A Dynamic Simulation Model of Academic Publications and Citations

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Abstract

In academia, the two main measures of research performance are publications and citations. These two measures in a sense quantify the research success of scientists and academic units. Perception of these performance measures can create pressures on researchers and cause different behaviors in different conditions. The aim of this study is to examine the behaviors of researchers in response to the dynamics of publication and citation pressures. A model including faculty members in a department, their publications and citations has been constructed by using system dynamics methodology. An important factor that determines citations for a paper is the quality of the paper. Reputation of an academic unit is established as a result of citations that the unit receives over time. There is an important feedback loop so that the reputation in turn influences the citations the units will enjoy. A researcher, who has citation pressure on him, would be forced to produce higher quality papers for getting more citations. On the other hand, publication pressure would cause the researcher to produce lower-quality papers in higher numbers, in shorter times. The main decisions of researchers are thus modeled through allocation of researchers' time in research activities and time devoted on each research. The results obtained agree with our dynamic hypothesis and qualitative information about the behavior of actual academic units.

1. Introduction

Academic knowledge proceeds by accumulation and an academician tries to make contribution to this accumulation by publication. He aims to be the part of the common knowledge and shares his work by publishing, but it does not mean that every publication means a good contribution. To get citation in others' papers has that indicator role. Citation can be defined as the glue that binds a research paper to the body of knowledge in a particular field (5). The journey is that somebody makes research and publishes it, and then others use it to make new researches. It can be conceptualized as generating, distributing and consuming the scientific knowledge (12). In this journey the key factor is to measure the contribution of a paper to the field, because it is very important to decide what to be read, especially in the expansion of scientific literature (7). The question is how the quality of a paper and an academician can be measured. For this question the *"scientometrics"*, the science of measuring and analyzing science, has emerged. Today, scientometrics have different kinds of measures all of which build on number of publication and citation (4).

In addition to deciding what to read, scientometrics has emerged in order to quantify the success of the academicians. The rapid expansion of the academic work has required an objective measure and firstly the number of the publications considered adequate to decide whether a researcher is successful or not. However, since the number of papers does not say anything about the quality of the work, indexing – citation issues have entered the measurement of science (4). Then there has emerged some publication citation balance measures (Like h-index, g-index). Today, h-index, and average number of citation per paper are widely used measures for an academician.

2. Problem Identification and Data Analysis

While in the past the reputation of the academician was important for personal satisfaction; today it is a necessity to survive. Because academic career, position, tenure, promotion, grants are all dependent on the reputation. The saying "publish or perish" explains the situation. How to measure reputation has affected the evolution of the science heavily and since for 50 years it is measured via number of publication and citation, today's science publishes with the question in the speed of progressing. Statistics compiled by the Institute for Scientific Information (ISI) indicate that 55% of the papers published between 1981 and 1985 in journals indexed by the institute received no citations at all in the 5 years after they published and the conventional wisdom in the field is that 10% of the journals get 90% of the citations. If the bottom 80% of the literature just vanishes, this confirms the suspicion that academic culture encourages spurious publication. It is totally against the aim of the publication, but no longer it represents a way of communication with scientific peers; rather, a way to enhance the status and accumulate points for promotion and grants (5).

The type of the citation received is another issue in evaluation of citations. If received citation is of international type, then it is logical to think that it is valuable, i.e. it contributes to reputation more. As opposed to that, if a large portion of the citations are received from colleagues in the same department, there is an ambiguous point about how to evaluate that.

Furthermore, if academic performance is evaluated by number of publications and citations, is there a policy to be followed in order to maximize the performance? It is possible to be very successful in one of the two. For example it is possible to increase the number of publications without much care about quality. On the other hand, it is another option to have a few publications that of high quality type. Is it better to have a balance between them?

Considering all these ambiguities and problems, it is true to say that there is not a specific cause of this situation. It is a systemic problem. In this complex system the leverage points should be found in order to design science policies for a better scientific progress.

