each of their policy decision for 20 years. In their research and Villa et al. (Villa et al., 2015) use minimizing costs as a performance indicator for the players. That is why I decided to use the cumulative cases as an information cue for the players and as a goal formulation treatment.

Duintjer Tebbens and Thompson in their analysis explore the effects of the different length of the time delay on the policy outcome. For the experimental setting, I choose two different time delays: one year delay, as in the original model to represent the general condition and two years delay, as the extreme tested by the authors (Tebbens & Thompson, 2009). As reported by Anker and Shaaf in their report for the WHO (Anker & Schaaf, 2000),

different factors may affect the delay in reporting. Passive surveillance goes along with communicable diseases and has many weaknesses. Poor access to the health facilities in remote areas in many countries does not allow patients to come and get the treatment, thus they are forced to stay at home to overcome a disease on their own or even die. New diseases or diseases with non-specific symptoms are hard to recognize. Laboratory equipment and the infrastructure in many areas are inadequate to perform tests for identification of a disease. Logistics problems, over-worked and underpaid staff, as well as lack of motivation and lack of feedback for reporting activities, high need for continuous training contribute to the low quality and irregular reporting activities. In addition, the quality, the procedure, and the standards for reporting on diseases differ in countries and only a specified list has to be reported to the WHO, not to burden the health services. Some countries fear the economic and political consequences and thus restrain from routinely reporting to the WHO on a certain disease. All these factors can substantially contribute to inadequate, underreporting or delayed reporting about the incidence. As described in the section Literature Review, dynamic decision making has been challenging under time delays present in the system. That is why I decided to test whether the strength of the perception delay will affect the decisions of the players.

Procedure

Due to the initially unknown number of subjects I have developed a distribution system, that assigned participants randomly to one of the treatment groups. This distribution system resulted in a set of unique ID numbers. I have created a list of 440 numbers, starting from 101. The four treatment groups are simply denoted as 1, 2, 3, 4 for each treatment group T1, T2, T3, T4 respectively. Each number from the set of 440 is combined with a treatment group number. For example, the first five ID numbers are 1011, 1022, 1033, 1044, 1051. This means, that a subject who gets ID = 1011 goes to the treatment group T1, the subject with an ID = 1022 goes to the treatment group T2 and so on. The subject with the number 1051 goes again to the treatment group T1. In this way, the ID system allows to randomly allocate the participants between the 4 groups and the subjects of the experiment can easily understand which button to choose on the game interface to proceed. In case there were technical problems with accessing the game (for example by accessing the game from a mobile device), or participants violated the navigation in the game interface (for example by using back buttons in the browser) I excluded those result from the analysis.

Each participant who agreed to participate received a personal game ID, the link to the game and the document with the navigation instructions (which can be found in English the Appendix C. All the materials distributed to the participants were in their preferred language. I downloaded the survey and game output once they were available.

Research Hypotheses

The goal of my research is to identify the general trends in the resource allocation strategies in the situation of limited budget and competing alternatives, as well as determine which information affects a certain decision. From the historical evidence, even when eradication was stated explicitly, due to various reasons the programs did not succeed.

In their article Duintjer Tebbens and Thompson (Tebbens & Thompson, 2009) explore commitment to wavering - a significant shift of resources from one disease to another, which undermines previous effort and does not allow for eradication to happen. I want to test what information factors might impact the preferred strategy that players adopt, what factors contribute to strategies other than eradication and if people waver while playing the game, how can it be explained. The four treatments allow me to test the effect of different control variables such as delay time and the goal formulation. In line with the treatment groups, I formulated the following hypotheses.

In the history of using simulation games for learning and research, there has been done a vast number of experiments in order to explore whether improvement of performance depends on the experience or if additional instructional support is necessary to enhance subjects understanding and improve learning. In line with the research on that topic (Sawicka & Kopainsky, 2008), (Kopainsky, Alessi, Pedercini, & Davidsen, 2009) I could expect that performance of the subject in my experiment will not improve significantly in the second round of the game. As the goal of my research is not an assessment of learning and knowledge transfer, I do not control explicitly for these factors of human-computer interaction. However, according to the experiential learning theory (Kolb, 2015), I would still expect players to either change their strategy for eradication or pursue another strategy that will yield a lower total cumulative number of cases by the end of the game in the second round. As the general goal of the game to eradicate the diseases, I define improvement in the second round if a player switches to an eradication strategy. Thus the first hypothesis is formulated as follows:

H_0. - participants will not improve their performance significantly in the second round of the game.
H_1. - participants will improve their performance significantly in the second round of the game.

From the historical evidence, the goal formulation of a program seemed to have an effect of the commitment to the strategy and contributing to the success (or failure) of the programs (considering all other factors remain constant). Größler (Größler, 2004) identifies goal formulation as one of the factors contributing to the performance. With regard to this, I want to test whether goal formulation will have an effect on the players' strategic choice and if yes, what kind of effect it will have. The related hypotheses are formulated below.

When the participants have a goal of achieving the lowest total cumulative number of incidence by the end of the 20 years (T3, T4),
H_2. - they will be less likely to consider eradication as an option
H_3. - they will tend to demonstrate control policies such as equal allocation or allocation with volatility between the diseases.

When the participants have a goal of eradicating of both diseases as soon as possible (T1, T2)
H_4. - they will be more likely to demonstrate wavering commitment - shifting significantly the resources between the two diseases.

Finally, from the literature on the reporting activities, it was evident that there are delays related to reporting and responding activitie (Anker & Schaaf, 2000). Sterman (Sterman, 1989), Villa et al. (Villa et al., 2015), Gary (Gary, Dosi, & Lovallo, 2007) and other researchers have documented in their experiments that time delays have a significant impact on the performance on various tasks. Thus, I expect that different time delays will have an effect on the preferred strategies among the different treatment groups. The hypotheses are as follows:

H_5. - the longer the perception delay is (T2, T4), the more often the participants will tend to change their decisions, thus demonstrating wavering commitment;
H_6. - the shorter is the delay (T1, T3), the more likely participants will perform sequential eradication strategy.

Results

Participants Profile

For the analysis I took the results of 120 participants. Slightly more than half (51%) of the subjects spoke Russian language (native speakers) and the rest were English speakers (49% not necessarily native). Most of the participants were between 25 to 34 years old (42%) and younger than 24 years old (38%). Next are people between 35 and 44, this group amounted to 12% and the rest were subjects who are between 45 and 54 (6%). Regarding gender, 49% were females and 51% were males. Most of the respondents had a Bachelor degree as their highest completed level of education (47%), the next are those who have a master degree (43%). There was equal amount of people who had high school and PhD as their highest levels of education (~ 3% each) and the rest were those who finished college (~ 2.5%). Most of the respondents are currently working (68%), and the rest are either students (29%) or unemployed (~ 3%). More than half of the subjects have no experience or knowledge in System Dynamics (61%), some are familiar with basic concepts in System Dynamics (11%), or had a course on it (18%). A few subjects have moderate experience in system dynamics (5%), and the rest either have a degree (~ 2.5%) or have substantial knowledge and experience in applying System Dynamics (~ 2.5%). Most of the subjects did not have any experience with vaccination activities (83%), while others have been involved in projects related to vaccination (17%).

Survey Results

Game difficulty evaluation

The post-survey provides with general results on the reasoning that subjects followed while interacting with the game. This allows me to get an insight into their perception about the game and have an overview to test several hypotheses. The table below summarizes the frequency of the responses on the subjects' perception on the difficulty of the game.

Table 2: Game Difficulty Evaluation

Difficulty	T1	T2	T3	T4	Total	% of total
Neither easy nor difficult	8	13	10	11	42	35
Rather difficult	11	10	10	10	41	34.16
Quite easy	6	4	3	5	18	15
Extremely difficult	4	1	6	4	15	12.5
Extremely easy	1	2	1	0	4	3.33
Total	30	30	30	30	120	100

[1]T1, T2, T3, T4 - Treatment groups 1, 2, 3, 4

From the player's own perspective the majority did not find the game either difficult or easy, however the next most popular response is that the game was rather difficult. This shows that despite the players had only one type of decision to make during the game, had all the necessary information to base their decisions and also had two rounds to practice their assumptions and tests different strategies, most of the people still found the game difficult. The underlying model for the game is a simple SIR model, the two diseases have the same dynamics and infectivity and there is only one way of treatment, that needs to be funded - which is the dynamic decision a player should make. The game interface is quite straightforward. Thus, I come to a conclusion that it is not the complexity of the underlying model, the combination and the variety of the decisions to make, or the game interface that create difficulty in the game, but the general dynamic complexity that arises from the problem at hand and the way it unfolds when people try control it.

Strategy consideration

In the survey the players were asked whether they considered eradication as their strategy and if not why. Below there are the results for this question.

Out of all subjects 35% did not consider eradication as their strategy. Among all the groups subjects who did not consider eradication of the diseases as follows: T1 - 5 subjects (17%), T2 - 9 subjects (30%), T3 - 15 subjects (50%) and T4 - 13 subjects (43%). The results are presented in the table below.

Table 3: Eradication Strategic Consideration

	T1	T2	T3	T4	Total
Did not consider eradication	5	9	15	13	42
Total number of subjects	30	30	30	30	120
% per group	16.66	30	50	43.33	
% of total					35

[2]T1, T2, T3, T4 - Treatment groups 1, 2, 3, 4

I run a pairwise t-test between the treatment groups to check for the significance in differences.

Table 4: Significance t-test Results for Strategic Consideration

Compared groups	t	p-value	95% CI	means (i, j)
T1(i) and T2(j)	1.216	0.2293	[-0.086; 0.353]	0.833 0.700
T1(i) and T3(j)	2.879	0.0057	[0.101; 0.566]	0.833 0.500
T1(i) and T4(j)	2.316	0.02439	[0.036; 0.498]	0.833 0.567
T2(i) and T3(j)	1.588	0.1178	[-0.052; 0.452]	0.700 0.500
T2(i) and T4(j)	1.064	0.2918	[-0.118; 0.384]	0.700 0.567
T3(i) and T4(j)	-0.510	0.612	[-0.328; 0.195]	0.500 0.567

[3]T1, T2, T3, T4 - Treatment groups 1, 2, 3, 4

For the pairwise comparison between groups T1 and T3 and T1 and T4 there is a significant difference (p-value <0.05). This supports hypothesis H_2 that states that when subjects do not have eradication stated explicitly as a goal (as in T3, T4) they are less likely to consider eradication as a strategy than those who do not have it stated explicitly. Nevertheless, even in cases when subjects had eradication stated explicitly as their goal in groups T1 and T2, there were still participants who did not consider eradication as their strategy.

Another question that participants had to respond in the survey was concerned with the reasoning for the choice if a player did not consider eradication. I coded the responses and summarized them in the table below according to their frequency.

Table 5: Reasoning for Non-Eradication Strategy

Number of Subjects	T1	T2	T3	T4	Total	% of total
No reason provided	2		5	2	9	21.42
Impossible to achieve		2	2	4	8	19.05
Fear of the other disease impact	2	2	1	2	7	16.67
No experience, low understanding		2	3	2	7	16.67
Preferred equal allocation	1	1	1	3	6	14.29
Insufficient budget would not allow eradication		2	1		3	7.14
Other reasons			2		2	4.76
Total	5	9	15	13	42	

[4]T1, T2, T3, T4 - Treatment groups 1, 2, 3, 4

Most of the participants did not provide any explanation on why they did not consider eradication (21%). The next most popular explanation is that the subjects had a feeling it is impossible to eradicate the diseases in general - 19% out of all respondents and with the most of participants with this reason from treatment T4. The following two reasons scored equally (~16%) among the participants which is they either their feared the impact of neglected disease or did not have experience or proper understanding of the eradication as a concept. 14% of the subjects communicated their willingness to keep the diseases equally low. 7% of the respondents decided that the constrained budget is insufficient for eradication, however several noted that, perhaps, parallel eradication will be impossible. 4% provided other reasons such as mutation of the diseases, not enough time to eradicate (in particular for treatment T2 and T4, which is indeed correct for eradication of both diseases), possible positive effects for the economy of the country and

increasing the budget base.

Information cues

In the survey participants were asked about the information cues that they took into consideration when making their allocation decisions. I summarize their responses in the table below by their frequency

Table 6: Information Cues Frequency

Information cues and frequency	T1	T2	T3	T4	Total
Development of the trend in incidence for the diseases that followed my decisions	19	21	22	25	87
Current reported incidence for Disease 1	22	14	20	19	75
Current reported incidence for Disease 2	18	13	15	17	63
Most pressing disease	10	9	8	9	36
Current total cumulative incidence	5	10	7	7	29
Relative strength of the disease	5	9	1	2	17
Other	3	0	1	1	5

[5] T1, T2, T3, T4 - Treatment groups 1, 2, 3, 4

The most frequent information that the participants identified was the development of the trend in incidence for the disease that followed their decision. Which means that the subjects were trying to control and understand the consequences of their choices. Interestingly, but the focus on the incidence for the Disease 1 is slightly bigger than for the Disease 2. Considering the fact, that diseases are presented equally important and dangerous in terms of infectivity and severeness of the consequences, subjects still took into consideration the incidence for the Disease 1 more often than for the Disease 2. Most pressing disease was the 4th most popular information cue, however that information had to be inferred and interpreted by the subjects on their own, as this information was not presented explicitly. Almost just a third as much as the most popular information cue scored the information regarding total cumulative incidence was relevant for the participants. One explanation for this could be, that subject do not have a full understanding of the concept of cumulative number of cases and the trajectory for its behavior for the eradication strategy. Lastly the relative strength of the disease was also an information cue that subjects would have to infer on their own based on the information presented. Nevertheless, it still had been identified as a decision cues guiding the choices of budget allocation. Among other information cues specified by the subjects were:

- The lowest level of the disease achieved with a certain budget proportion.
- Random allocation.
- "Logarithmic trajectory of decreases in deaths over time. This indicates that progress towards eradication is successful".
- Remained budget from total available budget.
- Relative rate of change.

What is interesting to note is the mentioning of the budget by two subjects in different context. What can be gained from this observation is that although subjects are given a certain budget and are allowed to use it few people still keep in mind this information cue. In real life decision makers should constantly make decisions in the conditions of budget constrains or earmarking. Thereafter, even under conditions where budget is a given and not a point to be have control over, participants still consider it while making the decisions. Perhaps, when the goal includes minimizing the costs, as it is oftentimes observed in reality, this will have a significant impact on the decisions.

Game Results

Results by treatment groups

In order to identify whether there are any general trends in allocation of the resources depending on the treatment group I plotted every participant and grouped them by their treatment. The output on the budget proportions and the corresponding incidence for each disease can be seen on the graphs below. From the first overview it is clear that there was no definitive pattern in preference towards a certain allocation strategy. In order to test the whether there are specific information cues that play a bigger role in choosing allocation strategy depending on the group I run a regression model. The general model I applied to each participant is the following:

$$Y_i = \beta_0 + \beta_1 * PI.ID.1 + \beta_2 * PI.ID.2 + \beta_3 * TC$$

Where
Y_i - Budget proportion to $Disease_i$
i - 1, 2
PI.ID.1, PI.ID.2 - Perceived Incidence of Infectious Disease 1,2
TC - Total Cumulative Incidence

For the regression analysis I exclude players who allocated equal budget proportions for both diseases without any change throughout the whole term of the game. Although this strategy is realistic and Duintjer Tebbens and Thompson (Tebbens & Thompson, 2009) also discuss it, I do not consider this type of strategy to be an example a dynamic decision making. Technically speaking, while playing the game the players were presented with the information upon which they were expected to base their decisions. When a player adopts a strategy such as equal allocation for the whole term of the game, it cannot be assumed that he or she took into consideration any information that he (she) saw as an immediate output feedback. Thus, a regression model will not provide any result for such players. In case there is a player in a treatment group with such a strategy, his regression result automatically referred as 0 for all the coefficients. The results of the regression can be seen in the regressions. By looking at the R^2 the chosen regression model demonstrates reasonable fit for some players, but not for others. On average in each treatment group the R^2 is rather low, about 0.3. The significance of the information cues is not generally consistent among the players in one treatment group, as well as between the groups.

In line with the approach adopted by Villa et al. (Villa et al., 2015), I decided to perform panel data analysis in order to see whether the proposed model would be able to explain

the collective decision making in each treatment group. I perform the set of tests for each treatment group and come to similar results. First I test whether to use simple pooling model, fixed or random effects. The Honda - Lagrange multiplier test (for balanced panels) shows significant effects for all treatments (p-value <0.05). This suggests that pooling model is not the best fit. After that, I do a Hausman test to decide between the fixed and random effects model. Again, for all treatments one model is inconsistent which suggest the use of fixed effects model. However, comparing the results from a fixed effect model across the treatments did not provide with consistent result that would allow to draw general conclusions. Moreover, when comparing these results with those of a pooling model, the pooling model had slightly higher results on R^2 and the significance of the coefficients. The results of the panel data analysis are provided in the table below.

Table 7: Results from the Panel Data Analysis

		Pooling Model		Fixed Effects Model	
T1		B1	B2	B1	B2
	R^2	0.104	0.18856	0.019	0.082
	Coefficient β_0	0.60546***	0.6084***		
	Coefficient β_1	-0.000142***	-0.000082783***	-0.000085344**	-0.00010185***
	Coefficient β_2	0.00001411	-0.00013311***	3.95E-05	-0.000056719*
	Coefficient β_3	-0.0000053164***	-0.0000040271***	-6.7685E-07	-1.4993E-06
Balanced Panel: n = 29, T = 21, N = 609					
T2		B1	B2	B1	B2
	R^2	0.084	0.066	0.026	0.003
	Coefficient β_0	0.57425***	0.59185***		
	Coefficient β_1	-1.4200e-04***	-1.5092e-05	-0.000079618**	-3.9962E-06
	Coefficient β_2	4.5222e-05*	-1.1208e-04***	0.000034726	-0.000023638
	Coefficient β_2	-2.3551e-06*	-4.8059e-06***	1.1219E-06	1.4092E-08
Balanced Panel: n = 26, T = 21, N = 546					
T3		B1	B2	B1	B2
	R^2	0.132	0.17055	0.066	0.118
	Coefficient β_0	0.53162***	5.2668e-01***		
	Coefficient β_1	-1.0378e-04***	6.1861e-05***	-0.000036674.	0.000052358*
	Coefficient β_2	1.0590e-04***	-1.8651e-04***	0.000081214***	-0.0000706**
	Coefficient β_3	-5.9183e-06***	1.7292e-06	-0.0000044426**	0.0000075864***
Balanced Panel: n = 28, T = 21, N = 588					
T4		B1	B2	B1	B2
	R^2	0.063	0.087155	0.004	0.046
	Coefficient β_0	0.62388***	5.7442e-01***		
	Coefficient β_1	-1.3536e-04***	-5.1688e-05*	1.25E-05	-0.000076549*
	Coefficient β_2	7.8478e-05**	-1.4040e-04***	5.31E-06	-1.44E-05
	Coefficient β_3	-0.0000064776***	-1.3080e-06	-1.22E-06	2.21E-06
Balanced Panel: n = 23, T = 21, N = 483					

[6] Significance codes: 0.001 "***", 0.01 "**", 0.05 "*", 0.1 "."

[7] B1, B2 - Budget for infectious disease 1, 2; T1, T2, T3, T4 - Treatment groups 1, 2, 3, 4

Overall, the panel data analysis did not provide with a solid confirmation for an assumption that a regression model fits well to describe general behavior of the players depending on the treatment. This makes me think, that the treatment groups did not have a significant effect in terms of defining strategic choices of the participants.