To criticize our performance in an activity, most of the time, we compare ourselves with the others; others, who are appropriate to be considered as a reference. In the academic world, the "others" is the world average. An academician, whose "number of citations per paper" is much lower than the average number of citations per paper in the world, would consider him as poor in terms of citations. That will cause a pressure on him to produce papers which are more likely to get citations. Similarly, comparing "number of publications" with the average number of publications per faculty in the world, one would determine his performance to be satisfactory or not. In order to be able to make those comparisons in the model, a data analysis is done.

Three main data are used in the data analysis part.

- Number of Publications

- Sum of times cited
- Number of faculty

For "number of publications" and "sum of times cited", the data is collected from ISI Web of Science which is a comprehensive database about publications and citations. It is an online academic database provided by Thomson Scientific. It covers about 8,700 leading journals of science, technology, social sciences, arts, and humanities. Seven particular fields are selected from different countries that are selected to be representative of the world. These are engineering, industrial engineering, biology, mathematics, physics, psychology and economics. Moreover, countries, which are chosen, are USA, China, India, Russia, European Union (Belgium, France, Germany, Italy, Luxembourg, Netherlands, Denmark, United Kingdom, Greece, Spain, Ireland, Portugal, Austria, Finland and Sweden), Australia and Turkey. "Number of publications" is of years 2000, 2003, and 2006. "sum of times cited" is for the publications which are published in year 2000 and have been cited up to now.

For finding "number of faculty" values, a sample of about 50 universities is chosen for each field. The universities are selected so as to represent the whole world. %60 of the universities selected for each field are from USA, %20 from European Countries and %20 from other countries. Data is collected from sample universities' web pages for 2006 (6).

It should be emphasized that, almost all countries selected are developed countries and their science figures are quite good. Besides, the universities selected are all in the top 500 list. So the average values used in the model are obviously higher than the actual world averages.

The data analysis showed that different fields have different characteristics in terms of academic publications and citations. Number of publications of a department in a field cannot be compared to a department in another field unless the numbers are normalized. To see the differences *Figure 1* can be examined.

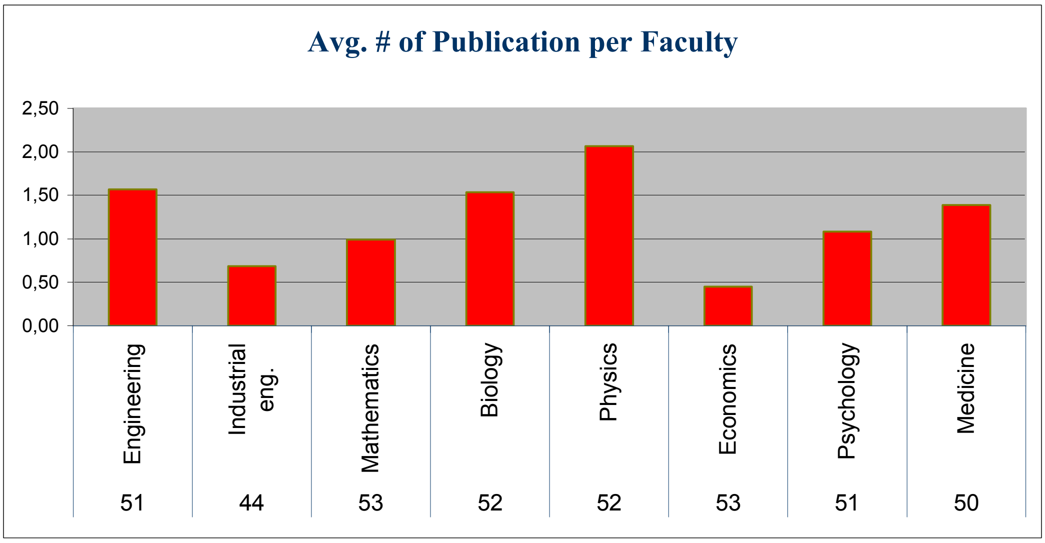


Figure 1: Average number of publications per faculty per year

The world average number of publications per author in engineering is more than 1.5 publications per year where the same measure for economics is below 0.5. So, if a particular measure of a discipline is to be evaluated, it must be compared to the worldwide average of that measure in the discipline.

The formula used in finding average number of publications per faculty per year is as follows;

$$\text{Avg \#of publications per faculty per year} = \frac{\text{Number of publications}}{\text{Number of Faculty}}$$

In our model, engineering department is selected to be studied. "average publication per faculty per year in engineering" is 1.6 which is used in the model as a reference in determining publication pressure. For finding "average citation per publication in the world in engineering", the following formula is used:

$$\text{Average number of citations per paper} = \frac{\text{Sum of times cited}}{\text{Number of publications}}$$

In engineering, average number of citations per paper is 9.6. This is used in the model as a reference in deter mining citation pressure. *Figure 2* shows the comparison of Bogazici University and world average for seven fields in terms of average number of publications per faculty.

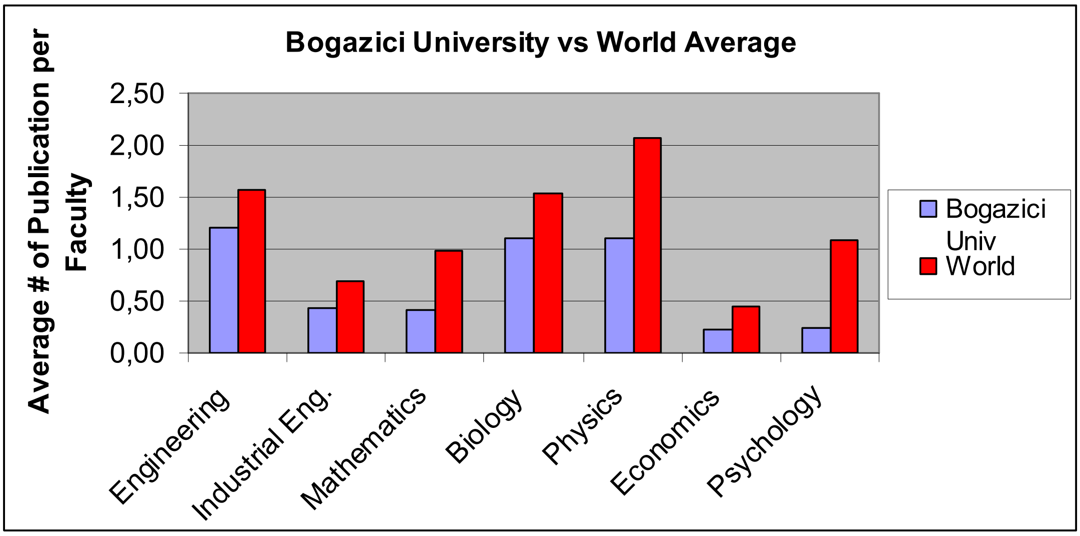


Figure 2: Average number of publications per faculty – Bogazici vs. World

In the model, the data obtained in this part is used as the initial values of the variables. Additionally, the qualitative information as *allocation of researchers' time in research activities, time devoted on each research, publishing time per paper* are obtained by observing the behaviors of researchers in Bogazici University Engineering Department.

3. Dynamic Simulation Model

The dynamic simulation model includes faculty members in a department, their publications and citations. System dynamics methodology is used in constructing the model. The aim is to examine the behaviors of researchers in response to the dynamics of publication and citation pressure. Reserved time per paper, total research time, reputation and quality of papers are included in the model as the main factors affecting the behavior. Complete stock-flow diagram can be seen in *Figure 3*.