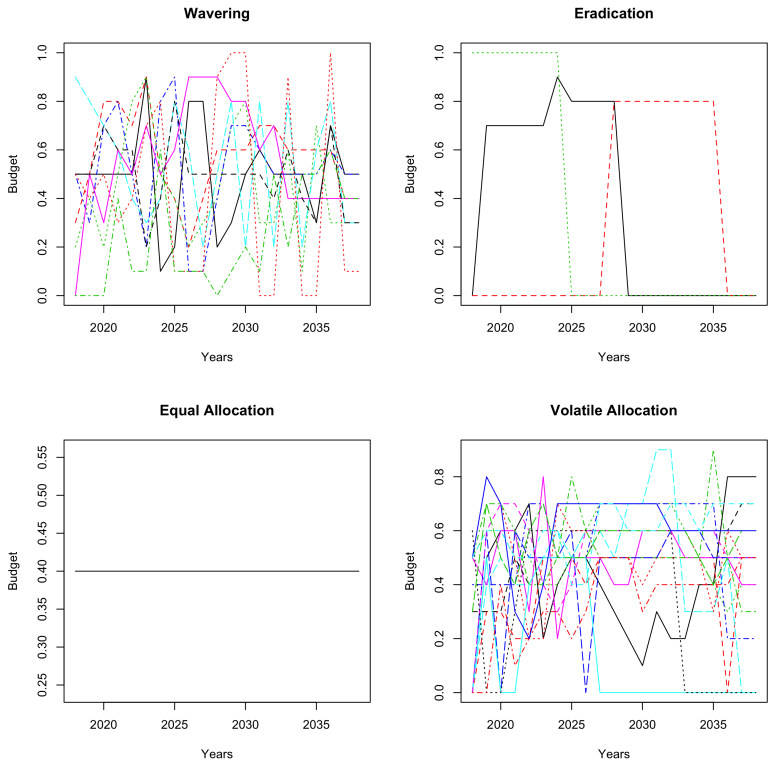
Results by clusters

While observing the results, I still noticed certain trends in allocation of the budget. In order to investigate whether players committed to any particular strategy I developed an algorithm that classifies the strategies into clusters. The R algorithm for clustering can be found in the Appendix H. As a result I came up with 4 distinct allocation strategy clusters:

- equal allocation strategy;
- eradication strategy;
- wavering strategy;
- volatile allocation strategy.

An example of the clustering result is presented on a graph below, from the treatment group T1 from the first round. Graphs for other treatment groups are placed in the Appendix A.

Figure 1: Cluster results for treatment group T1, round 1



I have tested several methods in order to identify the clusters. One of the methods I tried was using Pearson correlation coefficient. In order to differentiate between the different clusters I defined several template strategies. The high correlation of the player's strategy with a template would be an indicator for a player to be placed in one or another cluster. Despite the fact that the method seemed promising and quite formal, it did not perform well across all treatment groups, misplacing players to the clusters where they did not belong. For this reason I decided to have a specific method of identification for each of the clusters.

First, I separate those, who have allocated equal budget proportion for each disease throughout the whole game. As I have stated before, even though I do not consider equal allocation as a strategy that results from dynamic decision making, I still consider this as a valid and possible strategic choice. In different treatment groups it occurred that players were allocating equal budget proportions other than 0.5 for each disease, still under a 100% of the budget. This means they did not use the whole budget in some parts of the game, or even during the whole term. I decided not to exclude such players as I do not have enough evidence for the reasons why they have played the game this way. One of the possibilities can be that these subjects did not understand the task completely, however for this claim to have support the pre- and post- task understanding will need to be accessed. Moreover, I believe in real life setting there can be such sub optimal decisions, where even with a certain budget available people will not make a full use of it. In addition, as my task is to investigate all the decision pathways that were adopted by players, and there were more than one player that did not use the whole budget in their allocation strategies, I believe it can be also an interesting point for further investigation.

The next cluster that I have identified consists of players, who pursued eradication strategy. In their article Duintjer Tebbens and Thompson (Tebbens & Thompson, 2009) define optimal eradication policy as sequential eradication with full allocation of resources towards one disease, and once it is eradicated, shifting all the available resources towards another disease. They assess the policy to be optimal by comparing the cumulative number of cases by the end of 20 year period. Due to the fact that I have two different delays, the time span is longer for eradication policy to yield lower cumulative cases for the longer delay treatment. Moreover, I take into account that it may take considerable amount of time for people to realize that in order to achieve eradication, a significant amount of resources should be invested in one disease long enough. This would result in higher cumulative cases in comparison to the results provided by the Duintjer Tebbens and Thompson. In addition in their article eradication is fastest way to achieve eradication is by allocating a 100% of the budget. I anticipated that not every player will be as aggressive as defined by the authors of the article, still attempting eradication, which will in their case take longer. If the players do not allocate a 100% budget, or they attempt this strategy quite late in the game, they are less likely to be able to eradicate both diseases in a time span of the game. Still, the chances they eradicate one of the diseases are still high. Keeping this in mind, I decided to have the number of Perceived Incidence for Disease 1 or Disease 2 by the end of the final year to be an indicator for this cluster. As the idea of eradication with limited budget implies sequential significant investments in one disease and then the other for a certain period of time, even if players achieved eradicating of only one disease, they were following this type of strategy. Thus, I set a threshold of less or equal to 16 people per year for the perceived incidence for Disease 1 or Disease 2 to indicate that the strategy a player performed followed an eradication pattern. This threshold is rather artificial, and is mainly based on the patterns seen in the treatment groups T2 and T4 with a longer delay. If the incidence on the final year is below this threshold they have been surely investing long enough in order to reach this value, and if the term was longer I would expect them to continue with this strategy. For the other two treatment groups, T1 and T3 with a shorter delay, this threshold proved to be also robust in identifying all the players who achieved or attempted eradication.

The third cluster follows Duintjer Tebbens's and Thompson's wavering description. In their article they define this strategy as a shift of full budget towards the most pressing

disease. Similar to eradication strategy, I believed that the players would not be as aggressive as described in the article, and also not during the whole period of the game. In order to distinguish wavering from another strategies I adopt the following algorithm. If the difference between each next two budget proportions is greater or equal to 0.2 and such difference occurs more than 7 times (which is one third of the game) such player should be allocated to a wavering cluster. The 0.2 difference in budget proportions is a simple calculation from a possible budget difference. The mean in allocation is 0.5, as the full budget represents 1. In case a player allocated, for example 0.7 for one disease, for the other disease only 0.3 is left. I define this a significant difference in preference and commitment towards one of the diseases, which is capable of achieving eradication if pursued long enough. Now, if the player is shifting the budget proportions with this kind of amplitude, longer than one third of the game period (more than 7 times), the budget allocation strategy and the incidence that follow it for each disease follow a similar wavering pattern as described by Duintjer Tebbens and Thompson. I have tested different combinations of conditions for this cluster and a non strict 0.2 for the budget difference and strict 7 for the number of such shifts yielded the best fit in allocating the players into this particular cluster.

Finally, I allocate all the other players, who did not get into one of the previous clusters to the volatile allocation strategy. This cluster follows the pattern described by Duintjer Tebbens and Thompson as allocation of budget proportions relative to the significance of the diseases. This cluster collected the majority in each group in both rounds of the game. The strategies adopted by the players in this cluster are rather heterogeneous and mostly do not follow a definite pattern of allocating the budget proportions solely based on the prevalence of the disease. In my opinion, this strategies do not have neither a distinct pattern, nor a certain commitment towards any other strategy. It is mostly represented by attempts of eradication, but that was not pursued long enough to yield any positive results, short wavering commitments in different periods of the game and finally, what seemed like a desperate decision, commitment to an equal or steady budget allocations in the second period of the term.

Results interpretation

In order to investigate, whether the described above regression model would fit better, I run it on each cluster. In the table below the clusters with the regression results for each cluster can be seen.

Table 8: Regression Results for the Wavering Cluster

					T1					
	B1					B2				
Player	$\mathbf{R^2}$	β_0	β_1	β_2	β_3	$\mathbf{R^2}$	β_0	β_1	β_2	β_3
3	0.491	0.5644***	4e-04**	-4e-04**	-5.00E-06	0.491	0.4356**	-4e-04**	4e-04**	5.00E-06
4	0.033	0.7197**	-1.00E-04	-1.00E-04	-7.00E-06	0.07	0.3918.	0	0	5.00E-06
5	0.301	0.9241***	0	-3e-04*	-1.10E-05	0.146	0.3521	-1.00E-04	0	5.00E-06
9	0.429	0.8648***	1.00E-04	-4e-04**	-1.00E-05	0.429	0.1352	-1.00E-04	4e-04**	1.00E-05
11	0.307	0.4742*	4e-04*	0	-8.00E-06	0.307	0.5258*	-4e-04*	0	8.00E-06
14	0.49	0.8398**	-4e-04**	1.00E-04	-1.70E-05	0.127	0.3313	0	-1.00E-04	5.00E-06
18	0.373	0.8102***	2e-04.	-4e-04*	-2.1e-05*	0.373	0.1898	-2e-04.	4e-04*	2.1e-05*
24	0.125	0.2564	2.00E-04	1.00E-04	-8.00E-06	0.36	0.6094***	-2.00E-04	1.00E-04	-1.7e-05*
29	0.383	0.1977	-1.00E-04	0	7.00E-06	0.6	0.7748**	-5e-04**	2.00E-04	3.00E-06
Av	**0.326**					**0.323**				
					T2					
3	0.071	0.46	3.00E-04	-3.00E-04	-4.00E-06	0.019	0.391	-1.00E-04	1.00E-04	2.00E-06
6	0.433	0.7282**	3e-04*	-4e-04*	-1.8e-05.	0.433	0.2718	-3e-04*	4e-04*	1.8e-05.
17	0.365	0.7053***	2e-04*	-3e-04*	-1.10E-05	0.365	0.2947.	-2e-04*	3e-04*	1.10E-05
21	0.475	0.0679	2.00E-04	1.00E-04	3.1e-05**	0.475	0.9321***	-2.00E-04	-1.00E-04	-3.1e-05**
25	0.055	0.2613	0	0	7.00E-06	0.303	0.5183*	-5e-04*	3.00E-04	-7.00E-06
28	0.13	0.4117.	3.00E-04	-2.00E-04	2.00E-06	0.141	0.1559	-1.00E-04	3.00E-04	5.00E-06
30	0.299	0.629***	2e-04.	-3e-04*	-9.00E-06	0.299	0.371*	-2e-04.	3e-04*	9.00E-06
Av	**0.261**					**0.291**				
					T3					
5	0.464	1.1627***	-1.00E-04	-4e-04*	-3e-05**	0.685	0.0432	1e-04*	0	2e-05**
12	0.006	0.4316	1.00E-04	0	-2.00E-06	0.006	0.5684	-1.00E-04	0	2.00E-06
18	0.259	0.2937	-1.00E-04	0	1.4e-05.	0.574	0.1744	3e-04***	-2e-04.	1.00E-06
20	0.015	0.6451	0	-1.00E-04	-6.00E-06	0.338	-0.4347	1.00E-04	3e-04*	2.6e-05**
28	0.177	0.468**	1.00E-04	-1.00E-04	2.00E-06	0.177	0.532**	-1.00E-04	1.00E-04	-2.00E-06
Av	**0.184**					**0.356**				
					T4					
2	0.1	0.2528	1.00E-04	0	1.30E-05	0.1	0.7472**	-1.00E-04	0	-1.30E-05
7	0.676	0.2733	5e-04***	-4e-04**	9.00E-06	0.785	0.5323***	-4e-04***	3e-04***	2.00E-06
11	0.133	0.8532*	0	-3.00E-04	-1.20E-05	0.133	0.1468	0	3.00E-04	1.20E-05
12	0.169	0.3752	0	2.00E-04	-6.00E-06	0.209	0.0165	-1.00E-04	3.00E-04	1.40E-05
13	0.479	1.4138***	-2.00E-04	-3.00E-04	-3.4e-05**	0.057	0.2653	0	1.00E-04	-7.00E-06
20	0.465	1.2425***	-1.00E-04	-4e-04**	-2.6e-05**	0.465	-0.2425	1.00E-04	4e-04**	2.6e-05**
25	0.57	0.8065**	4e-04**	-3e-04*	-1.00E-05	0.57	0.1935	-4e-04**	3e-04*	1.00E-05
Av	**0.370**					**0.331**				

[8] Significance codes: 0.001 "***", 0.01 "**", 0.05 "*", 0.1 "."

[9] B1, B2 - Budget for infectious disease 1, 2; T1, T2, T3, T4 - Treatment groups 1, 2, 3, 4

[10] Av - average result

Table 9: Regression Results for the Eradication Cluster

					T1					
	B1					B2				
Player	$\mathbf{R^2}$	β_0	β_1	β_2	β_3	$\mathbf{R^2}$	β_0	β_1	β_2	β_3
8	0.682	1.1929*	-7e-04**	3e-04*	-7.3e-05**	0.371	-0.3214	3.00E-04	0	5.7e-05.
22	0.606	2.0534**	3e-04.	-0.0016**	1.20E-05	0.606	0.5134**	1e-04.	-4e-04**	3.00E-06
26	0.905	1.7731***	-6e-04**	1.00E-04	-0.000131***	0.318	-1.7482	8.00E-04	3.00E-04	0.000163*
Av	**0.731**					**0.432**				
					T2					

Continued...

12	0.747	1.2478***	2e-04*	-4e-04**	-4.4e-05***	0.13	-0.3342	1.00E-04	2.00E-04	1.30E-05
23	0.121	0.0994	-1.00E-04	3.00E-04	2.00E-05	0.707	1.4587***	1.00E-04	-6e-04**	-7.8e-05***
Av	**0.434**					**0.419**				
					T3					
3	0.096	0.3419.	0	-1.00E-04	-1.00E-05	0.766	0.219	3.00E-04	-2.00E-04	1.20E-05
11	0.504	0.762*	-3.00E-04	3e-04*	-2.2e-05*	0.504	0.238	3.00E-04	-3e-04*	2.2e-05*
19	0.922	1.2299***	-6e-04***	2e-04***	-8.6e-05***	0.309	-0.5121	5e-04.	0	8.2e-05*
24	0.826	1.5775***	-0.001***	2e-04**	-9.4e-05***	0.29	-0.4696	8e-04*	-1.00E-04	6.8e-05*
Av	**0.587**					**0.467**				
					T4					
4	0.741	1.4639***	-9e-04***	3e-04*	-6.9e-05***	0.725	-0.3856	8e-04***	-3e-04*	6.5e-05***
6	0.661	0.3384**	2.00E-04	-1.00E-04	2.4e-05*	0.765	0.438***	-1.00E-04	1.00E-04	-1.4e-05*
8	0.75	0.2225	0	2.00E-04	2.20E-05	0.771	0.4024*	1.00E-04	-1.00E-04	-1.30E-05
19	0.752	0.5708	-3.00E-04	5e-04**	-2.6e-05*	0.752	0.4292	3.00E-04	-5e-04**	2.6e-05*
27	0.481	-2.6655**	0.0013**	5e-04*	9e-05**	0.642	2.1047*	-9e-04*	-4e-04*	-3.60E-05
Av	**0.677**					**0.731**				

Table 10: Regression Results for the Volatility Cluster

					T1					
	B1					B2				
Player	$\mathbf{R^2}$	β_0	β_1	β_2	β_3	$\mathbf{R^2}$	β_0	β_1	β_2	β_3
1	0.311	0.0606	-3e-04*	4e-04.	3.3e-05.	0.261	1.0194**	2.00E-04	-5e-04*	-3.00E-05
2	0.373	0.2792.	1.00E-04	-2.00E-04	1.10E-05	0.088	0.5873*	-1.00E-04	-1.00E-04	-1.00E-06
6	0.279	0.4492***	-1.00E-04	2e-04*	-2.00E-06	0.282	0.4256***	1.00E-04	-2e-04.	7.00E-06
7	0.293	0.9243***	-5e-04*	1.00E-04	-3e-05*	0.269	0.1514	4e-04*	-1.00E-04	2.1e-05.
10	0.474	0.9506***	-4e-04**	0	-2e-05*	0.283	0.7112***	-3e-04*	0	-1.6e-05.
12	0.007	0.5259***	0	0	-2.00E-06	0.007	0.4741**	0	0	2.00E-06
13	0.883	0.3977**	0	-1.00E-04	1.6e-05*	0.473	0.7669***	-3.00E-04	0	-1.7e-05*
15	0.385	0.4396**	2e-04**	-1.00E-04	1.00E-06	0.385	0.5604***	-2e-04**	1.00E-04	-1.00E-06
16	0.44	0.703***	2e-04*	-3e-04**	-7.00E-06	0.44	0.297*	-2e-04*	3e-04**	7.00E-06
17	0.209	0.257	-1.00E-04	1.00E-04	1.20E-05	0.339	0.1176	-1.00E-04	2.00E-04	1.4e-05.
20	0.642	0.1003	0.0041***	-0.004***	-4e-06.	0.568	0.0954	0.0041**	-0.004**	-5e-06.
21	0.138	0.4807*	0	-1.00E-04	8.00E-06	0.449	0.6307***	-2e-04*	-1.00E-04	-6.00E-06
23	0.463	0.9381***	2.00E-04	-6e-04.	-8.00E-06	0.286	0.5728**	1.00E-04	-2.00E-04	-9e-06.
25	0.708	-0.0165	2e-04.	-2e-04.	1.4e-05**	0.559	0.4911*	-1.00E-04	-1.00E-04	4.00E-06
27	0.216	0.6677***	1.00E-04	-2e-04.	0	0.111	0.403***	-1.00E-04	1.00E-04	0
28	0.241	0.3221*	2e-04.	0	1.8e-05*	0.241	0.6779***	-2e-04.	0	-1.8e-05*
30	0.565	0.4268***	3e-04*	-2e-04*	2.3e-05***	0.565	0.5732***	-3e-04*	2e-04*	-2.3e-05***
Av	**0.390**					**0.330**				
					T2					
1	0.797	-0.4184	2.00E-04	2e-04.	2.4e-05*	0.755	1.0342**	-2.00E-04	-2e-04**	-1.8e-05*
4	0.187	0.3962***	0	1.00E-04	1e-05.	0.187	0.6038***	0	-1.00E-04	-1e-05.
5	0.48	-0.5961	4e-04*	1.00E-04	3.3e-05*	0.464	-0.3273	-1.00E-04	5e-04*	2.1e-05*
7	0.814	-0.6151	2.00E-04	1.00E-04	4.3e-05**	0.149	-0.464	4.00E-04	0	2.60E-05
9	0.355	0.9174**	3e-04.	-6e-04**	-1.10E-05	0.719	-0.0502	3e-04***	-1.00E-04	2e-05**
10	0.523	0.6434***	4e-04**	-4e-04**	-1.00E-05	0.523	0.3566*	-4e-04**	4e-04**	1.00E-05
11	0.382	0.2606*	1.00E-04	2e-04.	6.00E-06	0.382	0.7394***	-1.00E-04	-2e-04.	-6.00E-06
13	0.124	0.2099	0	1.00E-04	1.40E-05	0.124	0.7901**	0	-1.00E-04	-1.40E-05
14	0.271	0.66***	2e-04.	-3e-04*	-8.00E-06	0.271	0.34**	-2e-04.	3e-04*	8.00E-06
15	0.493	1.0058***	0	-3e-04**	-2e-05**	0.493	-0.0058	0	3e-04**	2e-05**
19	0.687	0.8422***	1.00E-04	-3e-04.	-2.5e-05***	0.516	0.6786***	-3.00E-04	2.00E-04	-2e-05**
20	0.096	0.4123***	0	1.00E-04	3.00E-06	0.493	0.6336***	-3e-04*	0	2.00E-06
22	0.462	0.3599**	2.00E-04	-2e-04*	8.00E-06	0.462	0.6401***	-2.00E-04	2e-04*	-8.00E-06
24	0.326	0.5187**	1.00E-04	-3.00E-04	3.00E-06	0.28	0.5509**	-3.00E-04	1.00E-04	1.00E-06
26	0.085	0.0659	1.00E-04	1.00E-04	1.30E-05	0.329	0.086	-1.00E-04	3e-04.	1.6e-05.
27	0.266	0.3027	2.00E-04	0	2.1e-05*	0.241	0.1148	2.00E-04	1.00E-04	7.00E-06
29	0.357	0.2896	4e-04.	-4e-04*	1.9e-05.	0.236	0.7391**	-5e-04.	2.00E-04	-1.20E-05
Av	**0.394**					**0.390**				
					T3					
1	0.16	0.3498***	0	1.00E-04	7.00E-06	0.16	0.6502***	0	-1.00E-04	-7.00E-06
2	0.694	0.5444***	6e-04***	-4e-04**	-1.4e-05***	0.074	0.4194***	2.00E-04	-2.00E-04	-2.00E-06