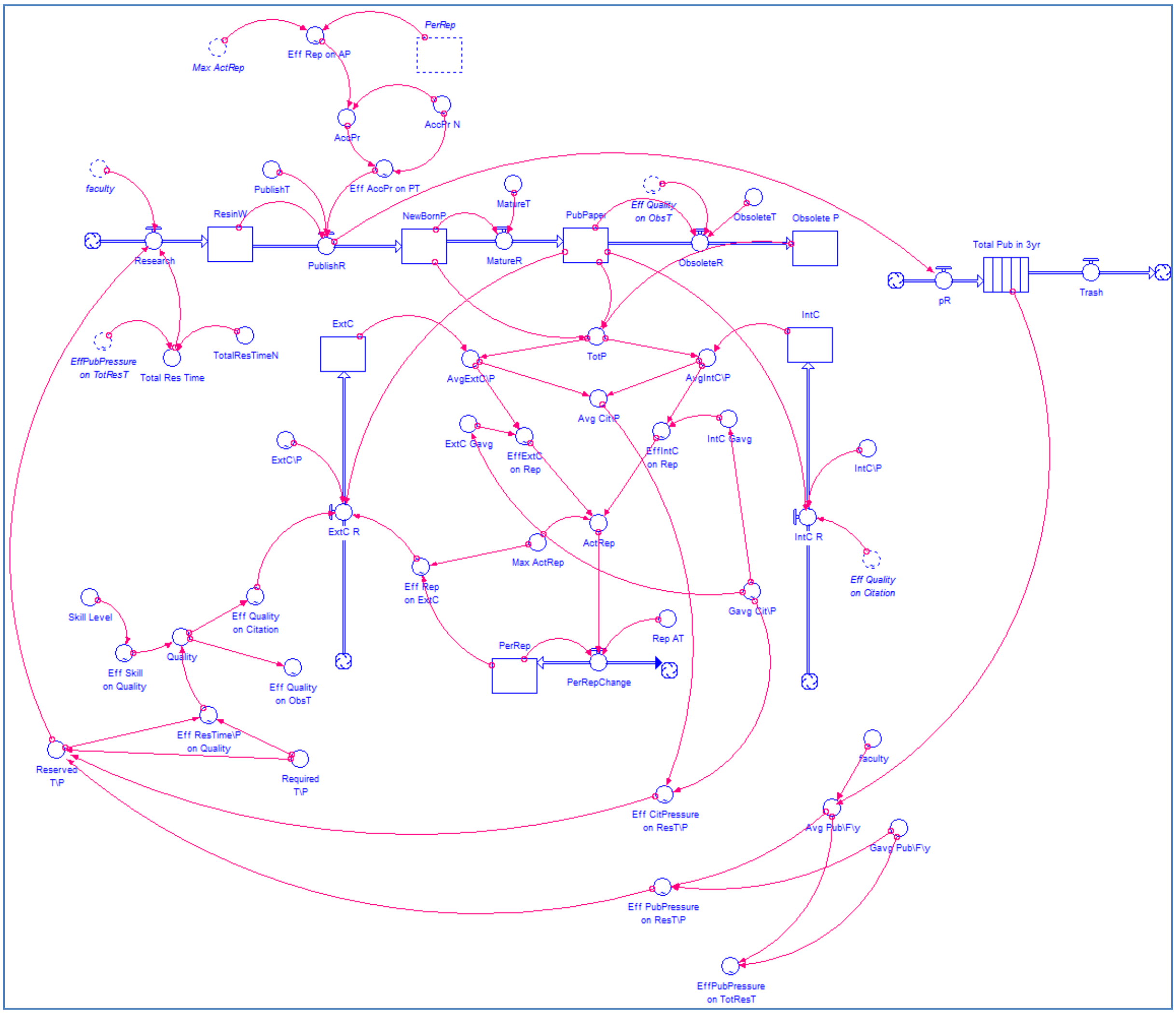


Figure 3: Stock- Flow Diagram of the complete model

Engineering faculty of Bogazici University is chosen to be examined. The initial conditions, the number faculty and grand average values are obtained in the data analysis part. Time unit in the model is quarters. 200 quarters (50 years) is examined in the simulation. Time step (dt) analysis is done and dt is chosen as 1/8.

The model has an aging structure of the papers and the relation of citation part with this structure. The stocks in the model without any detail can be seen in *Figure 4*. The four stocks seen in the upper line represent the papers in different stages. The first stock in this aging structure is *ResinW* (Research in Writing) stock and shows the papers which are in the research stage yet. The papers are published and are started to be cited after approximately 3 years and this transition stage is represented by the *NewBornP* stock which shows the published but not citable papers. The stock *PubPaper* represents the papers which are published and being cited. After staying in *PubPaper* for a long time depending on their quality, the papers become old (13). The stock *Obsolete P* represents the papers which are published a long time ago and do not get citation any more.

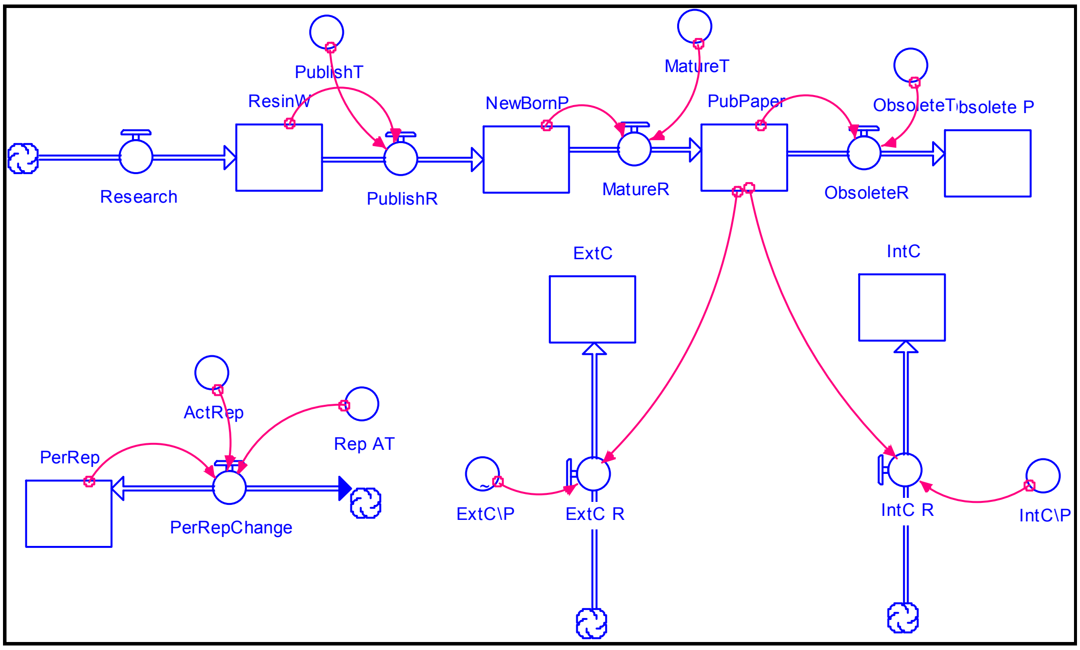


Figure 4: Simplified Stock-Flow model

IntC accumulates internal citations (citations from the same department of the author) and *ExtC* accumulates external citations (international). Finally, *PerRep* is the perceived reputation of the department all over the world. In the modeling of reputation, there is a first order information delay.

The most important effect variables which are not shown in *Figure 4* are shown with a causal-loop diagram in *Figure 5*. In *Figure 5 "total research time" is* the researchers' time in research activities and "*reserved time"* is the time devoted on each paper. As seen in the causal-loop diagram, r*eserved time per paper* is affected by publication and citation pressures. When *citation pressure* increases, a researcher would try to increase his citations by producing higher quality papers. So, he would increase reserved time, i.e. he would spend more time on each research. This would reduce *average publication per faculty per year* which would cause the publication pressure..When publication pressure increases, a researcher would be forced to increase his publications and so he would produce more publications in shorter times. There are two negative feedback loops regarding reserved time and the pressures. So the faculty members will come over these pressures by deciding on the amount of time per paper. Besides, *total research time* is affected by *publication pressure* in that if there is pressure, amount of time allocated to research activities would increase. This negative feedback loop will try also to overcome *publication pressure*. Apart from these, there is an important and well-known positive feedback loop between *reputation* and citations. If *average number of citations per paper* increases the faculty will increase its reputation and if its reputation is high it will get more citations.