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4	0.687	0.829***	0	-3e-04*	1.00E-06	0.261	0.3996**	0	-1.00E-04	5.00E-06
6	0.412	0.6092***	2e-04*	-2.00E-04	-2.5e-05*	0.391	0.4135**	-2e-04.	1.00E-04	2.2e-05*
7	0.32	0.6774*	2.00E-04	-1.00E-04	-1.7e-05*	0.23	-0.1207	0	1.00E-04	1e-05.
8	0.248	0.4414***	0	1.00E-04	5.00E-06	0.248	0.5586***	0	-1.00E-04	-5.00E-06
9	0.247	0.8129***	0	-1.00E-04	-1.8e-05*	0.247	0.1871	0	1.00E-04	1.8e-05*
10	0.204	0.6378***	1.00E-04	-2e-04.	-7.00E-06	0.469	0.1458	-1.00E-04	3e-04**	1.8e-05**
13	0.39	0.7587**	1.00E-04	0	-2.9e-05*	0.39	0.2413	-1.00E-04	0	2.9e-05*
14	0.279	0.5586***	1.00E-04	-1.00E-04	-5.00E-06	0.279	0.4414***	-1.00E-04	1.00E-04	5.00E-06
15	0.129	0.5602***	1.00E-04	-2.00E-04	2.00E-06	0.129	0.4398***	-1.00E-04	2.00E-04	-2.00E-06
16	0.354	0.935***	0	-1.00E-04	-2.3e-05*	0.354	0.065	0	1.00E-04	2.3e-05*
17	0.4	0.7992**	-2e-04*	-2.00E-04	-5.00E-06	0.328	-0.0508	2.00E-04	3e-04*	1.60E-05
21	0.218	0.4697***	2e-04*	-1e-04.	2.00E-06	0.218	0.5303***	-2e-04*	1e-04.	-2.00E-06
23	0.276	0.2543	-1.00E-04	2e-04*	0	0.499	0.5202***	-2e-04.	-1.00E-04	9e-06.
25	0.642	0.482***	2e-04**	0	-5.00E-06	0.809	0.5377***	-3e-04***	0	6.00E-06
26	0.278	0.6124***	0	-2e-04.	-1.3e-05*	0.142	0.4637***	0	1.00E-04	2.00E-06
27	0.278	0.9315***	-1.00E-04	-1.00E-04	-2.2e-05*	0.278	0.0685	1.00E-04	1.00E-04	2.2e-05*
30	0.179	0.3562**	1.00E-04	0	-4.00E-06	0.179	0.6438***	-1.00E-04	0	4.00E-06
Av	**0.337**					**0.299**				
					T4					
3	0.427	0.5539***	0	-2.00E-04	8.00E-06	0.27	0.4966***	0	1.00E-04	-8.00E-06
5	0.372	0.9824*	0	-5e-04*	-8.00E-06	0.136	0.2854	-2.00E-04	2.00E-04	5.00E-06
9	0.556	0.2114	3e-04*	-1.00E-04	2.8e-05**	0.077	0.4078.	-1.00E-04	0	-7.00E-06
10	0.733	0.3076*	7e-04***	-1e-04.	2.2e-05**	0.733	0.6924***	-7e-04***	1e-04.	-2.2e-05**
17	0.608	0.2681*	5e-04***	-3e-04*	1e-05.	0.608	0.7319***	-5e-04***	3e-04*	-1e-05.
18	0.353	0.5878***	-1.00E-04	1.00E-04	-7e-06*	0.353	0.4122***	1.00E-04	-1.00E-04	7e-06*
22	0.25	-0.0323	4e-04.	-3.00E-04	2.00E-06	0.17	-0.0332	-1.00E-04	3.00E-04	3.00E-06
24	0.569	0.2001	8e-04**	-7e-04***	2.8e-05*	0.569	0.7999***	-8e-04**	7e-04***	-2.8e-05*
26	0.256	0.8043**	0	-1.00E-04	-1.70E-05	0.256	0.1957	0	1.00E-04	1.70E-05
28	0.196	0.483***	3e-04.	-3e-04.	1.00E-06	0.196	0.517***	-3e-04.	3e-04.	-1.00E-06
29	0.593	0.4252***	3.00E-04	-4.00E-04	6.00E-06	0.523	0.5161***	-3.00E-04	1.00E-04	2.00E-06
Av	**0.447**					**0.354**				

By the overview of the clustering results, I can assess the hypotheses that I have developed. Across all the treatments the distribution of people with one or another strategy does not differ significantly depending on the treatment conditions. Thus, there is not enough evidence to support hypotheses H_4, H_5, and H_6. For each treatment the results are rather similar, with the majority of players belonging to volatile allocation cluster, then wavering and lastly eradication, for the first round, and in the second round still, with the majority in a volatile cluster, and then more switching to eradication and less being left in the wavering cluster. Regarding the equal allocation, in the second round there were more people committing to this policy across all the treatments. There were no significant differences in the number of people who chose equal or volatile allocation between the treatments, thus hypothesis H_3 also does not have enough evidence for support. The fact that different treatment conditions did not significantly impact the strategic choices, made me think that there must be other reasons influencing the decisions of the participants.

The regression model fits best for the eradication cluster in all of the treatment groups. The individual and average R^2 there is the highest compared to all the other clusters. Due to the fact that the dependent variable is several times smaller than the independent variables, the coefficients for each regressors other than the constant are very small, in fact are less than 0. This brings considerate difficulties in interpreting the regression results and the effect these variables have on the budget proportion. Nevertheless, there are similar trends in the significance of the factors. For example, the players for whom the regression coefficient R^2 is very high ($>= 0.7$) either all, or at lest two of the information cues are marked as highly important. In addition, for the player 23 in T2, who started eradication from the second disease, the R^2 and the significance information cues are higher for the second budget proportion. Players with the highest regression coefficient

R^2 (26 from T1, 19, 24 from T3) all have adopted a similar strategy that allowed to eradicate both of the diseases during the given term. First of all, the possibility to eradicate both diseases in this time span is possible only for this treatments as they gave a shorter delay. All these players started with the first eradication from Disease 1 early enough investing significant amount of resources long enough, which allowed them to shift the resources to the other disease once they got rid of the first one. Nevertheless, the players did not invest full budget, splitting it in a way, that a small proportion (~ 0.1 or 0.2) was still allocated towards the other disease. The players, who have a smaller R^2 and less consistent results on the significance of the information cues, either pursued eradication rather late, were not as aggressive in terms of the budget proportions they allocated, or achieved eradication only of one of the diseases. The results on the second round (can be found in the Appendix F) of the game confirm this observation .

This brings me to a conclusion, that the players who have all the information cues highly significant and high R^2 (>= 0.8), all have in common several characteristics:

- they took into consideration all the information cues with and gave them similar priority;
- they were rather aggressive in their budget allocations in order to eradicate the disease (>= 80% of budget towards one disease);
- were committed to this strategy early enough and for long enough;

and as a consequence of these factors:

- managed to fully (in treatments T1, and T3) or almost fully (eradicated one disease, and were about to eradicate the other disease in treatments T2 and T4) eradicate both of the diseases

For the wavering and the volatile allocation clusters the R^2 and the significance of the information cues is way lower. Both, the individual and the average R^2 are below 0.5, which tells that the model does not fit in those clusters as well as it does for the eradication cluster. The coefficients for the information cues are mainly insignificant. This brings me to a conclusion, that for players in these clusters the provided information did not matter as much as it did for those, who attempted eradication. However, the given output feedback was the only information the participants could base their decisions off of. Thereafter, I believe that players, who did not attempt eradication, but were wavering or had volatile allocation strategy could not make proper sense of the provided information in order to form their decisions and infer which budget allocation decisions will lead to eradication. That is why, the regression model has relatively poor fit and with low significance of information cues. Despite the fact, that people had the necessary information in order to make decisions, that would lead to eradication, some people were able to analyze this information and make use of it (like in the eradication cluster) and other could not do that (like wavering and volatile allocation cluster). This leaves me with a feeling, that without a proper understanding of the system at hand, the majority of people, even though they are provided with information and a possibility to test the system's behavior, cannot properly attribute the results of their decisions and thus, further use the information cues that they see as on outcome feedback.

Second round, experience and learning

I check for the improvements in the second round of the game, in order to test my H_1 hypothesis. As Duintjer Tebbens and Thompson asses the optimality of a policy by looking at the final cumulative number of cases by the end of 20 year period I compare these values as well, for each strategic choice in both rounds. The results can be seen in the table below. The lowest total cumulative number of incidence in all treatment groups (except for T2 and T4 in round 1) was reached by players, who pursued eradication strategy. (The R algorithm for comparing the results of the two rounds can be found in the Appendix I).

Table 11: Strategy Choice Comparison by Rounds

	T1				**T2**			
Player	**Cluster R1**	**Total C**	**Cluster R2**	**Total C**	**Cluster R1**	**Total C**	**Cluster R2**	**Total C**
1	Volat	22168.49	Volat	19744.79	Volat	36375.99	Volat	21774.98
2	Volat	25987.52	Volat	19761.79	Equal	41113.71	Volat	18780.88
3	Waver	20053.44	Volat	21540.74	Waver	31460.36	Waver	27899.95
4	Waver	20105.93	Volat	22912.76	Volat	18809.02	Equal	17820.92
5	Waver	29133.05	Waver	26333.04	Volat	28936.24	Volat	18128.06
6	Volat	19789.68	Volat	18625.63	Waver	21884.95	Waver	20547.75
7	Volat**	19086.64	Erad	23669.52	Volat**	31690.9	Erad	23908.72
8	Erad*	16698.03	Erad	17444.41	Equal	**17820.92**	Equal	17820.92
9	Waver	20681.13	Volat	17943.02	Volat	26986.79	Waver	19660.23
10	Volat	24044.69	Volat	20651.77	Volat	19239.82	Equal	17820.92
11	Waver	19952.39	Waver	21103.53	Volat	18465.01	Volat	18829.19
12	Volat	18213.81	Volat	20726.67	Erad***	39941.25	Volat	19830.71
13	Volat	22035.68	Volat	19707.96	Volat	21000.41	Waver	18210.22
14	Waver	23483.12	Volat	36642.71	Volat	18407.82	Volat	17840.67
15	Volat	19452.45	Volat	18157.02	Volat	18259.03	Volat	18114.24
16	Volat	19127.8	Equal	17820.92	Equal**	**17820.92**	Erad	**14619.69**
17	Volat	26243.03	Volat	19473.43	Waver	19347.17	Volat	18539.26
18	Waver	18721.04	Waver	23532.5	Equal	17820.92	Volat	18165.3
19	Equal**	18038.32	Erad	25941.62	Volat	26026.94	Volat	23220.77
20	Volat**	53787.93	Erad	19339.78	Volat	19694.91	Equal	17820.92
21	Volat	21065.11	Volat	18325.81	Waver	22588.41	Volat	20772.36
22	Erad*	47983.24	Erad	24378.3	Volat	18431.01	Volat	20234.07
23	Volat**	36323.37	Erad	22275.47	Erad*	22292.32	Erad	21836.54
24	Waver	34940.53	Waver	32052.34	Volat	20853.78	Equal	17820.92
25	Volat	34049.07	Volat	26070.71	Waver	33622.54	Volat	20079.61
26	Erad*	**13656.41**	Erad	15619.8	Volat	24308.45	Volat	17995.64
27	Volat*	18596.01	Volat	18310.82	Volat**	22551.81	Erad	19713.06
28	Volat	19627.97	Volat	18355.04	Waver	28047.48	Waver	24255.91
29	Waver	40776.66	Volat	18286.64	Volat	20945.14	Volat	21860.64
30	Volat**	19054.09	Erad	**15115.43**	Waver	19942.1	Volat	21753.32
	T3				**T4**			
Player	**Cluster R1**	**Total C**	**Cluster R2**	**Total C**	**Cluster R1**	**Total C**	**Cluster R2**	**Total C**
1	Volat	18257.06	Volat	18404.88	Equal	**17820.92**	Equal	17820.92
2	Volat	31765.43	Volat	27157.34	Waver	19977.86	Volat	18839.54
3	Erad***	32447.52	Equal	50877.74	Volat	19767.31	Volat	18088.62
4	Volat	22059.05	Volat	25178.86	Erad***	22660.65	Waver	21985.35
5	Waver	26098.2	Volat	22027.63	Volat	23094.26	Waver	22486.94
6	Volat**	20649.6	Erad	20688.54	Erad***	21088.63	Waver	19389.37
7	Volat	46370.72	Waver	25077.66	Waver	23902.45	Waver	20158.02
8	Volat**	17968.84	Erad	13848.89	Erad*	30941.9	Erad	28144.79
9	Volat**	19260.07	Equal	17820.92	Volat**	24732.88	Erad	22931.72
10	Volat**	20476.85	Erad	11515.84	Volat	20595.87	Volat	18753.27
11	Erad*	26528.83	Erad	16927.81	Waver	20801.05	Waver	22392.5
12	Waver	19934.47	Volat	18836.22	Waver	28014	Waver	27845.67
13	Volat**	21799.75	Erad	15619.8	Waver	25170.34	Waver	20210.95
14	Volat	18009.21	Volat	18022.25	Equal	**17820.92**	Volat	25605.27
15	Volat	18177.09	Volat	18588.33	Equal	**17820.92**	Volat	18875.62
16	Volat	19180.01	Equal	17820.92	Equal	**17820.92**	Volat	19797.9

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17	Volat	22013.6	Equal	17820.92	Volat	19374.13	Volat	23515
18	Waver	36346.99	Waver	32767.98	Volat	18093.58	Equal	17820.92
19	Erad***	**13147.68**	Volat	19471.81	Erad*	28984.29	Erad	29619.35
20	Waver	30749.49	Volat	22236.58	Waver	19190.84	Volat	18019.72
21	Volat**	17953.8	Erad	20824.3	Equal	**17820.92**	Volat	18932.13
22	Equal	17820.92	Waver	21261.05	Volat	47733.2	Equal	47614.71
23	Volat	29706.66	Volat	41430.85	Equal	**17820.92**	Volat	18463.59
24	Erad*	15928.94	Erad	27018.65	Volat**	19993.25	Erad	18734.12
25	Volat	19433.21	Equal	17820.92	Waver	28893.15	Waver	22970.23
26	Volat	20821.95	Volat	19197.57	Volat**	18919.7	Erad	**15998.32**
27	Volat	20137.7	Volat	18363.03	Erad***	28556.05	Waver	31166.85
28	Waver	19368.77	Volat	21868.19	Volat	17883.62	Equal	17820.92
29	Equal	17820.92	Volat	18086.44	Volat**	22366.83	Erad	18440.79
30	Volat	19069.74	Volat	18215.06	Equal	**17820.92**	Volat	18237.11

[11] Applied eradication in both rounds of the game (*); Switched **to** eradication in the second round of the game (**); Switched **from** eradication in the second round of the game(***); **bold** - lowest cumulative number for the group

[12] T1, T2, T3, T4 - Treatment groups 1, 2, 3, 4

[13] R1, R2 - Rounds 1, 2

[14] Total C - Total cumulative number of incidence by the end of the round

Eradication cluster

By scanning the results, I have noticed that in the second round more players have turned to eradication strategy. In order to check hypothesis H_1 I run a t-test to check for the significance in improvements. I define improvement by pursuing eradication as a strategy. The results of a t-test for improvements by attempting eradication in the second round versus the first round can be seen in the table below.

Table 12: Second Round Improvement t-test Results

Compared groups	t	p-value	95% CI	means (r1, r2)
T1(r1) and T1(r2)	-1.680	0.0992	[-0.366; 0.033]	0.1 0.27
T2(r1) and T2(r2)	-0.851	0.3983	[-0.224; 0.090]	0.067 0.133
T3(r1) and T3(r2)	-0.992	0.3253	[-0.302; 0.102]	0.133 0.233
T4(r1) and T4(r2)	-0.328	0.7438	[-0.237; 0.170]	0.167 0.20

[15] T1, T2, T3, T4 - Treatment groups 1, 2, 3, 4; r1, r2 - rounds 1,2

Even though in the second round more players attempted eradication, the improvements compared to the first round are not statistically significant (p-value for all the treatments is > 0.05). This rejects the hypothesis H_1, proving the alternative H_0 to have more support. With the most players in T1 switching to eradication strategy (8 in the second round, compared to 3 in the first round) the eradication cluster still did not represent the majority of the strategic choices. The fact that more participants chose in favor of eradication in all treatments supports the notion, that there might be some kind of learning occurring while interacting with the game, and the experience of the first round allowed the participants to gain necessary skills in terms of analyzing the information cues provided for them. As I did not explicitly measure understanding and learning, I decided to check for the comments from the survey, that the participants provided when describing their strategies and decisions.

An interesting example is the player 16 from the T2 treatment group. For this player the conditions were 2 years of perception delay and eradication stated explicitly as a goal.

This person had no experience in vaccination activities, however, had an advanced knowledge and experience in application of System Dynamics. According to the reasoning for the actions, the subject noted that in the first round chose equal allocation for the whole turn in order to understand the behavior of the system, and consequences of actions and possible bottlenecks. After testing the system, in the second round this player performed sequential eradication from the first years investing full resources into one disease and then gradually reversing the budget proportions. For this player the results of the decisions were the main source of information for planning actions. Generally speaking, this kind of performance would be usually excluded from the research analysis, as an out-performer. However, this proves my conclusions stated above. The analytical approach to the provided information allowed this person to draw necessary conclusion about the system at hand. The player made use of all the information cues provided, with the same level of importance, used a first round to test out the assumptions and attempted and achieved eradication in the second round of the game.

Another interesting example is the player 19, from the treatment T4. For this player, the conditions differed in the goal formulation (T4 - achieve the lowest total cumulative number of cases by the end of 20 years period), and had the same time delay. In contrast, this subject did not have any knowledge in or experience with System Dynamics, however, was involved in vaccination activities. In both rounds the player chose eradication as a strategy. Interestingly, for this player the decision results did not change the choices on the budget proportions.

The two players seemed to apply different ways in approaching the problem. A person with substantial knowledge in system dynamics have used the game as a tool to test assumptions and observe the system's behavior, used the provided information to base the strategy and performed eradication in the second round. This player has the highest R^2 from the regression and all the information cues marked as significant. The other player, from a different treatment attempts eradication already from the first round, stating that the results of the decisions did not influence the following budget proportions allocation decisions. This player seems to use the background knowledge for solving the problem. In comparison to player 16, from T2, player 19 from T4 has lower R^2 from the regression model, and information cues marked to be less significant.

Out of 32 players in eradication cluster from both rounds, only 7 had been involved in vaccination activities, 10 had some sort of knowledge in System Dynamics. The rest did not have experience in any of the fields. The two players (16 from T2, and 19 from T4) seem to be exceptional in the reasoning for their strategic choice and the way they approached a problem. Thus, their results cannot be taken as a general representation of the cluster performance. However, they can serve as a fruitful indicator for the further research, that could test background as a mean to inform decision making and analytical approaches to DDM.

Among other players, who shifted to eradication in their second round, or attempted it during the first round, several players specified that their strategy was trial an error, few others did not know how to describe their strategy. Many, however, pointed out that in their first attempts they tried balancing the budget proportions, hoping for this strategy to achieve eradication, but after they realized it was not working, they have attempted eradication. For most of the players, who attempted eradication in any of the rounds, the system behavior was mostly expected. Nevertheless, there were several subjects for whom

the behavior did not follow their expectations. For many the concept of total cumulative incidence was confusing, as players expected it to go down once eradication was achieved. Overall, the players, who attempted eradication in the second round seemed to pursue this strategy as they realized from the experience, that their previous strategic choice did not bring the desirable results. This brings me to a conclusion, that the improvement in their performance comes from experience and the interaction with the game more, than it comes from a thorough understanding of the underlying dynamics of the system. However, this claim would need to have further research and assessment.

Volatility and Wavering clusters

The players in this clusters had similar reasoning for the decisions they made. The difference between the two strategies is that people who wavered were more aggressive in budget proportions and were consistent with shifting the resources for a period of time longer, than those from the volatility cluster. In both cases, the reasoning that the players provided was allocating more budget to the disease that was more pressing, and once the incidence got lower, shifting the resources towards the opposite disease. This follows along the control policies described by Duintjer Tebbens and Thompson, when the resources are allocated based on the prevalence of perceived incidence. For these clusters, once again, the concept of cumulative incidence was rather confusing, people were expecting it to decrease. From my observations almost no player mentioned the delay time, except for one player in the wavering cluster, who perceived the reporting delay to be an indicator for waning of immunity. In the reasoning this player provided the vaccination was only needed in certain periods, thus deciding that odd years should be dedicated to vaccination against one disease, and even years - for vaccination against another disease. Once again, this is a one standing out explanation, provided in the survey, which cannot be generalized over the whole cluster, however it indicates that players may misunderstand the given constants and values and attribute different meanings to them, which will guide their policy. In fact, for this player, it turns out that not the information cues were driving the strategy, but the internal understanding of the concept of time delay. This observation stronger encourages the need for pre- and post- assessment of understanding.