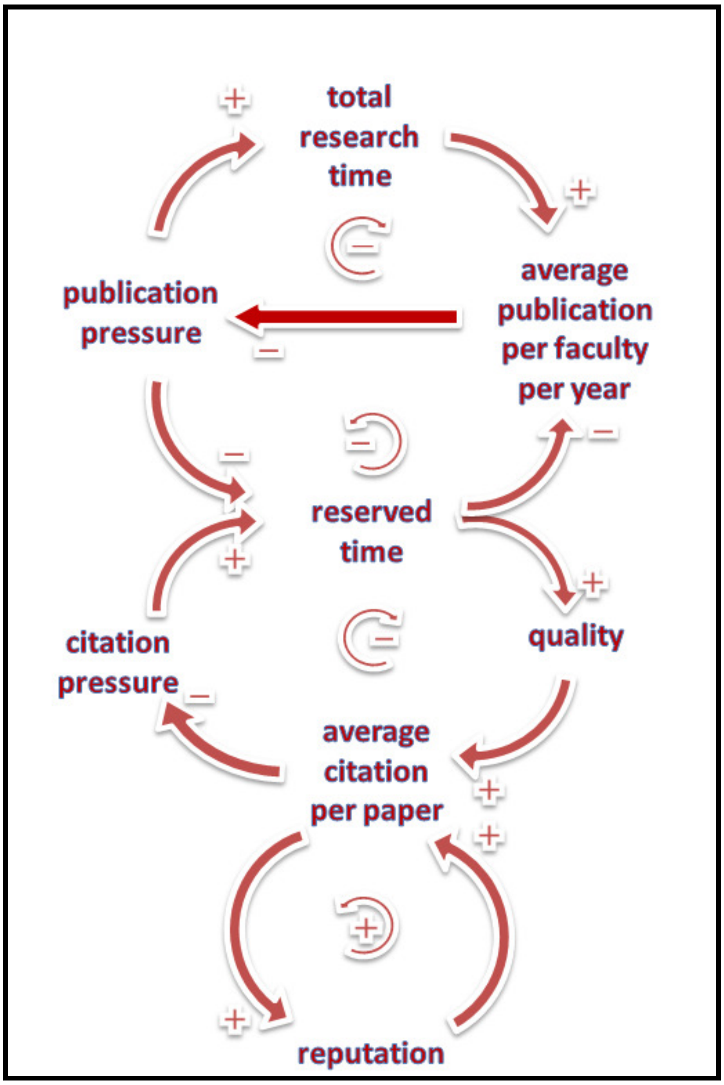


Figure 5: Causal-Loop diagram

3.1. Formulations

3.1.1. Citation Pressure and Publication Pressure

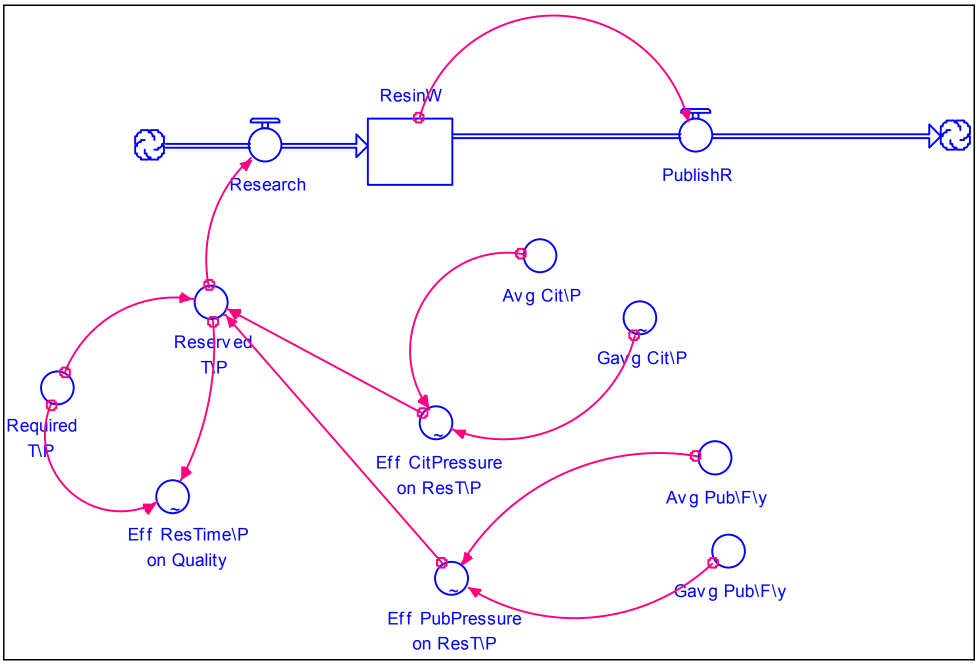


Figure 6: Citation pressure and publication pressure in the model

One of the main effects in the model is the balance between citation pressure and publication pressure.