Discussion

Results Summary

As a summary of this research, I want to note several interesting results. First of all, despite the fact that different treatments did not have a significant impact on the strategic choices as I hypothesized, the experiment proved to be successful in identifying the general strategic pathways that people apply in a task of resource allocation for eradicating infectious diseases. As I have observed, different clusters, although with slight differences in the distribution of players between them among the treatment groups, are still quite representative of the choices that people make. The heterogeneous sample group and the fact that a very small proportion of people (only 40% counting from both rounds) attempted eradication tells me that no matter what is the background and the experience of a person, a very small fraction of people will be able to realize an optimal strategy and commit to it. This finding follows the insight that Homer found in his experiment (Homer,

1985). The gaming setting and two rounds of practice provided the players with a safe environment for experimentation, conditions with the minimized complexity of the system that they had to control, and a limited variety of decisions that they needed to make. Still, the results show a rather small proportion of players who succeeded in eradicating the diseases

The majority of players were placed in the volatile allocation cluster in all the treatments, which means that they attempted a rather indistinctive strategy. Many noted the ethical dilemma on the equal allocation and the consequences of neglecting one disease while prioritizing the other, which certainly cannot be ruled out and ignored. A considerable number of players tried to be more aggressive in their budget allocations, making one disease a priority, and, later on, abandoning this strategy as they were scared of the impact from another disease. After the resource was withdrawn from one disease, a severe outburst followed, which was caused by the remaining infectivity and the delay in reporting. The players seemed to fail to understand the reasons for such behavior of the system, which prevented them from trying other strategies and flattened out their resource allocation in the second half of the term. The players who wavered got into this trap, stating that they were balancing the diseases by allocating the bigger budget proportion to a more pressing disease. They described that they understood what they needed to do and felt like they had the system under control. Despite such self-confidence in their responses in the survey, most of the players who stated that they felt like the behavior of the system followed their expectations, I believe, had a wrong perspective on the reasons for the observed behavior. That is why they reasoned that shifting resources to the more prevalent disease made sense. The regression model applied to the clusters proved to fit best only in the eradication cluster, also with the most consistent results on the significance of the information cues. I believe these results can be interpreted as a means of understanding how to use the provided information in order to form dynamic decisions. The treatments did not have a significant impact on the way the strategies were distributed. That is why I am convinced that the strategic choice was less impacted by the information cues provided to the participants, than by how they used this information. In other words, players who were able to analyze the information developed an understanding, which allowed them to figure out how to eradicate the diseases. However, in order to assess whether understanding occurred for these players, a more thorough investigation needs to take place. For this purpose, the game should be transformed into an ILE and used for a research to investigate learning and understanding as proposed by Sawica, Kopainsky and their colleagues (Sawicka & Kopainsky, 2008), (Tabacaru, Kopainsky, Sawicka, Stave, & Skaza, 2009). They had conducted a thorough investigation into learning and how to better study these processes with the use of interactive learning environments.

In my opinion, despite the differences in treatments, all the players had the same task, the same goal and had the same information available. Some of them were able to analyze the consequences of their decisions by looking at the output graphs to make a strategic choice and achieve eradication, and others did not manage to do so. For this reason, the empirical results provide the basis for my conclusion that the ability to analyze the information and make use of it plays a crucial role in dynamic decision making. Players who achieved eradication figured out that the limited resource was only enough to fund the vaccination sequentially to achieve eradication. The fact that in the second round more people pursued eradication strategy shows a positive tendency, however, the improvement was not statistically significant and the underlying reasons for such improvement should

be further investigated. Better performance can be explained by luck (participants just tried investing all the resources out of curiosity); trial and error (players tried different strategies and got enough evidence that equal or nearly equal allocation will not lead to eradication); experience of a repeated game; or, more preferably, by actually learning about the system and understanding the underlying dynamics. The survey results were not informative enough to assess the player's understanding, but the overview provides evidence that even those who switched to eradication in the second round did not do so due to a thorough system's understanding. Now, even if the trial and error method and the learning from experience were a reason for improvement in the second round, first, it was not overarching for the majority of the players, and second, in case of real life, we only get one chance to make a decision, and there are no more rounds to try out a different strategy or test assumptions. And if there are, - it is a different situation to handle, a different person making decisions, and the different people who will need help.

Limitations and Improvements

While analyzing the experimental results I have noticed possible ways for further improvement.

Experimental design and simulator design

The 20-year time span for the simulation was enough for the two treatment groups T1 and T3 with a shorter perception delay but was not enough for the other two treatments in order to eradicate both diseases by the end of the game. Different time scales for different treatments would jeopardize the conditions for the treatment groups, and longer terms would increase the time required to complete the game. This, potentially, could lead to making the players rather tired, as the range of actions in the game is limited, as well as lose interest and willingness to continue the game. Moreover, a longer time scale would not be realistic in terms of the game setting, as the players are put into a role of the Minister of Health. The time delays as treatment conditions do not significantly impact the strategic choices of the players. With regard to this observation, if the research is to continue, the time span should be considered more carefully, probably eliminating the delayed treatment as a condition, but testing more complex systems and allowing a wider range of decisions under the same delay conditions.

As some players did not use the whole budget, I believe there was a misunderstanding from their side on the mechanics of budget proportion calculations. In the simulator, the proportion for the second disease is calculated automatically in case the total available budget is exceeded after allocating the budget to the Disease 1. Otherwise, the players are free to choose proportions at their will. One solution could be to automatically calculate the second budget proportion, but this will basically leave the players with a single decision. Another way would be to create a notification, in case the whole budget is not used, so that a player pays attention and reconsiders the budget proportions to use all the available resources. The budget proportions were also constrained by a .1 increment which potentially could be more flexible, allowing the players to chose any budget proportions.

The fact that Duintjer Tebbens and Thompsom in their article focus on the total cumulative incidence as a metric to assess how different policies perform over time, does

not bring as much value for the experimental setting with different time delays. As the treatment groups had different perception delays, it would make more sense to collect the information on the delayed cumulative number of cases. In this case, such a metric would be more representative for the different treatments. When using the delayed total cumulative incidence, the participants could also be distributed into different clusters based on their performance on the final delayed cumulative number of cases. The best strategies in different conditions would differ depending on the final number of cumulative cases.

The regression model was based on the information cues provided to the participants. In order to check other combinations of factors, for example, a model of differences on budget proportions, the cumulative number of cases would need to be presented separately for each disease.

In general, the interface proved to be user-friendly, as the vast majority of the players understood the given task and were able to interact with the simulator. However, as some players experienced problems, did not understand the mechanics of the simulator, the task at hand, the goal and the given concepts, more emphasis should be given to the design and the description of the task. In addition, more beta testing would significantly improve the simulator and the experimental design.

Model validity and statistical significance

The deterministic model proved to represent the results reported by the authors of the original model. The small adjustments described in the section Model Description driven by the deterministic type of the model that was underlying the simulator did not change the general dynamics. However, after reviewing the strategies applied by the different players, in particular, those who attempted eradication, I have noticed that many of them do not pursue eradication strategy as aggressively as described by the professors (Tebbens & Thompson, 2009). Often, people gradually decrease the proportions when they are approaching eradication, or do not allocate 100%, but around 80% of the budget and still achieve eradication. A good validation test would be to compare the output of the original stochastic model with such a customized strategy.

The sample size for the research resulted in 120 players being equally distributed between the treatment groups. Even though this amount of subject is a minimum necessary number for the statistical evidence to be reliable, I believe a bigger sample size could increase the statistical power of the results. Another interesting change would be to test for different demographic groups, to control whether background matters in this type of DDM.

Implications for Further Research

Decision diversity and increased complexity

As I have mentioned before, in case of eradication policies, I have noticed many, that were not as aggressive in the budget proportions, however still achieved eradication. What resulted in lower total cumulative cases, perhaps came at a cost of longer investment periods. This brings into the light a question of costs associated with a certain policy. In this research I decided to eliminate this from the player's concern by fixing the budget and not discussing the costs at any point of the game. However, realistically speaking, in every project the decision makers need to consider costs, that are associated with their

decisions. Including this metric would add up to the complexity of the decisions, but would also make it more interesting to test different trade-offs when it comes to saving lives versus saving money. Perhaps, when costs are included, the long-term / short-term conditions can be an interesting experimental setting.

Other settings

Numerous participants mentioned the ethics while explaining their reasoning for strategic choices. Several admitted that they realized how sequential eradication was more optimal, as it allowed getting rid of the diseases, however, required neglecting one of the diseases, for the long-term sake of eradication. This debate has a real-life implication, is definitely viable, and cannot be ignored. Equality is one of the core foundations in the decision making processes that are related to public health. The problem with the eradication of infectious diseases is not the only one where resource allocation can be demanding. This research used a simplified version of dealing with the disease by financing vaccination. A more complex model, which would include different ways of dealing with the problem (prevention, quarantine, R&D), can be a fruitful setting for a simulator in order to test the strategic choices and DDM with different options and emerging trade-offs. The facelessness of the diseases in this research, their general similarity in infectivity and severity makes it rather artificial in terms of relating it to real life. Tailoring the model to fit a specific disease and testing the simulator with certain diseases, can be another option of further investigating the DDM in the resource allocation setting.

ILE potential

The simulator can be transformed into an Interactive Learning Environment, which can be used to enhance learning about the dynamics and the complexity of SIR models, and the concepts of delays and accumulation. The experiments with the ILE's can enrich the research related to improving understanding and learning by using simulators. Understanding the difficulties that people face when they have to make dynamic decisions in the setting of disease management and resource allocation can provide suggestions for better training techniques and potentially increase the use of models and simulators as research tools, for teaching, and as a flight simulator for decision support.

Conclusion

Eradication of infectious diseases has a long history of success stories and failures, and many stories of continuous battles and research for improvement. Eradication requires consistent effort and significant resources: monetary, time, human. As all resources are scarce in nature, managing these resources and allocating them in order to achieve a certain goal is challenging. No disease behaves alike, and no disease can be considered less important than the other. Despite the differences in biological factors and severity of a certain disease, one thing they all have in common is that they affect human lives. At a minimum, a disease can cause severe complications, even when the person has recovered, at most, it can cost one's life. Eradication of a certain infectious disease is not a matter of a single factor, but many. Different aspects affect the problem at hand: the biological possibility for eradication, the history of the success of previous efforts, the political, economic, social, ethical considerations. If eradication is possible to achieve, it is in the hands of the decision-makers to know the right choices to make, the time to make them, and the power to commit to these decisions under pressure of trade-offs and uncertainty.

Dynamic decision making is a demanding activity posed by people's inherent inability to process large quantities of information and make use of it. Yet people have to engage in this type of activity because the world where we live will only get more and more complicated. Thus, in order to succeed, people need to learn how to make dynamic decisions. To improve decision-making abilities, one should first start by investigating the general decision trends in a problematic situation.

I developed a game based on a generic existing model that looked at the competition between two equal infectious diseases and required the decision maker to allocate budget to fund vaccination activities and eradicate the diseases. The sample groups represented a general sample of a population with different age ranges, backgrounds, and current occupation. The results of their interaction with the game provided several interesting insights. Despite the fact that different treatment groups did not significantly affect the strategic choices of the players, the experiment still proved valuable in identifying the general trends in this resource allocation task. The majority of the players performed poorly in the game: only 40% in total from both rounds of players attempted and achieved eradication. The information factors that were associated with the eradication strategy compared with other strategies made me come to the conclusion that in a given setting, it was not the difference in treatments that affected the strategic choice of a certain player. All were presented with the same information in all treatments, but for the players who pursued eradication, these information factors were marked as highly significant, however, for the rest of the players, there was a lot of inconsistency regarding the significance and the actual factors that influenced their budget allocation choices. Instead, I believe that success, as I defined by attempting eradication in the game, comes from the players paying attention to all the information cues provided and being able to analyze this information in a way that allowed them to figure out which policy yields the desired result. However, in order to test this assumption, a further investigation should be conducted on participants' development of an understanding of the underlying system.

When the situation is considered in the context of real life, managing infectious diseases is in fact much more complex than how it is presented in the game, and the development of an infectious disease depends not only on the decisions that are made by people. It also

on the disease's endogenous infectivity factors, the environment where it is spread, the general health care system, health conditions of the population and many other factors. All these factors certainly complicate eradication efforts, no matter how well thought out the strategies are to tackle them and how efficient and sufficient are the resources. If people do not understand how to make optimal decisions and do not attempt them in a safe environment of a game, how can we expect them to make the right decisions and stick to them in real life, when the system at hand is far more uncertain and there are many more aspects and trade-offs that must be considered? If people perform rather poorly in a game, even after they have a chance to experiment and learn, what will happen in real life with real money to invest and real lives at stake?

The results of the experiment provided with the implications to the broader problem of resource allocation and decision making in following ways. The game results from the heterogeneous sample group provided with the empirical evidence, that despite a wide variety of background knowledge and experience, the majority of people do not manage to make a full use of the provided information and analyze it in a way that would allow them to infer what strategy leads to eradication. A rather simple underlying SIR model and a single dynamic decision of resource allocation created enough complexity for more than half of the participants, which undermined their success in the game. In real life, the decision makers are most of the times people with experience in the process and/or content. The experiment indicates, that a person who is chosen to make such decisions shall be selected with care, as the majority would not be able to analyze the situation correctly and understand what are the necessary actions.

Following this suggestion, such type of simulators can be used at different stages of managerial management: application stage, teaching, and intermediate assessment. The background of the players was not assessed in this study, to control for its impact on the output. However, from the overview of the results from the players who achieved eradication and who did not, the background experience varied. As I noted previously, the results suggest that successful players (those who achieved eradication) were able to take into consideration provided information and make use of it. The typical application process for the managerial position that would require intense problem solving and dynamic decision making can integrate using simulators for initial assessment of the analytical abilities of an applicant. Think aloud procedure while the applicant is interacting with the game can be a fruitful source of the abilities in dynamic thinking and on-the-fly analysis of the situation at hand. The result of the interaction with such simulator may prove to be more informative of the person to be able to succeed in dynamic decision applied on complex tasks, in addition to a usual curriculum vitae that only describes in words the capabilities of an applicant.

Another use of the simulator in a form of an interactive learning environment (ILE) can be helpful in teaching the managerial stuff on the complexity of resource allocation and other dynamic decision tasks. These procedures can be periodic, in order to train and maintain the systems thinking among the decision makers. In the case of disease management, the game can be adapted to fit a certain area, incorporate different diseases, or alternatives for funds distribution. The ILE will be a toolbox for learning about the possible bottleneck and pitfalls in allocating the resource while managing infectious diseases. On a broader scale, the simulator can be developed for other domains as mentioned by Duintjer Tebbens and Thompson (Tebbens & Thompson, 2009) that have a similar dynamics that depends on the resource allocation decisions, for instance development of a new product, project

and task management, emergency response.

Finally, intermediate assessment is another application of such type of simulator, where the decision-makers are placed in a problematic situation and need to solve a problem at hand. This can help with checking on the current level of dynamic decision-making capabilities, identify in advance in case a decision maker should put more emphasis into the way he or she approaches dynamic problems and provides a new, challenging, but also an entertaining way of keeping analytical and system's thinking skills of the decision makers "in shape".

The experiment also sets the ground for further investigation. Future research can focus on different structural components of the model that create complexity for the decision-makers in this type of task. Similar to the experiments conducted by Moxnes (Moxnes, 2000), future experiments should look into the factors that hinder or enhance people's understanding of the underlying model and the created dynamics and its effect on the decisions people make. This can help us understand what makes it difficult to infer the correct strategy and commit to it.

There is no doubt that making dynamic decisions requires a great deal of thinking and it is never easy, considering the ever-changing environment, constraints, and high uncertainty. Nonetheless, if the decision-makers are equipped with skills that empower them to use tools that help them properly make sense of the available information and analyze the situation, the results of their decisions will be more and more successful.

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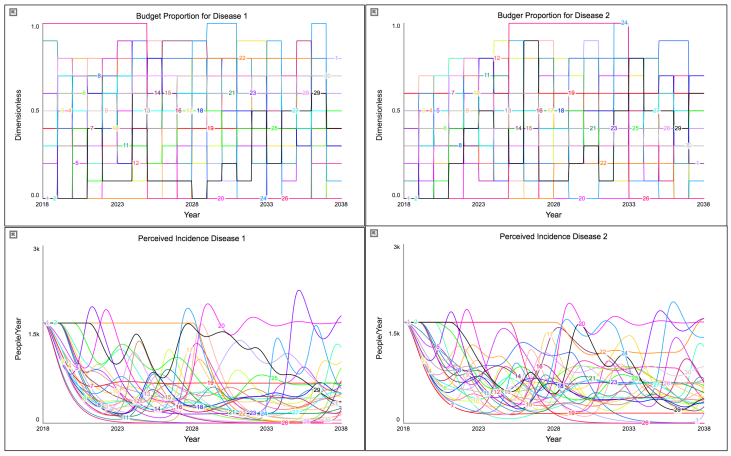
Appendices

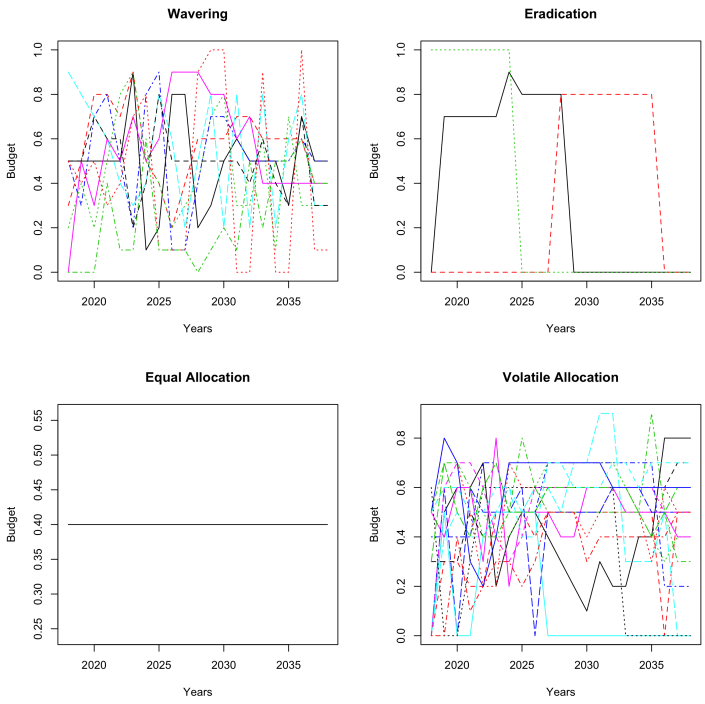
Appendix A

Game Output Graphs, Round 1

Figure 2: Treatment group T1

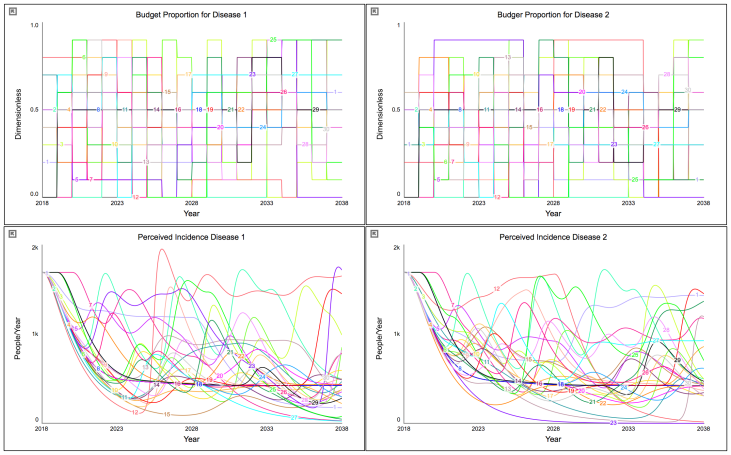


(a) Game Output

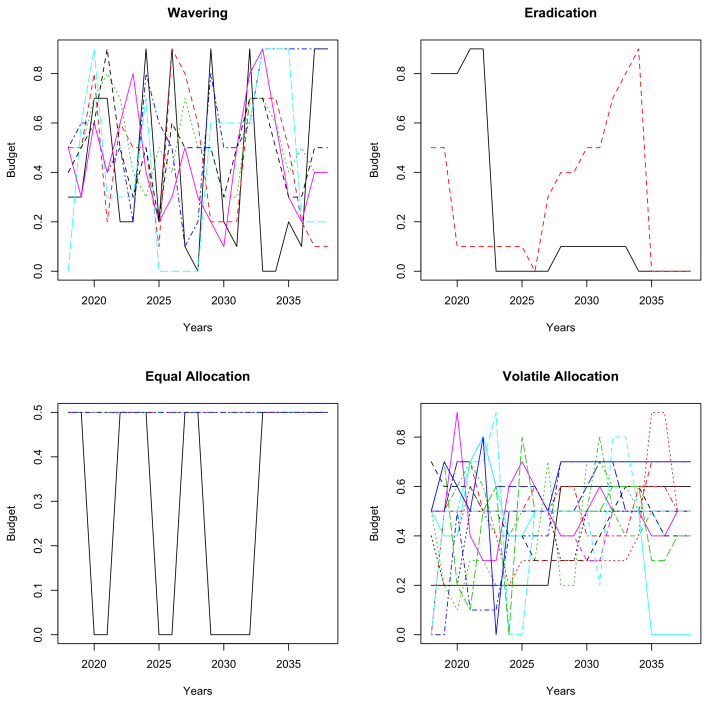


(b) Clusters

Figure 3: Treatment group T2

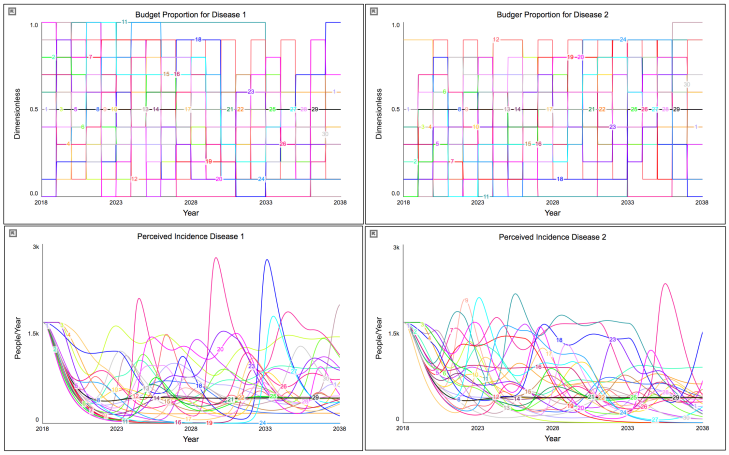


(a) Game Output

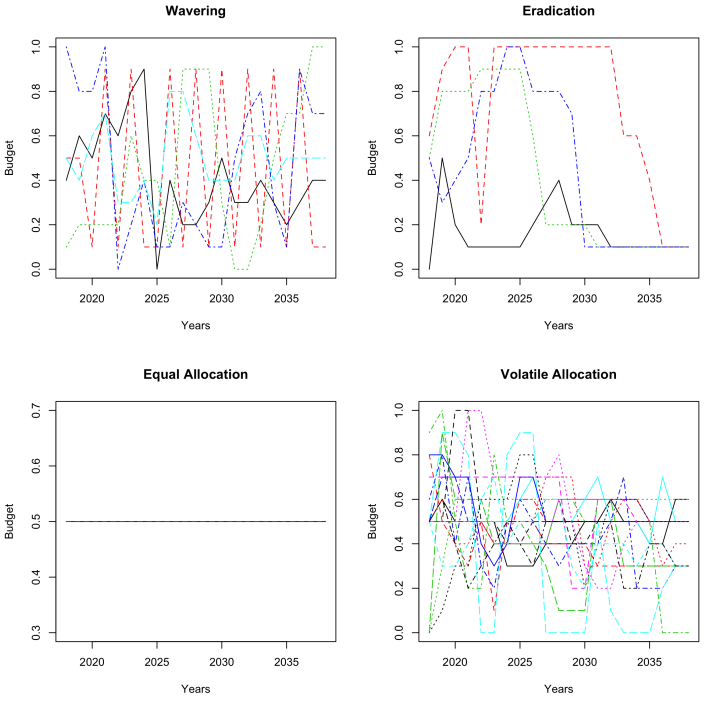


(b) Clusters

Figure 4: Treatment group T3

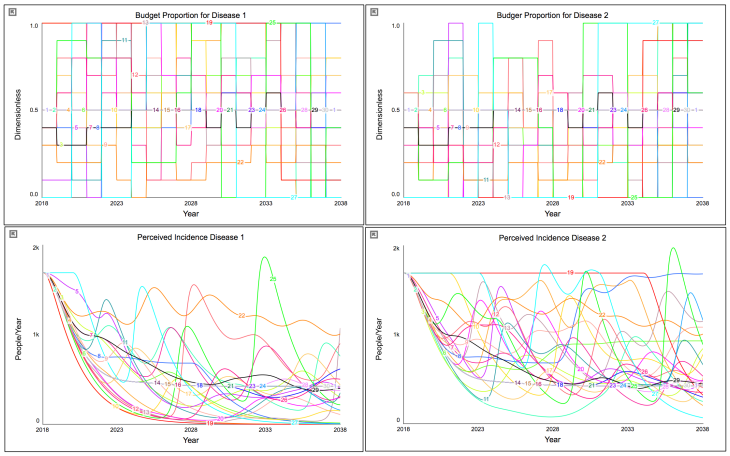


(a) Game Output

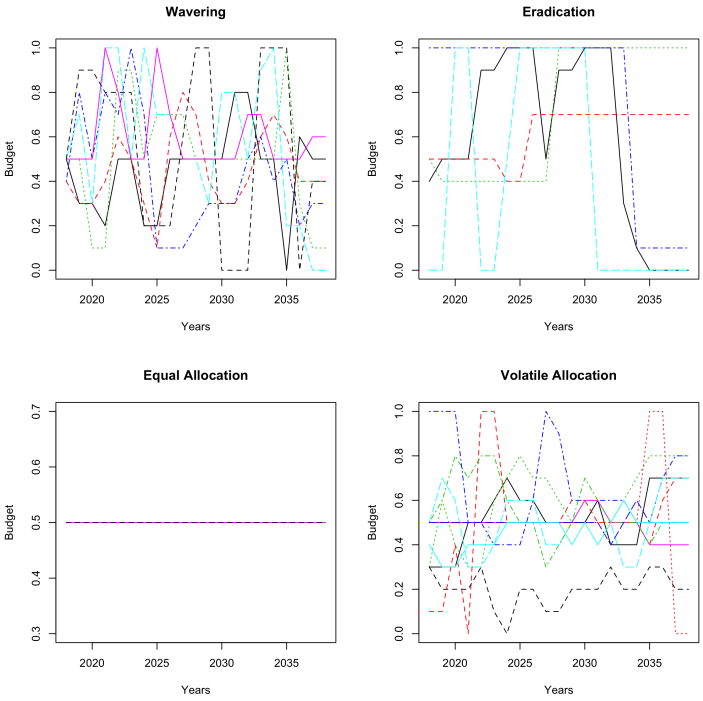


(b) Clusters

Figure 5: Treatment group T4



(a) Game Output



(b) Clusters

Appendix B

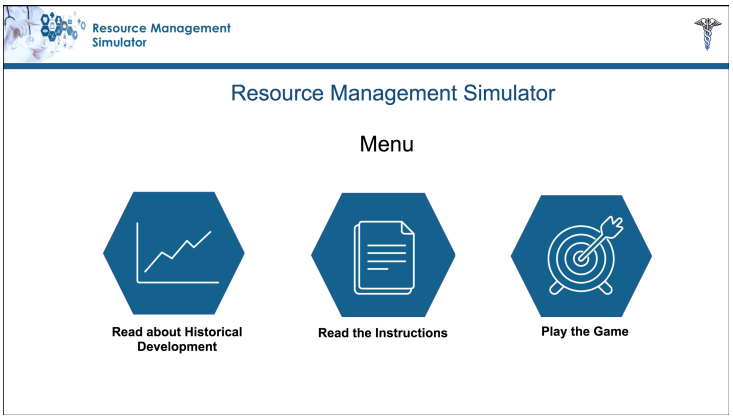
Interface Example

Figure 6: An example of Resource Management Simulator (RMS) interface for a player from a treatment group T1.

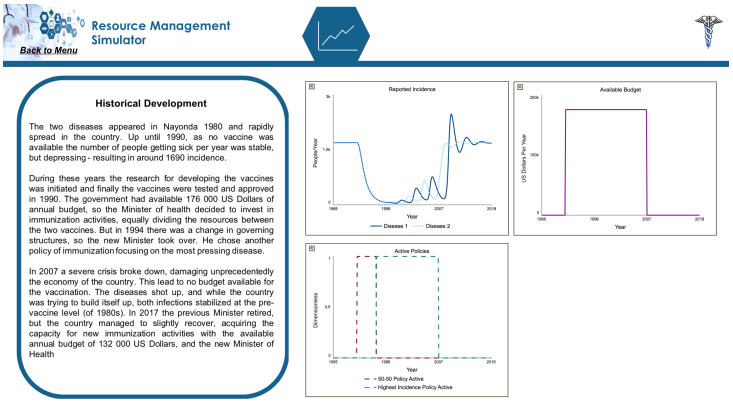
(a) Central Page

(b) ID Page

Figure 7: RMS Interface continued...

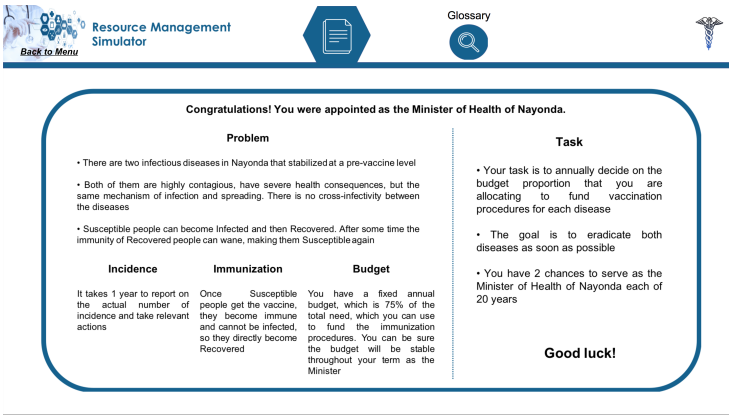


(a) Navigation Page

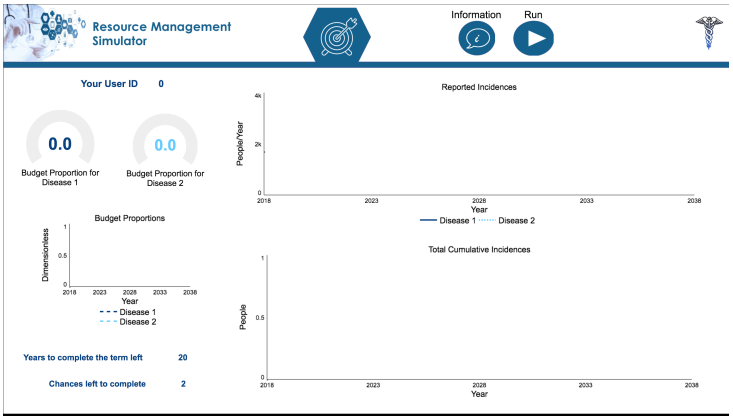


(b) Historical Development Page

Figure 8: RMS Interface continued...

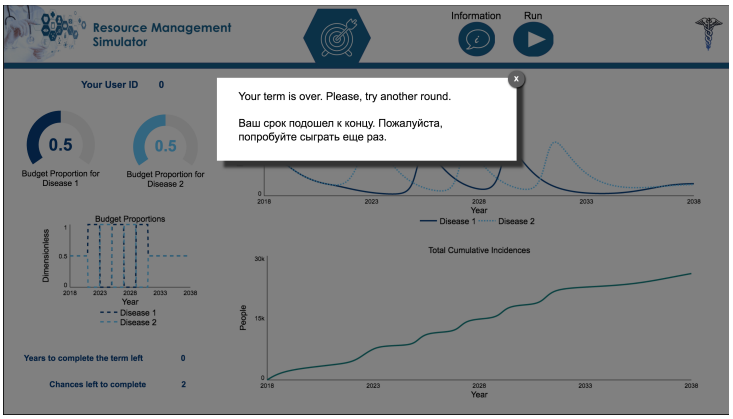


(a) Instructions Page



(b) Game Page (Start)

Figure 9: RMS Interface continued...



(a) Game Page (End)

(b) Final Page

Appendix C

Simulator Historical Development, Task, Navigation

RMS. Historical Development

The two diseases appeared in Nayonda 1980 and rapidly spread in the country. Up until 1990, as no vaccine was available the number of people getting sick per year was stable, but depressing - resulting in around 1690 incidence.

During these years the research for developing the vaccines was initiated and finally the vaccines were tested and approved in 1990. The government had available 176 000 US Dollars of annual budget, so the Minister of health decided to invest in immunization activities, equally dividing the resources between the two vaccines. But in 1994 there was a change in governing structures, so the new Minister took over. He chose another policy of immunization focusing on the most pressing disease.

In 2007 a severe crisis broke down, damaging unprecedentedly the economy of the country. This lead to no budget available for the vaccination. The diseases shot up, and while the country was trying to build itself up, both infections stabilized at the pre-vaccine level (of 1980s). In 2017 the previous Minister retired, but the country managed to slightly recover, acquiring the capacity for new immunization activities with the available annual budget of 132 000 US Dollars, and the new Minister of Health.

RMS. Task (T1)

Congratulations! You were appointed as the Minister of Health of Nayonda.
Problem
There are two infectious diseases in Nayonda that stabilized at a pre-vaccine level.
Both of them are highly contagious, have severe health consequences, but the same mechanism of infection and spreading. There is no cross-infectivity between the diseases.
Susceptible people can become Infected and then Recovered. After some time the immunity of Recovered people can wane, making them Susceptible again.
Incidence
It takes 1 year to report on the actual number of incidence and take relevant actions.
Immunization
Once Susceptible people get the vaccine, they become immune and cannot be infected, so they directly become Recovered.
Budget
You have a fixed annual budget, which is 75% of the total need, which you can use to fund the immunization procedures. You can be sure the budget will be stable throughout your term as the Minister.
Task
Your task is to annually decide on the budget proportion that you are allocating to fund vaccination procedures for each disease.
The goal is to eradicate both diseases as soon as possible.
You have 2 chances to serve as the Minister of Health of Nayonda each of 20 years.
Good Luck!

RMS. Navigation Instructions

Hello and thank you for participating in the research. My name is Olga and I am doing a master thesis research in dynamic decision making. You are invited to play a game and complete a post-game survey.

PLAESE DO NOT USE THE "BACK" BUTTON IN YOUR BROWSER TO NAVIGATE BETWEEN THE PAGES

Please, use your PC or laptop to play the game. Use the given link only once and play only 2 rounds. If you are interested to do more rounds, please write to olga.poletaeva94@gmail.com and I will provide you with another link for unlimited trials.

1. Follow the link you were provided
2. Select your language
3. Enter the ID number that you were given and press on the corresponding button on the menu to begin
4. You will be directed to the main navigation menu of the game
5. Fell free to read the "Historical Development" and the "Instructions"
6. Notice, to go back, there is a button in the upper left corner "Back to Menu"
7. IMPORTANT: you cannot go back to the historical development or instructions once you click on the button to play the game

   (Please, **DO NOT** use the browser back button for the navigation)
8. In the game you need to make single annual decisions on the budget proportion and submit it by the "Run" button

   (detailed instructions on the interaction are provided in the game)
9. You have 2 chances to play the game, each round of 20 years
10. Once you are done with the first round, you will receive a notification that the first round is over.

    To continue to the next round, simply close the notification and proceed to the budget proportions allocations. Consider it as a second chance to play the same game.
11. Once you will complete the second round, you will receive a notification about it and will be automatically redirected to the page with the questionnaire
12. PLEASE, FILL IN THE QUESTIONNAIRE, as it is an important part of the research
13. After you are done with the questionnaire, don't forget to submit it

Thank you very much and good luck! Olga Poletaeva. European Master in System Dynamics

Appendix D

Survey

Demographic information

1. What was your ID in the game?
2. What is your age?
    - Less than 24
    - 25 - 34
    - 35 - 44
    - 45 - 54
    - More than 55
3. What is your sex?
    - Male
    - Female

Background information

4. What is the highest level of education that you have obtained so far?
    - High school
    - College
    - Bachelor degree
    - Master degree
    - Doctorate degree
5. What is your current occupation?
    - Student
    - Working
    - Unemployed
6. Do you have any experience with System Dynamics (SD)?
    - No experience
    - Elementary knowledge, familiar with concepts and general ideas
    - Basic knowledge, had a course related to SD
    - Intermediate knowledge, have a degree focused on SD
    - Moderate knowledge, have some experience in application of SD
    - Advanced knowledge, have substantial experience in application of SD
7. Do you have any experience with (knowledge about) vaccination activities?
    - No
    - Yes, I have been involved in vaccination related projects

Game experience

8. How did you try solve to the task? What strategy for budget proportions allocation did you follow? (Describe briefly)

9. Did you consider eradicating the diseases as your strategy to solve the task? Why /why not? (Explain briefly)
10. Did you consider controlling the diseases incidence at a certain level for a long period of time as your strategy to solve the task? Why / why not? (Explain briefly)
11. What was your starting choice of budget proportion for each disease and why? (Describe briefly)
12. What information cues were you looking for when making budget proportions allocation decision? (You can choose several options)
    - Current reported incidence for Disease 1
    - Current reported incidence for Disease 2
    - Relative strength of the disease
    - Most pressing disease
    - Current total cumulative incidence
    - Development of the trend in incidence for the diseases that followed my decisions
    - Other (please specify)
13. Did the system develop according to your expectations after a certain decision on budget proportions allocation? If no, what was different? (Describe briefly)
14. Did the results of your decision influence your next choice regarding the budget proportion allocation? If yes, how? (Describe briefly)
15. Did you change your strategy of budget proportions allocation during the first round of the game? Why / why not? If yes, how? (Describe briefly)
16. Did you change your strategy of budget proportions allocation during the second round of the game? Why / why not? If yes, how? (Describe briefly)
17. Did you achieve the goal?
    - No
    - Yes, in the first round
    - Yes, in the second round
18. How difficult did you find the task while interacting in the game?
    - Extremely easy, I had complete control over the problem and knew exactly what I needed to do
    - Quite easy, I felt quite confident with my decisions and could anticipate what result they will bring
    - Neither easy nor difficult
    - Rather difficult, but after the first round I had an idea what I should do
    - Extremely difficult, I could not take the system under control

Appendix E

Regression Results by the Treatment Group, Round 1

Table 13: Regression Results for the Treatment Group T1

	B1					B2				
Player	$\mathbf{R^2}$	β_0	β_1	β_2	β_3	$\mathbf{R^2}$	β_0	β_1	β_2	β_3
1	0.311	0.0606	-3e-04*	4e-04.	3.3e-05.	0.261	1.0194**	2.00E-04	-5e-04*	-3.00E-05
2	0.373	0.2792.	1.00E-04	-2.00E-04	1.10E-05	0.088	0.5873*	-1.00E-04	-1.00E-04	-1.00E-06
3	0.491	0.5644***	4e-04**	-4e-04**	-5.00E-06	0.491	0.4356**	-4e-04**	4e-04**	5.00E-06
4	0.033	0.7197**	-1.00E-04	-1.00E-04	-7.00E-06	0.07	0.3918.	0	0	5.00E-06
5	0.301	0.9241***	0	-3e-04*	-1.10E-05	0.146	0.3521	-1.00E-04	0	5.00E-06
6	0.279	0.4492***	-1.00E-04	2e-04*	-2.00E-06	0.282	0.4256***	1.00E-04	-2e-04.	7.00E-06
7	0.293	0.9243***	-5e-04*	1.00E-04	-3e-05*	0.269	0.1514	4e-04*	-1.00E-04	2.1e-05.
8	0.682	1.1929*	-7e-04**	3e-04*	-7.3e-05**	0.371	-0.3214	3.00E-04	0	5.7e-05.
9	0.429	0.8648***	1.00E-04	-4e-04**	-1.00E-05	0.429	0.1352	-1.00E-04	4e-04**	1.00E-05
10	0.474	0.9506***	-4e-04**	0	-2e-05*	0.283	0.7112***	-3e-04*	0	-1.6e-05.
11	0.307	0.4742*	4e-04*	0	-8.00E-06	0.307	0.5258*	-4e-04*	0	8.00E-06
12	0.007	0.5259***	0	0	-2.00E-06	0.007	0.4741**	0	0	2.00E-06
13	0.883	0.3977**	0	-1.00E-04	1.6e-05*	0.473	0.7669***	-3.00E-04	0	-1.7e-05*
14	0.49	0.8398**	-4e-04**	1.00E-04	-1.70E-05	0.127	0.3313	0	-1.00E-04	5.00E-06
15	0.385	0.4396**	2e-04**	-1.00E-04	1.00E-06	0.385	0.5604***	-2e-04**	1.00E-04	-1.00E-06
16	0.44	0.703***	2e-04*	-3e-04**	-7.00E-06	0.44	0.297*	-2e-04*	3e-04**	7.00E-06
17	0.209	0.257	-1.00E-04	1.00E-04	1.20E-05	0.339	0.1176	-1.00E-04	2.00E-04	1.4e-05.
18	0.373	0.8102***	2e-04.	-4e-04*	-2.1e-05*	0.373	0.1898	-2e-04.	4e-04*	2.1e-05*
19	0	0	0	0	0	0	0	0	0	0
20	0.642	0.1003	0.0041***	-0.004***	-4e-06.	0.568	0.0954	0.0041**	-0.004**	-5e-06.
21	0.138	0.4807*	0	-1.00E-04	8.00E-06	0.449	0.6307***	-2e-04*	-1.00E-04	-6.00E-06
22	0.606	2.0534**	3e-04.	-0.0016**	1.20E-05	0.606	0.5134**	1e-04.	-4e-04**	3.00E-06
23	0.463	0.9381***	2.00E-04	-6e-04.	-8.00E-06	0.286	0.5728**	1.00E-04	-2.00E-04	-9e-06.
24	0.125	0.2564	2.00E-04	1.00E-04	-8.00E-06	0.36	0.6094***	-2.00E-04	1.00E-04	-1.7e-05*
25	0.708	-0.0165	2e-04.	-2e-04.	1.4e-05**	0.559	0.4911*	-1.00E-04	-1.00E-04	4.00E-06
26	0.905	1.7731***	-6e-04**	1.00E-04	-0.000131***	0.318	-1.7482	8.00E-04	3.00E-04	0.000163*
27	0.216	0.6677***	1.00E-04	-2e-04.	0	0.111	0.403***	-1.00E-04	1.00E-04	0
28	0.241	0.3221*	2e-04.	0	1.8e-05*	0.241	0.6779***	-2e-04.	0	-1.8e-05*
29	0.383	0.1977	-1.00E-04	0	7.00E-06	0.6	0.7748**	-5e-04**	2.00E-04	3.00E-06
30	0.565	0.4268***	3e-04*	-2e-04*	2.3e-05***	0.565	0.5732***	-3e-04*	2e-04*	-2.3e-05***
Av	**0.392**					**0.327**				

[16]Significance codes: 0.001 "***", 0.01 "**", 0.05 "*", 0.1 "."