$$\text{Citation Pressure} = \frac{\text{Average Citation per Paper}}{\text{Grand Average Citation per Paper}}$$

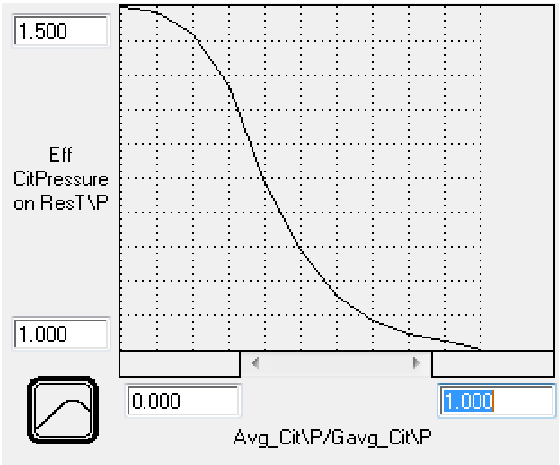
$$\text{Publication Pressure} = \frac{\text{Average Publication per Faculty per Year}}{\text{Grand Average Publication per Faculty per Year}}$$

where *grand average publication per faculty per year* and *grand average citation per paper* are variables that are obtained from world data in the data analysis part.

It is assumed in the model that, the time the researchers spend on each research depends on the pressures on them. If the average number of citations per paper is lower than the world average, than the researchers will feel a pressure to produce higher quality papers to get more citations. For higher-quality papers, the researchers will need to spend more time on each paper. The formulation of *reserved time* in the model is as follows;

$$\begin{aligned}&\text{Reserved time per paper}\\&\quad = \text{Required time per paper*Effect of Citation Pressure*Effect of Publication Pressure}\end{aligned}$$

On the other hand if the number of publications of the researchers is much lower than the world average number of publications in the particular field, the researchers will feel a pressure to produce more publications. In order to increase the number of publications, they will decrease time devoted on each paper. This will provide more publications which are lower-quality. The effect formulations can be seen in *Figure 7*.



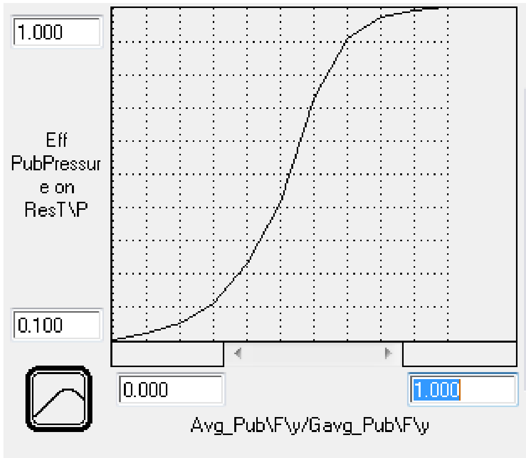


Figure 7: Effect of citation pressure and publication pressure on reserved time

3.1.2. Total Research Time

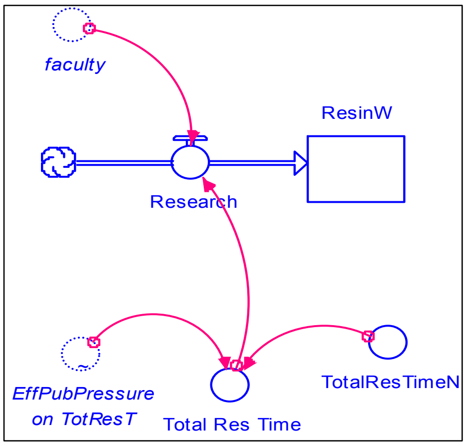


Figure 8: Total research time in the model

It is assumed that, if there is publication pressure, then in addition to decreasing the reserved time, the researchers will also try to increase the total time they spend on research activities.