[17]B1, B2 - Budget for infectious disease 1, 2

[18]Av - average result

Table 14: Regression Results for the Treatment Group T2

	B1					B2				
Player	$\mathbf{R^2}$	β_0	β_1	β_2	β_3	$\mathbf{R^2}$	β_0	β_1	β_2	β_3
1	0.797	-0.4184	2.00E-04	2e-04.	2.4e-05*	0.755	1.0342**	-2.00E-04	-2e-04**	-1.8e-05*
2	0	0	0	0	0	0	0	0	0	0
3	0.071	0.46	3.00E-04	-3.00E-04	-4.00E-06	0.019	0.391	-1.00E-04	1.00E-04	2.00E-06
4	0.187	0.3962***	0	1.00E-04	1e-05.	0.187	0.6038***	0	-1.00E-04	-1e-05.
5	0.48	-0.5961	4e-04*	1.00E-04	3.3e-05*	0.464	-0.3273	-1.00E-04	5e-04*	2.1e-05*
6	0.433	0.7282**	3e-04*	-4e-04*	-1.8e-05.	0.433	0.2718	-3e-04*	4e-04*	1.8e-05.
7	0.814	-0.6151	2.00E-04	1.00E-04	4.3e-05**	0.149	-0.464	4.00E-04	0	2.60E-05
8	0	0	0	0	0	0	0	0	0	0
9	0.355	0.9174**	3e-04.	-6e-04**	-1.10E-05	0.719	-0.0502	3e-04***	-1.00E-04	2e-05**
10	0.523	0.6434***	4e-04**	-4e-04**	-1.00E-05	0.523	0.3566*	-4e-04**	4e-04**	1.00E-05
11	0.382	0.2606*	1.00E-04	2e-04.	6.00E-06	0.382	0.7394***	-1.00E-04	-2e-04.	-6.00E-06
12	0.747	1.2478***	2e-04*	-4e-04**	-4.4e-05***	0.13	-0.3342	1.00E-04	2.00E-04	1.30E-05
13	0.124	0.2099	0	1.00E-04	1.40E-05	0.124	0.7901**	0	-1.00E-04	-1.40E-05
14	0.271	0.66***	2e-04.	-3e-04*	-8.00E-06	0.271	0.34**	-2e-04.	3e-04*	8.00E-06
15	0.493	1.0058***	0	-3e-04**	-2e-05**	0.493	-0.0058	0	3e-04**	2e-05**
16	0	0	0	0	0	0	0	0	0	0

Continued...

17	0.365	0.7053***	2e-04*	-3e-04*	-1.10E-05	0.365	0.2947.	-2e-04*	3e-04*	1.10E-05
18	0	0	0	0	0	0	0	0	0	0
19	0.687	0.8422***	1.00E-04	-3e-04.	-2.5e-05***	0.516	0.6786***	-3.00E-04	2.00E-04	-2e-05**
20	0.096	0.4123***	0	1.00E-04	3.00E-06	0.493	0.6336***	-3e-04*	0	2.00E-06
21	0.475	0.0679	2.00E-04	1.00E-04	3.1e-05**	0.475	0.9321***	-2.00E-04	-1.00E-04	-3.1e-05**
22	0.462	0.3599**	2.00E-04	-2e-04*	8.00E-06	0.462	0.6401***	-2.00E-04	2e-04*	-8.00E-06
23	0.121	0.0994	-1.00E-04	3.00E-04	2.00E-05	0.707	1.4587***	1.00E-04	-6e-04**	-7.8e-05***
24	0.326	0.5187**	1.00E-04	-3.00E-04	3.00E-06	0.28	0.5509**	-3.00E-04	1.00E-04	1.00E-06
25	0.055	0.2613	0	0	7.00E-06	0.303	0.5183*	-5e-04*	3.00E-04	-7.00E-06
26	0.085	0.0659	1.00E-04	1.00E-04	1.30E-05	0.329	0.086	-1.00E-04	3e-04.	1.6e-05.
27	0.266	0.3027	2.00E-04	0	2.1e-05*	0.241	0.1148	2.00E-04	1.00E-04	7.00E-06
28	0.13	0.4117.	3.00E-04	-2.00E-04	2.00E-06	0.141	0.1559	-1.00E-04	3.00E-04	5.00E-06
29	0.357	0.2896	4e-04.	-4e-04*	1.9e-05.	0.236	0.7391**	-5e-04.	2.00E-04	-1.20E-05
30	0.299	0.629***	2e-04.	-3e-04*	-9.00E-06	0.299	0.371*	-2e-04.	3e-04*	9.00E-06
Av	**0.313**					**0.317**				

Table 15: Regression Results for the Treatment Group T3

	B1					B2				
Player	$\mathbf{R^2}$	β_0	β_1	β_2	β_3	$\mathbf{R^2}$	β_0	β_1	β_2	β_3
1	0.16	0.3498***	0	1.00E-04	7.00E-06	0.16	0.6502***	0	-1.00E-04	-7.00E-06
2	0.694	0.5444***	6e-04***	-4e-04**	-1.4e-05***	0.074	0.4194***	2.00E-04	-2.00E-04	-2.00E-06
3	0.096	0.3419.	0	-1.00E-04	-1.00E-05	0.766	0.219	3.00E-04	-2.00E-04	1.20E-05
4	0.687	0.829***	0	-3e-04*	1.00E-06	0.261	0.3996**	0	-1.00E-04	5.00E-06
5	0.464	1.1627***	-1.00E-04	-4e-04*	-3e-05**	0.685	0.0432	1e-04*	0	2e-05**
6	0.412	0.6092***	2e-04*	-2.00E-04	-2.5e-05*	0.391	0.4135**	-2e-04.	1.00E-04	2.2e-05*
7	0.32	0.6774*	2.00E-04	-1.00E-04	-1.7e-05*	0.23	-0.1207	0	1.00E-04	1e-05.
8	0.248	0.4414***	0	1.00E-04	5.00E-06	0.248	0.5586***	0	-1.00E-04	-5.00E-06
9	0.247	0.8129***	0	-1.00E-04	-1.8e-05*	0.247	0.1871	0	1.00E-04	1.8e-05*
10	0.204	0.6378***	1.00E-04	-2e-04.	-7.00E-06	0.469	0.1458	-1.00E-04	3e-04**	1.8e-05**
11	0.504	0.762*	-3.00E-04	3e-04*	-2.2e-05*	0.504	0.238	3.00E-04	-3e-04*	2.2e-05*
12	0.006	0.4316	1.00E-04	0	-2.00E-06	0.006	0.5684	-1.00E-04	0	2.00E-06
13	0.39	0.7587**	1.00E-04	0	-2.9e-05*	0.39	0.2413	-1.00E-04	0	2.9e-05*
14	0.279	0.5586***	1.00E-04	-1.00E-04	-5.00E-06	0.279	0.4414***	-1.00E-04	1.00E-04	5.00E-06
15	0.129	0.5602***	1.00E-04	-2.00E-04	2.00E-06	0.129	0.4398***	-1.00E-04	2.00E-04	-2.00E-06
16	0.354	0.935***	0	-1.00E-04	-2.3e-05*	0.354	0.065	0	1.00E-04	2.3e-05*
17	0.4	0.7992**	-2e-04*	-2.00E-04	-5.00E-06	0.328	-0.0508	2.00E-04	3e-04*	1.60E-05
18	0.259	0.2937	-1.00E-04	0	1.4e-05.	0.574	0.1744	3e-04***	-2e-04.	1.00E-06
19	0.922	1.2299***	-6e-04***	2e-04***	-8.6e-05***	0.309	-0.5121	5e-04.	0	8.2e-05*
20	0.015	0.6451	0	-1.00E-04	-6.00E-06	0.338	-0.4347	1.00E-04	3e-04*	2.6e-05**
21	0.218	0.4697***	2e-04*	-1e-04.	2.00E-06	0.218	0.5303***	-2e-04*	1e-04.	-2.00E-06
22	0	0	0	0	0	0	0	0	0	0
23	0.276	0.2543	-1.00E-04	2e-04*	0	0.499	0.5202***	-2e-04.	-1.00E-04	9e-06.
24	0.826	1.5775***	-0.001***	2e-04**	-9.4e-05***	0.29	-0.4696	8e-04*	-1.00E-04	6.8e-05*
25	0.642	0.482***	2e-04**	0	-5.00E-06	0.809	0.5377***	-3e-04***	0	6.00E-06
26	0.278	0.6124***	0	-2e-04.	-1.3e-05*	0.142	0.4637***	0	1.00E-04	2.00E-06
27	0.278	0.9315***	-1.00E-04	-1.00E-04	-2.2e-05*	0.278	0.0685	1.00E-04	1.00E-04	2.2e-05*
28	0.177	0.468**	1.00E-04	-1.00E-04	2.00E-06	0.177	0.532**	-1.00E-04	1.00E-04	-2.00E-06
29	0	0	0	0	0	0	0	0	0	0
30	0.179	0.3562**	1.00E-04	0	-4.00E-06	0.179	0.6438***	-1.00E-04	0	4.00E-06
Av	**0.322**					**0.311**				

Table 16: Regression Results for the Treatment Group T4

	B1					B2				
Player	$\mathbf{R^2}$	β_0	β_1	β_2	β_3	$\mathbf{R^2}$	β_0	β_1	β_2	β_3
1	0	0	0	0	0	0	0	0	0	0
2	0.1	0.2528	1.00E-04	0	1.30E-05	0.1	0.7472**	-1.00E-04	0	-1.30E-05
3	0.427	0.5539***	0	-2.00E-04	8.00E-06	0.27	0.4966***	0	1.00E-04	-8.00E-06
4	0.741	1.4639***	-9e-04***	3e-04*	-6.9e-05***	0.725	-0.3856	8e-04***	-3e-04*	6.5e-05***
5	0.372	0.9824*	0	-5e-04*	-8.00E-06	0.136	0.2854	-2.00E-04	2.00E-04	5.00E-06
6	0.661	0.3384**	2.00E-04	-1.00E-04	2.4e-05*	0.765	0.438***	-1.00E-04	1.00E-04	-1.4e-05*
7	0.676	0.2733	5e-04***	-4e-04**	9.00E-06	0.785	0.5323***	-4e-04***	3e-04***	2.00E-06
8	0.75	0.2225	0	2.00E-04	2.20E-05	0.771	0.4024*	1.00E-04	-1.00E-04	-1.30E-05

Continued. . .

9	0.556	0.2114	3e-04*	-1.00E-04	2.8e-05**	0.077	0.4078.	-1.00E-04	0	-7.00E-06
10	0.733	0.3076*	7e-04***	-1e-04.	2.2e-05**	0.733	0.6924***	-7e-04***	1e-04.	-2.2e-05**
11	0.133	0.8532*	0	-3.00E-04	-1.20E-05	0.133	0.1468	0	3.00E-04	1.20E-05
12	0.169	0.3752	0	2.00E-04	-6.00E-06	0.209	0.0165	-1.00E-04	3.00E-04	1.40E-05
13	0.479	1.4138***	-2.00E-04	-3.00E-04	-3.4e-05**	0.057	0.2653	0	1.00E-04	-7.00E-06
14	0	0	0	0	0	0	0	0	0	0
15	0	0	0	0	0	0	0	0	0	0
16	0	0	0	0	0	0	0	0	0	0
17	0.608	0.2681*	5e-04***	-3e-04*	1e-05.	0.608	0.7319***	-5e-04***	3e-04*	-1e-05.
18	0.353	0.5878***	-1.00E-04	1.00E-04	-7e-06*	0.353	0.4122***	1.00E-04	-1.00E-04	7e-06*
19	0.752	0.5708	-3.00E-04	5e-04**	-2.6e-05*	0.752	0.4292	3.00E-04	-5e-04**	2.6e-05*
20	0.465	1.2425***	-1.00E-04	-4e-04**	-2.6e-05**	0.465	-0.2425	1.00E-04	4e-04**	2.6e-05**
21	0	0	0	0	0	0	0	0	0	0
22	0.25	-0.0323	4e-04.	-3.00E-04	2.00E-06	0.17	-0.0332	-1.00E-04	3.00E-04	3.00E-06
23	0	0	0	0	0	0	0	0	0	0
24	0.569	0.2001	8e-04**	-7e-04***	2.8e-05*	0.569	0.7999***	-8e-04**	7e-04***	-2.8e-05*
25	0.57	0.8065**	4e-04**	-3e-04*	-1.00E-05	0.57	0.1935	-4e-04**	3e-04*	1.00E-05
26	0.256	0.8043**	0	-1.00E-04	-1.70E-05	0.256	0.1957	0	1.00E-04	1.70E-05
27	0.481	-2.6655**	0.0013**	5e-04*	9e-05**	0.642	2.1047*	-9e-04*	-4e-04*	-3.60E-05
28	0.196	0.483***	3e-04.	-3e-04.	1.00E-06	0.196	0.517***	-3e-04.	3e-04.	-1.00E-06
29	0.593	0.4252***	3.00E-04	-4.00E-04	6.00E-06	0.523	0.5161***	-3.00E-04	1.00E-04	2.00E-06
30	0	0	0	0	0	0	0	0	0	0
Av	**0.363**					**0.329**				

Appendix F

Cluster Results, Round 2

Table 17: Regression Results for the Wavering Cluster

					T1					
	B1					B2				
Player	$\mathbf{R^2}$	β_0	β_1	β_2	β_3	$\mathbf{R^2}$	β_0	β_1	β_2	β_3
5	0.16	0.6824*	-2.00E-04	0	-4.00E-06	0.18	0.1173	0	1.00E-04	1.10E-05
11	0.306	0.4573.	3e-04*	-3.00E-04	4.00E-06	0.306	0.5427*	-3e-04*	3.00E-04	-4.00E-06
18	0.288	0.9169*	2.00E-04	-4e-04.	-2.10E-05	0.288	0.0831	-2.00E-04	4e-04.	2.10E-05
24	0.073	0.6514	1.00E-04	-2.00E-04	8.00E-06	0.04	0.13	0	0	5.00E-06
Av	**0.207**					**0.204**				
					T2					
3	0.322	0.3688	4e-04*	-1.00E-04	-2.00E-06	0.154	0.4558	-3.00E-04	1.00E-04	1.00E-06
6	0.31	0.9111***	2.00E-04	-4e-04*	-1.30E-05	0.31	0.0889	-2.00E-04	4e-04*	1.30E-05
9	0.421	0.4743*	4e-04**	-2e-04.	-5.00E-06	0.417	0.6036**	-4e-04**	2.00E-04	0
13	0.011	0.4766**	1.00E-04	-1.00E-04	0	0.011	0.5234***	-1.00E-04	1.00E-04	0
28	0.492	-0.0732	6e-04**	-3e-04.	2.6e-05**	0.385	0.5616*	-4e-04*	4e-04*	-9.00E-06
Av	**0.311**					**0.255**				
					T3					
7	0.445	0.8433**	1.00E-04	-4e-04*	-1.8e-05.	0.445	0.1567	-1.00E-04	4e-04*	1.8e-05.
18	0.5	-0.4977	5e-04**	3e-04.	1.8e-05*	0.4	1.1649***	-3e-04*	-4e-04*	-1.10E-05
22	0.05	0.1439	2.00E-04	0	2.10E-05	0.05	0.8561.	-2.00E-04	0	-2.10E-05
Av	**0.332**					**0.298**				
					T4					
4	0.12	0.7587*	0	-3.00E-04	-6.00E-06	0.099	0.2462	0	2.00E-04	8.00E-06
5	0.314	0.5093.	5e-04*	-4e-04*	0	0.314	0.4907.	-5e-04*	4e-04*	0
6	0.326	1.1444*	-0.005*	0.0044*	-3.00E-05	0.326	-0.1444	0.005*	-0.0044*	3.00E-05
7	0.424	0.6042**	4e-04*	-5e-04**	-1.00E-06	0.424	0.3958*	-4e-04*	5e-04**	1.00E-06
11	0.49	0.508	5e-04*	-5e-04*	-3.00E-06	0.49	0.492	-5e-04*	5e-04*	3.00E-06
12	0.596	-0.3312	6e-04***	0	2.3e-05**	0.363	0.6572.	-4e-04*	1.00E-04	-3.00E-06
13	0.616	6.1692***	-0.0024***	-9e-04**	-0.000292***	0.574	-3.8879**	0.0018**	6e-04*	0.000224**
25	0.413	0.7125*	3e-04.	-6e-04**	-3.00E-06	0.413	0.2875	-3e-04.	6e-04**	3.00E-06
27	0.289	0.223	4e-04.	-3.00E-04	2.3e-05*	0.247	0.6472	-4.00E-04	3.00E-04	-2e-05.
Av	**0.399**					**0.361**				

[19]Significance codes: 0.001 "***", 0.01 "**", 0.05 "*", 0.1 "."

[20]B1, B2 - Budget for infectious disease 1, 2; T1, T2, T3, T4 - Treatment groups 1, 2, 3, 4

[21]Av - average result

Table 18: Regression Results for the Eradication Cluster

					T1					
	B1					B2				
Player	$\mathbf{R^2}$	β_0	β_1	β_2	β_3	$\mathbf{R^2}$	β_0	β_1	β_2	β_3
7	0.667	1.2997	-8e-04.	4e-04**	-5.7e-05.	0.393	-1.5026	0.0011.	0	9.3e-05*
8	0.609	0.7064	-5e-04.	4e-04.	-4.20E-05	0.821	-0.2502	4e-04*	-3.00E-04	7.1e-05*
19	0.619	0.8984***	-5e-04*	2e-04*	-1.20E-05	0.619	0.1016	5e-04*	-2e-04*	1.20E-05
20	0.608	2.2065***	-0.0011***	1.00E-04	-0.000111***	0.608	-1.2065*	0.0011***	-1.00E-04	0.000111***
22	0.357	0.3357.	3.00E-04	-1.00E-04	3.8e-05**	0.357	0.6643**	-3.00E-04	1.00E-04	-3.8e-05**
23	0.76	0.1725*	3e-04***	3e-04***	1.7e-05**	0.76	0.8275***	-3e-04***	-3e-04***	-1.7e-05**
26	0.367	-0.2495	-1.00E-04	3.00E-04	5.70E-05	0.924	0.5831.	4e-04***	-2.00E-04	-4e-05*
30	0.943	0.8746***	-4e-04***	3e-04***	-5.3e-05***	0.555	-0.158	4.00E-04	-2.00E-04	5.9e-05.
Av	**0.616**					**0.630**				
					T2					
7	0.47	-0.4532	4e-04*	4e-04*	2.7e-05*	0.53	0.6111*	0	-3e-04*	7.00E-06
16	0.975	1.5462***	-6e-04***	3e-04***	-0.000108***	0.975	-0.5462*	6e-04***	-3e-04***	0.000108***
23	0.83	-0.2176	3e-04***	4e-04***	1.30E-05	0.83	1.2176***	-3e-04***	-4e-04***	-1.30E-05
27	0.429	0.6481***	3e-04**	-2e-04.	1.6e-05**	0.429	0.3519***	-3e-04**	2e-04.	-1.6e-05**
Av	**0.676**					**0.691**				
					T3					
6	0.75	0.6138***	-5e-04***	3e-04**	1.1e-05*	0.756	0.4125**	5e-04***	-3e-04**	-1.5e-05**
8	0.66	-0.8985.	0	8e-04*	0.000118**	0.66	1.8985**	0	-8e-04*	-0.000118**
10	0.297	-2.1336.	3.00E-04	0.0012.	0.00023*	0.91	2.5152***	0	-0.0011***	-0.000219***
11	0.272	0.9716.	-4.00E-04	2.00E-04	-5.00E-05	0.272	0.0284	4.00E-04	-2.00E-04	5.00E-05
13	0.726	0.0837	-3e-04*	3.00E-04	4.90E-05	0.726	0.9163.	3e-04*	-3.00E-04	-4.90E-05
21	0.502	1.4041***	-9e-04**	3e-04**	-6.8e-05**	0.502	-0.4041	9e-04**	-3e-04**	6.8e-05**
24	0.017	0.7177.	-1.00E-04	0	-3.00E-06	0.049	0.3511	0	-1.00E-04	4.00E-06
Av	**0.461**					**0.554**				
					T4					
8	0.793	0.3445	-2.00E-04	6e-04***	-2.3e-05*	0.793	0.6555.	2.00E-04	-6e-04***	2.3e-05*
9	0.758	0.0856	-5e-04***	9e-04*	-3.3e-05**	0.758	0.4041**	1e-04***	-3e-04*	9e-06**
19	0.551	0.9858.	-5e-04*	4e-04.	-3.7e-05*	0.551	0.0142	5e-04*	-4e-04.	3.7e-05*
24	0.877	1.7065***	-7e-04**	2e-04*	-9.4e-05***	0.877	-0.7065	7e-04**	-2e-04*	9.4e-05***
26	0.939	1.7953***	-7e-04**	2e-04**	-0.000111***	0.939	-0.7953*	7e-04**	-2e-04**	0.000111***
29	0.907	1.3311***	-7e-04***	3e-04***	-7.1e-05***	0.907	-0.3311	7e-04***	-3e-04***	7.1e-05***
Av	**0.804**					**0.804**				

Table 19: Regression Results for the Volatility Cluster

					T1					
	B1					B2				
Player	$\mathbf{R^2}$	β_0	β_1	β_2	β_3	$\mathbf{R^2}$	β_0	β_1	β_2	β_3
1	0.463	0.1876	0	3e-04*	8.00E-06	0.463	0.8124***	0	-3e-04*	-8.00E-06
2	0.696	0.3279*	2e-04*	2e-04**	1.00E-06	0.696	0.6721***	-2e-04*	-2e-04**	-1.00E-06
3	0.621	0.208	4e-04**	-3e-04*	1.30E-05	0.621	0.792***	-4e-04**	3e-04*	-1.30E-05
4	0.016	0.5138*	0	-1.00E-04	-1.00E-06	0.016	0.4862*	0	1.00E-04	1.00E-06
6	0.101	0.3961**	1.00E-04	0	1.10E-05	0.101	0.6039***	-1.00E-04	0	-1.10E-05
9	0.462	0.5786***	3e-04**	-3e-04**	-5e-06*	0.462	0.4214***	-3e-04**	3e-04**	5e-06*
10	0.619	0.0532	3e-04***	2e-04**	1.5e-05*	0.619	0.9468***	-3e-04***	-2e-04**	-1.5e-05*
12	0.05	0.436	2.00E-04	-2.00E-04	1.10E-05	0.05	0.564.	-2.00E-04	2.00E-04	-1.10E-05
13	0.363	0.4446***	1e-04.	1.00E-04	8.00E-06	0.363	0.5554***	-1e-04.	-1.00E-04	-8.00E-06
14	0.085	0.6627	-1.00E-04	-1.00E-04	-6.00E-06	0.463	-0.2148	0	3.00E-04	1.8e-05**
15	0.389	0.5968***	2e-04*	-2e-04*	-7e-06*	0.389	0.4032***	-2e-04*	2e-04*	7e-06*
17	0.428	0.7944***	2e-04*	-2e-04*	-1.8e-05*	0.428	0.2056	-2e-04*	2e-04*	1.8e-05*
21	0.191	0.4116***	1.00E-04	-1.00E-04	7e-06.	0.177	0.5485***	-1.00E-04	1.00E-04	-5.00E-06
25	0.033	0.3324	0	1.00E-04	5.00E-06	0.533	0.2015*	-1e-04*	2e-04**	7e-06**
27	0.024	0.5811***	-1.00E-04	0	-4.00E-06	0.024	0.4189**	1.00E-04	0	4.00E-06
28	0.3	0.5468***	-1.00E-04	1.00E-04	3.00E-06	0.328	0.453***	1.00E-04	-1.00E-04	-4.00E-06
29	0.373	0.5479***	2e-04*	-3e-04**	-4.00E-06	0.373	0.4521***	-2e-04*	3e-04**	4.00E-06
Av	**0.307**					**0.359**				

Continued. . .

T2

1	0.283	0.8733**	0	-4.00E-04	-1.8e-05*	0.458	0.6399***	0	-3e-04.	-8e-06*
2	0.086	0.5419**	3.00E-04	-3.00E-04	-2.00E-06	0.086	0.4581**	-3.00E-04	3.00E-04	2.00E-06
5	0.18	0.3318*	1.00E-04	0	1.10E-05	0.18	0.6682***	-1.00E-04	0	-1.10E-05
11	0.199	0.3623.	3.00E-04	-3e-04.	5.00E-06	0.199	0.6377**	-3.00E-04	3e-04.	-5.00E-06
12	0.847	0.9075***	-3e-04**	-2e-04***	-7.00E-06	0.847	0.0925	3e-04**	2e-04***	7.00E-06
14	0.106	0.5382***	1.00E-04	-1.00E-04	-2.00E-06	0.106	0.4618***	-1.00E-04	1.00E-04	2.00E-06
15	0.155	0.2881**	1.00E-04	0	5.00E-06	0.155	0.7119***	-1.00E-04	0	-5.00E-06
17	0.226	0.637***	1.00E-04	-2e-04*	-6.00E-06	0.226	0.363**	-1.00E-04	2e-04*	6.00E-06
18	0.793	0.1887	1.00E-04	0	2.3e-05**	0.793	0.8113***	-1.00E-04	0	-2.3e-05**
19	0.382	1.1699**	2.00E-04	-6e-04*	-2.8e-05.	0.382	-0.1699	-2.00E-04	6e-04*	2.8e-05.
21	0.079	0.7023**	0	-1.00E-04	-1.00E-05	0.079	0.2977	0	1.00E-04	1.00E-05
22	0.502	0.0061	3e-04*	2e-04*	2.7e-05**	0.502	0.9939***	-3e-04*	-2e-04*	-2.7e-05**
25	0.637	0.2533	1.00E-04	-2e-04*	2.7e-05*	0.637	0.7467***	-1.00E-04	2e-04*	-2.7e-05*
26	0.518	0.4435***	3e-04*	-3e-04*	7e-06*	0.518	0.5565***	-3e-04*	3e-04*	-7e-06*
29	0.25	0.453	3.00E-04	-3e-04*	6.00E-06	0.25	0.547	-3.00E-04	3e-04*	-6.00E-06
30	0.365	0.3677	4e-04*	-2.00E-04	0	0.365	0.6323	-4e-04*	2.00E-04	0
Av	**0.351**					**0.361**				

T3

1	0.211	0.4202***	2e-04*	-1.00E-04	4.00E-06	0.211	0.5798***	-2e-04*	1.00E-04	-4.00E-06
2	0.338	0.6427***	-3e-04*	1.00E-04	-6.00E-06	0.211	0.2493	2.00E-04	-1.00E-04	9e-06.
4	0.345	0.366*	-1.00E-04	2.00E-04	1e-05.	0.389	0.4545***	2e-04.	-2e-04.	-6.00E-06
5	0.037	0.4497**	-1.00E-04	0	-2.00E-06	0.132	0.3907**	1.00E-04	0	8.00E-06
12	0.02	0.6241*	0	-2.00E-04	-3.00E-06	0.02	0.3759	0	2.00E-04	3.00E-06
14	0.218	0.5302***	1.00E-04	0	-3.00E-06	0.218	0.4698***	-1.00E-04	0	3.00E-06
15	0.48	0.9728***	1.00E-04	-3e-04*	-2.1e-05**	0.48	0.0272	-1.00E-04	3e-04*	2.1e-05**
19	0.34	0.3532*	0	2.00E-04	0	0.34	0.6468***	0	-2.00E-04	0
20	0.165	0.157	0	1.00E-04	1.90E-05	0.156	0.8414**	-1.00E-04	-1.00E-04	-1.90E-05
23	0.404	0.6032**	0	0	-1.3e-05**	0.333	0.1119	-1.00E-04	2.00E-04	-6e-06*
26	0.562	0.3345***	1.00E-04	-1.00E-04	1.2e-05**	0.32	0.6272***	-1.00E-04	0	-8e-06*
27	0.152	0.4893***	0	0	6.00E-06	0.152	0.5107***	0	0	-6.00E-06
28	0.26	0.4625***	0	0	2.00E-06	0.442	0.4359***	1.00E-04	0	-4.00E-06
29	0.363	0.506***	3e-04**	-3e-04*	0	0.363	0.494***	-3e-04**	3e-04*	0
30	0.466	0.2128*	2e-04.	-2e-04*	4.00E-06	0.466	0.7872***	-2e-04.	2e-04*	-4.00E-06
Av	**0.291**					**0.282**				

T4

2	0.023	0.5373**	1.00E-04	-1.00E-04	-1.00E-06	0.023	0.4627**	-1.00E-04	1.00E-04	1.00E-06
3	0.518	0.6178***	4e-04**	-4e-04**	-1.3e-05**	0.518	0.3822***	-4e-04**	4e-04**	1.3e-05**
10	0.242	0.9811***	2e-04.	-4e-04.	-1.50E-05	0.242	0.0189	-2e-04.	4e-04.	1.50E-05
14	0.66	0.4976	5e-04**	-4e-04*	-2.00E-06	0.66	0.5024	-5e-04**	4e-04*	2.00E-06
15	0.228	0.8605*	0	-1.00E-04	-2.20E-05	0.228	0.1395	0	1.00E-04	2.20E-05
16	0.622	0.0685	0	2e-04**	2.9e-05**	0.622	0.9315***	0	-2e-04**	-2.9e-05**
17	0.269	0.5478*	2e-04.	-2e-04.	7.00E-06	0.269	0.4522*	-2e-04.	2e-04.	-7.00E-06
20	0.457	0.8643***	5e-04**	-7e-04**	-9e-06.	0.457	0.1357	-5e-04**	7e-04**	9e-06.
21	0.297	0.7474***	-1.00E-04	-2e-04.	-8.00E-06	0.297	0.2526	1.00E-04	2e-04.	8.00E-06
23	0.086	0.4609**	3.00E-04	-3.00E-04	2.00E-06	0.086	0.5391**	-3.00E-04	3.00E-04	-2.00E-06
30	0.254	0.4648***	3e-04*	-2e-04*	0	0.254	0.5352***	-3e-04*	2e-04*	0
Av	**0.332**					**0.332**				

Appendix G

Model Equations

```
Top-Level Model:
Cumulative_Cases_ID_1(t) = Cumulative_Cases_ID_1(t - dt) + (Annual_Incidence_ID_1) * dt
    INIT Cumulative_Cases_ID_1 = 0
    UNITS: People
    INFLOWS:
        Annual_Incidence_ID_1 = Infection_ID_1 {UNIFLOW}
            UNITS: People/Year
Cumulative_Cases_ID_2(t) = Cumulative_Cases_ID_2(t - dt) + (Annual_Incidence_ID_2) * dt
    INIT Cumulative_Cases_ID_2 = 0
    UNITS: People
    INFLOWS:
        Annual_Incidence_ID_2 = Infection_ID_2 {UNIFLOW}
            UNITS: People/Year
Cumulative_Costs(t) = Cumulative_Costs(t - dt) + (Annual_Costs) * dt
    INIT Cumulative_Costs = 0
    UNITS: $
    INFLOWS:
        Annual_Costs = ((Immunization_Rate_ID_1+Immunization_Rate_ID_2)/Treshold_Immuniztion_Rate)*Average_Immunization_Cost_per_Person*
        Populaiton_Size {UNIFLOW}
            UNITS: US Dollars Per Year
Infected_Individuals_ID_1(t) = Infected_Individuals_ID_1(t - dt) + (Infection_ID_1 - Recovery_ID_1 - Death_I_1) * dt
    INIT Infected_Individuals_ID_1 = 337
    UNITS: People
    INFLOWS:
        Infection_ID_1 = IF Susceptible_Individuals_ID_1*
        Force_of_Infection_ID_1 < 1 THEN  0 ELSE Susceptible_Individuals_ID_1*Force_of_Infection_ID_1 {UNIFLOW}
            UNITS: People/Year
    OUTFLOWS:
        Recovery_ID_1 = Infected_Individuals_ID_1*Recovery_Rate {UNIFLOW}
            UNITS: People/Year
        Death_I_1 = Infected_Individuals_ID_1*Death_Rate {UNIFLOW}
            UNITS: People/Year
Infected_Individuals_ID_2(t) = Infected_Individuals_ID_2(t - dt) + (Infection_ID_2 - Recovery_ID_2 - Death_I_2) * dt
    INIT Infected_Individuals_ID_2 = 337
    UNITS: People
    INFLOWS:
        Infection_ID_2 = IF Susceptible_Individuals_ID_2*
        Force_of_Infection_ID_2 < 1 THEN 0 ELSE  Susceptible_Individuals_ID_2*Force_of_Infection_ID_2 {UNIFLOW}
            UNITS: People/Year
    OUTFLOWS:
        Recovery_ID_2 = Infected_Individuals_ID_2*Recovery_Rate {UNIFLOW}
            UNITS: People/Year
        Death_I_2 = Infected_Individuals_ID_2*Death_Rate {UNIFLOW}
            UNITS: People/Year
Removed_Individuals_ID_1(t) = Removed_Individuals_ID_1(t - dt) + (Recovery_ID_1 + Immunization_ID_1 - Death_R_1 - Waning_ID_1) * dt
    INIT Removed_Individuals_ID_1 = 7663
    UNITS: People
    INFLOWS:
        Recovery_ID_1 = Infected_Individuals_ID_1*Recovery_Rate {UNIFLOW}
            UNITS: People/Year
        Immunization_ID_1 = Susceptible_Individuals_ID_1*Immunization_Rate_ID_1 {UNIFLOW}
            UNITS: People/Year
    OUTFLOWS:
        Death_R_1 = Removed_Individuals_ID_1*Death_Rate {UNIFLOW}
            UNITS: People/Year
        Waning_ID_1 = Removed_Individuals_ID_1*Waning_Rate {UNIFLOW}
            UNITS: People/Year
Removed_Individuals_ID_2(t) = Removed_Individuals_ID_2(t - dt) + (Recovery_ID_2 + Immunization_ID_2 - Death_R_2 - Waning_ID_2) * dt
    INIT Removed_Individuals_ID_2 = 7663
    UNITS: People
    INFLOWS:
        Recovery_ID_2 = Infected_Individuals_ID_2*Recovery_Rate {UNIFLOW}
            UNITS: People/Year
        Immunization_ID_2 = Susceptible_Individuals_ID_2*Immunization_Rate_ID_2 {UNIFLOW}
            UNITS: People/Year
    OUTFLOWS:
        Death_R_2 = Removed_Individuals_ID_2*Death_Rate {UNIFLOW}
            UNITS: People/Year
        Waning_ID_2 = Removed_Individuals_ID_2*Waning_Rate {UNIFLOW}
            UNITS: People/Year
Susceptible_Individuals_ID_1(t) = Susceptible_Individuals_ID_1(t - dt) + (Births_1 + Waning_ID_1 - Infection_ID_1 - Death_S_1 - Immunization_ID_1) * dt
    INIT Susceptible_Individuals_ID_1 = 2000
    UNITS: People
    INFLOWS:
        Births_1 = Populaiton_Size*Birth_Rate {UNIFLOW}
            UNITS: People/Year
        Waning_ID_1 = Removed_Individuals_ID_1*Waning_Rate {UNIFLOW}
            UNITS: People/Year
    OUTFLOWS:
        Infection_ID_1 = IF Susceptible_Individuals_ID_1*
        Force_of_Infection_ID_1 < 1 THEN  0 ELSE Susceptible_Individuals_ID_1*Force_of_Infection_ID_1 {UNIFLOW}
            UNITS: People/Year
```

```
        Death_S_1 = Susceptible_Individuals_ID_1*Death_Rate {UNIFLOW}
            UNITS: People/Year
        Immunization_ID_1 = Susceptible_Individuals_ID_1*Immunization_Rate_ID_1 {UNIFLOW}
            UNITS: People/Year
Susceptible_Individuals_ID_2(t) = Susceptible_Individuals_ID_2(t - dt) + (Births_2 + Waning_ID_2 - Infection_ID_2 - Death_S_2 - Immunization_ID_2) * dt
    INIT Susceptible_Individuals_ID_2 = 2000
    UNITS: People
    INFLOWS:
        Births_2 = Populaiton_Size*Birth_Rate {UNIFLOW}
            UNITS: People/Year
        Waning_ID_2 = Removed_Individuals_ID_2*Waning_Rate {UNIFLOW}
            UNITS: People/Year
    OUTFLOWS:
        Infection_ID_2 = IF Susceptible_Individuals_ID_2*
        Force_of_Infection_ID_2 < 1 THEN 0 ELSE  Susceptible_Individuals_ID_2*Force_of_Infection_ID_2 {UNIFLOW}
            UNITS: People/Year
        Death_S_2 = Susceptible_Individuals_ID_2*Death_Rate {UNIFLOW}
            UNITS: People/Year
        Immunization_ID_2 = Susceptible_Individuals_ID_2*Immunization_Rate_ID_2 {UNIFLOW}
            UNITS: People/Year
Available_Budget_Proportion = 0.75
    UNITS: Dimensionless
    DOCUMENT: Imposed budget constraint
Average_Immunization_Cost_per_Person = 8.8
    UNITS: $/People/Year
Birth_Rate = 0.02
    UNITS: 1/Year
Budget = Average_Immunization_Cost_per_Person*Populaiton_Size*2*Available_Budget_Proportion
    UNITS: US Dollars Per Year
    DOCUMENT: Available annual resources for vaccination against the two infectious diseases
Budget_Proportion_for_ID_1 = User_Budget_Proportion_for_ID_1
    UNITS: Dimensionless
Budget_Proportion_for_ID_2 = IF User_Budget_Proportion_for_ID_2 > (1-Budget_Proportion_for_ID_1) THEN (1-Budget_Proportion_for_ID_1)
ELSE User_Budget_Proportion_for_ID_2
    UNITS: Dimensionless
    DOCUMENT: User decision for the budget proportion to fund vaccination activities against infectious disease 2
Budgeted_VDR_1 = Budget*(Budget_Proportion_for_ID_1)
    UNITS: US Dollars Per Year
Budgeted_VDR_2 = Budget*(Budget_Proportion_for_ID_2)
    UNITS: US Dollars Per Year
Death_Rate = 0.02
    UNITS: 1/Year
EQ_Immunization_Rate = 0  {Equilibrium Condition Immunization Rate}
    UNITS: 1/Year
EQ_Switch = 0  {EQ Conditions} {0 - to turn the switch OFF, 1 - to turn it ON}
    UNITS: Dimensionless
    DOCUMENT: Enables the steady state development equal to prevaccine period
Force_of_Infection_ID_1 = (Death_Rate+Recovery_Rate)*Ro*Infected_Individuals_ID_1/Populaiton_Size
    UNITS: 1/Year
Force_of_Infection_ID_2 = (Death_Rate+Recovery_Rate)*Ro*Infected_Individuals_ID_2/Populaiton_Size
    UNITS: 1/Year
Immunization_Rate_ID_1 = VACCINATION_DECISION_RULE_1
    UNITS: 1/Year
Immunization_Rate_ID_2 = VACCINATION_DECISION_RULE_2
    UNITS: 1/Year
Incidence_Perception_Time = 1
    UNITS: Year
    DOCUMENT: Perception delay in reporting (and responding to: (Tebbens and Thompson, 2009) the incidence of the infectious disease
Perceived_Incidence_ID_1 =  SMTH1(Infection_ID_1, Incidence_Perception_Time)
    UNITS: People/Year
    DOCUMENT: Reported incidence for the infectious disease 1
Perceived_Incidence_ID_2 = SMTH1(Infection_ID_2, Incidence_Perception_Time)
    UNITS: People/Year
    DOCUMENT: Reported incidence for the infectious disease 2
Populaiton_Size = 10000
    UNITS: People
Recovery_Rate = 5
    UNITS: 1/Year
    DOCUMENT: Reciprocal of average duration of infectiousness of 73 days
Ro = 5
    UNITS: Dimensionless
    DOCUMENT: Basic reproductive number
Total_Budgeted_Immunization_1 = VDR_1_Fraction*Treshold_Immuniztion_Rate
    UNITS: 1/Year
Total_Budgeted_Immunization_2 = VDR_2_Fraction*Treshold_Immuniztion_Rate
    UNITS: 1/Year
Treshold_Immuniztion_Rate = 0.88
    UNITS: 1/Year
    DOCUMENT: Theoretical threshold value above which infection prevalence permanently decreases
User_Budget_Proportion_for_ID_1 = 0.5
    UNITS: Dimensionless
    DOCUMENT: User decision for the budget proportion to fund vaccination activities against infectious disease 1
User_Budget_Proportion_for_ID_2 = 0.5
    UNITS: Dimensionless
USER_Policy = 1 {Allocation of the assigned budget proportion} {1 - Policy is ON, 0 - Policy is OFF}
    UNITS: Dimensionless
VACCINATION_DECISION_RULE_1 = EQ_Switch*(1-USER_Policy)*EQ_Immunization_Rate+ USER_Policy*(1-EQ_Switch)*Total_Budgeted_Immunization_1
```

```
    UNITS: 1/Year
    DOCUMENT: The decision rule that is driven by the decision maker for the infectious disease 1.
    EQ switch - enables equilibrium conditions, USER Policy - enables the game setting with user defined policies
VACCINATION_DECISION_RULE_2 =
EQ_Switch*(1-USER_Policy)*EQ_Immunization_Rate+
USER_Policy*(1-EQ_Switch)*Total_Budgeted_Immunization_2
    UNITS: 1/Year
    DOCUMENT: The decision rule that is driven by the decision maker for the
    infectious disease 2. EQ sqitch - enables equilibrium conditions,
    USER Policy - enables the game setting with user defined policies
VDR_1_Fraction = Budgeted_VDR_1/Populaiton_Size/Average_Immunization_Cost_per_Person
    UNITS: Dimensionless
    DOCUMENT: Fraction of the budget for the vaccination decesion rule 1
VDR_2_Fraction = Budgeted_VDR_2/Populaiton_Size/Average_Immunization_Cost_per_Person
    UNITS: Dimensionless
    DOCUMENT: Fraction of the budget for the vaccination decesion rule 2
Waning_Rate = 0.2
    UNITS: 1/Year
    DOCUMENT: Fractional loss of immunity
{ The model has 60 (60) variables (array expansion in parens).
  In root model and 0 additional modules with 0 sectors.
  Stocks: 9 (9) Flows: 19 (19) Converters: 32 (32)
  Constants: 15 (15) Equations: 36 (36) Graphicals: 0 (0)
  There are also 10  expanded macro variables.
  }
```

Appendix H

R Algorithm for Clusters and Regressions

```
rm(list = ls())

group <- 4 # Treatment group (T1, T2, T3, T4)
round <- 1 # Round (R1, R2)
set <- " A" # Dataset: A - total cumulative incidence, B - delayed total cumulative incidence

GameData <-read.csv(paste("T", as.character(group), " Round ",  as.character(round), set, ".csv", sep=''), header = TRUE)
Year <- as.numeric(as.character(GameData [2:22, "YEAR"]))
NYears <-(nrow(GameData)-1)
NPlayers <- (ncol(GameData)-1)/5

Results <- vector(mode = "character", length = NPlayers)

Erad.df <- data.frame(Year=Year)
Volat.df <- data.frame(Year=Year)
Waver.df <- data.frame(Year=Year)
Equal.df <- data.frame(Year=Year)

for (i in 1:NPlayers){
  Header_Budget_ID_1 <- paste("Budget.ID.1", as.character(round), as.character(i), sep = '.')
  Header_Budget_ID_2 <- paste("Budget.ID.2", as.character(round), as.character(i), sep = '.')
  Header_PI_ID_1 <- paste("PI.ID.1", as.character(round), as.character(i), sep = '.')
  Header_PI_ID_2 <- paste("PI.ID.2", as.character(round), as.character(i), sep = '.')
  Header_Total_Cum <- paste("Total.Cum", as.character(round), as.character(i), sep = '.')
  Budget_ID_1 <- as.numeric(as.character(GameData [2:22, Header_Budget_ID_1]))
  Budget_ID_2 <- as.numeric(as.character(GameData [2:22, Header_Budget_ID_2]))
  PI_ID_1 <-as.numeric(as.character(GameData [2:22, Header_PI_ID_1]))
  PI_ID_2 <-as.numeric(as.character(GameData [2:22, Header_PI_ID_2]))
  Total_Cum <-as.numeric(as.character(GameData [2:22, Header_Total_Cum]))
  Budget <-c(Budget_ID_1, Budget_ID_2)

  Temp_vector <- rep(Budget_ID_1[1], NYears)
  if (all(Budget_ID_1 == Temp_vector) | (all(Budget_ID_1 == Budget_ID_2))) {
    Results[i] <- "Equal"
    Equal.df[Header_Budget_ID_1] <- Budget_ID_1
    Equal.df[Header_Budget_ID_2] <- Budget_ID_2
    Equal.df[Header_PI_ID_1] <- PI_ID_1
    Equal.df[Header_PI_ID_2] <- PI_ID_2
    Equal.df[Header_Total_Cum] <- Total_Cum
  } else {

    S <- 0
    for (j in 1:(length(Budget_ID_1)-1)){
      if (round(abs(Budget_ID_1[j]-Budget_ID_1[j+1]), digits=1)>=0.2)
      {S <- S+1}
    }

    if (S>7) {Results[i] <-"Waver"
    Waver.df[Header_Budget_ID_1] <- Budget_ID_1
    Waver.df[Header_Budget_ID_2] <- Budget_ID_2
    Waver.df[Header_PI_ID_1] <- PI_ID_1
    Waver.df[Header_PI_ID_2] <- PI_ID_2
    Waver.df[Header_Total_Cum] <- Total_Cum
    } else {
      if (PI_ID_1[21] <=16 |PI_ID_2[21] <=16)
          {Results[i] <- "Erad";
          Erad.df[Header_Budget_ID_1] <- Budget_ID_1
          Erad.df[Header_Budget_ID_2] <- Budget_ID_2
          Erad.df[Header_PI_ID_1] <- PI_ID_1
          Erad.df[Header_PI_ID_2] <- PI_ID_2
          Erad.df[Header_Total_Cum] <- Total_Cum

      } else {
        Volat.df[Header_Budget_ID_1] <- Budget_ID_1
        Volat.df[Header_Budget_ID_2] <- Budget_ID_2
        Volat.df[Header_PI_ID_1] <- PI_ID_1
        Volat.df[Header_PI_ID_2] <- PI_ID_2
        Volat.df[Header_Total_Cum] <- Total_Cum
      }
    }}}

Out.df <- data.frame(1:NPlayers, Results)
names(Out.df) <- c("Player", "Group")

# Arranging plots into an overall graph
#https://www.statmethods.net/advgraphs/layout.html

# dev.copy(tiff, paste("Cluster Results. ", "Wavering.", " T", group, " R", round, ".tiff", sep = ''),
#          width = 9, height = 9, units = 'in', res = 300)
#

 dev.copy(png, paste("Cluster Results1. ", " T", group, " R", round, ".png", sep = ''),
```

```
         width = 9, height = 9, units = 'in', res = 300)
par(mfrow=c(2,2))
n <- 2
y1 <- vector()
for (w in 1:(ncol(Waver.df)-1)/5){
   Header_Budget <- names(Waver.df)[n]
   y <- as.numeric(as.character(Waver.df [1:21, Header_Budget]))
   y1 <- cbind(y1, y)
   x <-Waver.df$Year
   n <- n+5
}
 matplot(x, y1, type="l", xlab = "Years", ylab = "Budget", main = "Wavering")
#  dev.off ()
#
# dev.copy(tiff, paste("Cluster Results. ", "Eradication.", " T", group, " R",round, ".tiff", sep = ''),
#           width = 9, height = 9, units = 'in', res = 300)
 n <- 2
 y2 <- vector()
 for (k in 1:(ncol(Erad.df)-1)/5){
   Header_Budget <- names(Erad.df)[n]
   yy <- as.numeric(as.character(Erad.df [1:21, Header_Budget]))
   y2 <- cbind(y2, yy)
   x <-Erad.df$Year
   n <- n+5
 }
 matplot(x, y2, type="l", xlab = "Years", ylab = "Budget", main = "Eradication")
#  dev.off ()
#
# dev.copy(tiff, paste("Cluster Results. ", "Equal Allocation.", " T", group, " R",round, ".tiff", sep = ''),
#           width = 9, height = 9, units = 'in', res = 300)
 n <- 2
 y3 <- vector()
 for (l in 1:(ncol(Equal.df)-1)/5){
   Header_Budget <- names(Equal.df)[n]
   yy <- as.numeric(as.character(Equal.df [1:21, Header_Budget]))
   y3 <- cbind(y3, yy)
   x <-Equal.df$Year
   n <- n+5
 }
 matplot(x, y3, type="l", xlab = "Years", ylab = "Budget", main = "Equal Allocation")
#  dev.off ()
#
# dev.copy(tiff, paste("Cluster Results. ", "Volatile Allocation.", " T", group, " R",round, ".tiff", sep = ''),
#           width = 9, height = 9, units = 'in', res = 300)
 n <- 2
 y4 <- vector()
 for (m in 1:(ncol(Volat.df)-1)/5){
   Header_Budget <- names(Volat.df)[n]
   yy <- as.numeric(as.character(Volat.df [1:21, Header_Budget]))
   y4 <- cbind(y4, yy)
   x <-Volat.df$Year
   n <- n+5
 }
 matplot(x, y4, type="l", xlab = "Years", ylab = "Budget", main = "Volatile Allocation")
dev.off ()

#Regression Function

function_regression <- function(DataFrame.df) {

  NPlayers <- (ncol(DataFrame.df)-1)/5
  Players <- vector(mode = "numeric", NPlayers)

  k <- 2
  l <- 4
  m <- 5
  n <- 6
  Matrix <-matrix(, nrow = NPlayers, ncol = 0)

  for (q in 1:2){
    R.sq <- vector(mode = "numeric", length = NPlayers)
    b0 <- vector(mode = "numeric", length = NPlayers)
    b1 <- vector(mode = "numeric", length = NPlayers)
    b2 <- vector(mode = "numeric", length = NPlayers)
    b3 <- vector(mode = "numeric", length = NPlayers)

    for (p in 1:NPlayers){
      Header_Budget_ID <-names(DataFrame.df)[k]
      Header_PI_ID_1 <-names(DataFrame.df)[l]
      Header_PI_ID_2 <-names(DataFrame.df)[m]
      Header_Total_Cum <-names(DataFrame.df)[n]
      Player <-substr(Header_Budget_ID, 15, nchar(Header_Budget_ID))
      Players[p] <- Player

      Budget_ID <- DataFrame.df [1:21, Header_Budget_ID]
      PI_ID_1 <- DataFrame.df [1:21, Header_PI_ID_1]
      PI_ID_2 <- DataFrame.df [1:21, Header_PI_ID_2]
```

```
      Total_Cum <- DataFrame.df [1:21, Header_Total_Cum]

      Y <- Budget_ID

      Fit <- lm(Y ~ PI_ID_1 + PI_ID_2 + Total_Cum)
      summary(Fit)

      V0 <- unname(coefficients(Fit)[1])
      V <- unname(coefficients(Fit)[2:4])
      X <- cbind(PI_ID_1, PI_ID_2, Total_Cum)
      Yr <- V0 + X%*%V

      R.sq [p] <- as.numeric(as.character(round(summary(Fit)$r.squared, 3)))

      b0 [p] <- ifelse(summary(Fit)$coefficients[1,4]<0.001,paste0(round(summary(Fit)$coefficients[1], 4),"***"),
                       ifelse(summary(Fit)$coefficients[1,4]<0.01,paste0(round(summary(Fit)$coefficients[1],4),"**"),
                              ifelse(summary(Fit)$coefficients[1,4]<0.05,paste0(round(summary(Fit)$coefficients[1],4),"*"),
                                     ifelse(summary(Fit)$coefficients[1,4]<0.1,paste0(round(summary(Fit)$coefficients[1],4),"."),
                                            paste0(round(summary(Fit)$coefficients[1],4)," ")))))

      b1 [p] <- ifelse(summary(Fit)$coefficients[2,4]<0.001,paste0(round(summary(Fit)$coefficients[2], 4),"***"),
                       ifelse(summary(Fit)$coefficients[2,4]<0.01,paste0(round(summary(Fit)$coefficients[2], 4),"**"),
                              ifelse(summary(Fit)$coefficients[2,4]<0.05,paste0(round(summary(Fit)$coefficients[2], 4),"*"),
                                     ifelse(summary(Fit)$coefficients[2,4]<0.1,paste0(round(summary(Fit)$coefficients[2], 4),"."),
                                            paste0(round(summary(Fit)$coefficients[2], 4)," ")))))

      b2 [p] <- ifelse(summary(Fit)$coefficients[3,4]<0.001,paste0(round(summary(Fit)$coefficients[3], 4),"***"),
                       ifelse(summary(Fit)$coefficients[3,4]<0.01,paste0(round(summary(Fit)$coefficients[3], 4),"**"),
                              ifelse(summary(Fit)$coefficients[3,4]<0.05,paste0(round(summary(Fit)$coefficients[3], 4),"*"),
                                     ifelse(summary(Fit)$coefficients[3,4]<0.1,paste0(round(summary(Fit)$coefficients[3], 4),"."),
                                            paste0(round(summary(Fit)$coefficients[3], 4)," ")))))

      b3 [p] <- ifelse(summary(Fit)$coefficients[4,4]<0.001,paste0(round(summary(Fit)$coefficients[4], 6),"***"),
                       ifelse(summary(Fit)$coefficients[4,4]<0.01,paste0(round(summary(Fit)$coefficients[4], 6),"**"),
                              ifelse(summary(Fit)$coefficients[4,4]<0.05,paste0(round(summary(Fit)$coefficients[4], 6),"*"),
                                     ifelse(summary(Fit)$coefficients[4,4]<0.1,paste0(round(summary(Fit)$coefficients[4], 6),"."),
                                            paste0(round(summary(Fit)$coefficients[4], 6)," ")))))

      k <-k+5
      l <-l+5
      m <-m+5
      n <-n+5
    }

    Buffer_Matrix <-cbind(R.sq, b0, b1, b2, b3)
    Matrix <-cbind(Matrix, Buffer_Matrix)

    k <- 3
    l <- 4
    m <- 5
    n <- 6
  }
  Results.df <- cbind(Players,Matrix)
  return(Results.df)
}

if ((ncol(Waver.df)) < 6) {stop("No data for regression")} else {Results.df <- function_regression(Waver.df)
print(Results.df)}
#write.csv(Results.df, paste("RegResults. ", "T", as.character(group), " Round ",
            #as.character(round), set, " Waver ", ".csv", sep=''))
```

Appendix I

R Algorithm for Strategic Comparison by Rounds

```
rm(list = ls())

group <- 1 #Treatment group (T1, T2, T3, T4)
round <- cbind(1,2) #Round (R1, R2)
set <- " A" # Dataset: A - total cumulative incidence, B - delayed total cumulative incidence

OutData.df <- data.frame(Player=1:30)

function_clustering <- function(group, round, set) {

GameData <-read.csv(paste("T", as.character(group), " Round ",  as.character(round), set, ".csv", sep=''), header = TRUE)
Year <- as.numeric(as.character(GameData [2:22, "YEAR"]))
NYears <-(nrow(GameData)-1)
NPlayers <- (ncol(GameData)-1)/5

Results <- vector(mode = "character", length = NPlayers)
Buf_Cumulative <- vector(mode = "numeric", length = NPlayers)
Matrix <- matrix(, nrow = NPlayers, ncol = 0)

Erad.df <- data.frame(Year=Year)
Volat.df <- data.frame(Year=Year)
Waver.df <- data.frame(Year=Year)
Equal.df <- data.frame(Year=Year)


for (i in 1:NPlayers){
  Header_Budget_ID_1 <- paste("Budget.ID.1", as.character(round), as.character(i), sep = '.')
  Header_Budget_ID_2 <- paste("Budget.ID.2", as.character(round), as.character(i), sep = '.')
  Header_PI_ID_1 <- paste("PI.ID.1", as.character(round), as.character(i), sep = '.')
  Header_PI_ID_2 <- paste("PI.ID.2", as.character(round), as.character(i), sep = '.')
  Header_Total_Cum <- paste("Total.Cum", as.character(round), as.character(i), sep = '.')
  Budget_ID_1 <- as.numeric(as.character(GameData [2:22, Header_Budget_ID_1]))
  Budget_ID_2 <- as.numeric(as.character(GameData [2:22, Header_Budget_ID_2]))
  PI_ID_1 <-as.numeric(as.character(GameData [2:22, Header_PI_ID_1]))
  PI_ID_2 <-as.numeric(as.character(GameData [2:22, Header_PI_ID_2]))
  Total_Cum <-as.numeric(as.character(GameData [2:22, Header_Total_Cum]))
  Buf_Cumulative[i] <- as.numeric(as.character(GameData [22, Header_Total_Cum]))

  Temp_vector <- rep(Budget_ID_1[1], NYears)
  if (all(Budget_ID_1 == Temp_vector) | (all(Budget_ID_1 == Budget_ID_2))) {
    Results[i] <- "Equal"
    Equal.df[Header_Budget_ID_1] <- Budget_ID_1
    Equal.df[Header_Budget_ID_2] <- Budget_ID_2
    Equal.df[Header_PI_ID_1] <- PI_ID_1
    Equal.df[Header_PI_ID_2] <- PI_ID_2
    Equal.df[Header_Total_Cum] <- Total_Cum
  } else {

    S <- 0
    for (j in 1:(length(Budget_ID_1)-1)){
      if (round(abs(Budget_ID_1[j]-Budget_ID_1[j+1]), digits=1)>=0.2)
      {S <- S+1}
    }

    if (S>7) {Results[i] <-"Waver"
    Waver.df[Header_Budget_ID_1] <- Budget_ID_1
    Waver.df[Header_Budget_ID_2] <- Budget_ID_2
    Waver.df[Header_PI_ID_1] <- PI_ID_1
    Waver.df[Header_PI_ID_2] <- PI_ID_2
    Waver.df[Header_Total_Cum] <- Total_Cum
    } else {
      if (PI_ID_1[21] <=16 |PI_ID_2[21] <=16)
      {Results[i] <- "Erad";
      Erad.df[Header_Budget_ID_1] <- Budget_ID_1
      Erad.df[Header_Budget_ID_2] <- Budget_ID_2
      Erad.df[Header_PI_ID_1] <- PI_ID_1
      Erad.df[Header_PI_ID_2] <- PI_ID_2
      Erad.df[Header_Total_Cum] <- Total_Cum

      } else {Results[i] <-"Volat"
        Volat.df[Header_Budget_ID_1] <- Budget_ID_1
        Volat.df[Header_Budget_ID_2] <- Budget_ID_2
        Volat.df[Header_PI_ID_1] <- PI_ID_1
        Volat.df[Header_PI_ID_2] <- PI_ID_2
        Volat.df[Header_Total_Cum] <- Total_Cum
      }
    }}}

Buffer.df <- data.frame(Results, Buf_Cumulative)
return(Buffer.df)
```

```
}

for (k in 1:length(round)){
  Buffer.df <- function_clustering(group, round(k), set)
  Header_Result <- paste("Group R", as.character(round[k]), sep = ' ')
  Header_Cumulative <- paste("Cumulative R", as.character(round[k]), sep = ' ')
  OutData.df[Header_Result] <- Buffer.df["Results"]
  OutData.df[Header_Cumulative] <- Buffer.df["Buf_Cumulative"]
}
print(OutData.df)
```