$$\text{Research} = \text{Faculty} * \frac{\text{Total Research Time}}{\text{Reserved Time per Paper}}$$

$$\text{Total Research time} = \text{Effect of PubPressure on Res Time} * \text{Total Res Time Normal}$$

3.1.3. Quality

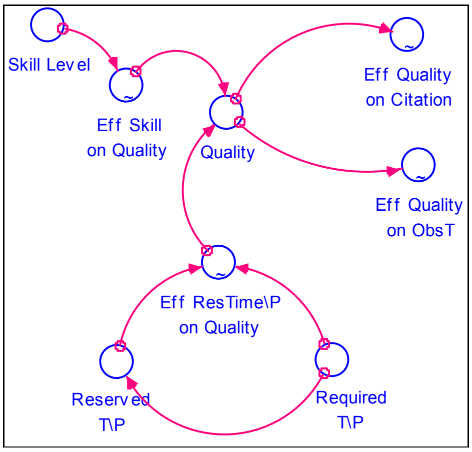


Figure 9: Quality in the model

Quality is one of the key effects in the model. Skill level of members of the department is very important in the quality of the papers. It is assumed that, good-quality universities hire researchers who produce good-quality papers. So, one of the indicators of the quality is the overall skill level of the members of the department. In the model, skill level is an exogenous variable. *Required T/P* (required time per paper) is the time that is needed to produce a paper in normal quality level.

The other indicator of quality is *reserved time*. If *reserved time* is lower than the required time, which is the time that is needed to produce a paper in normal quality level, then the paper will be a low-quality one. As the time spent on a paper increases, its quality level increases. The formulation of quality in the model is seen below.

$$\text{Quality} = \text{Effect of Research Time per Paper} * \text{Effect of Skill}$$

A good-quality paper gets more citations than the others. So there is a positive relationship between quality and number of citations. Additionally, if a paper is a good-quality one, its obsolete time is longer. Obsolete time is the time that how long a paper stays in the stock *published papers (PubPaper)* after being published.

3.1.4. Reputation

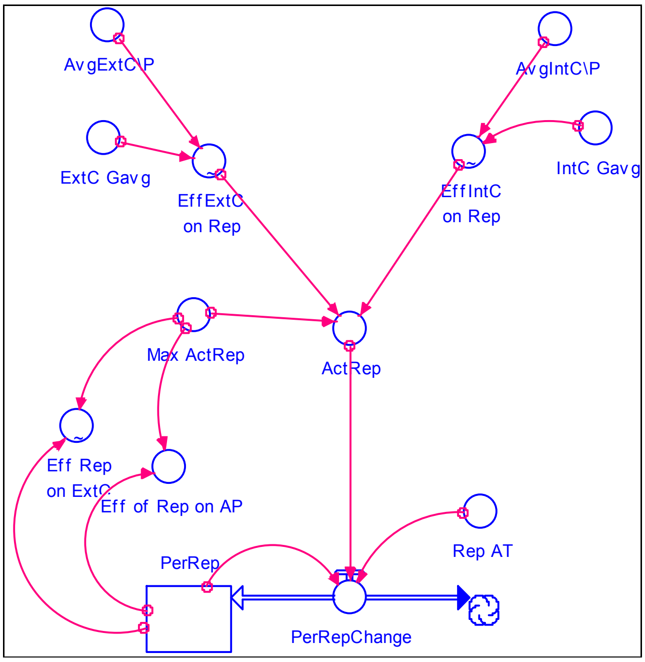


Figure 10: Reputation in the model

Reputation of the department is determined by the average number of citations of the department. The average external citations and the average internal citations of the faculty are compared with the grand average (world average) values which are obtained in data analysis part. Since there is a time delay in perceiving any change in reputation, first order information delay structure is used in modeling this part.

$$\text{Perceived Reputation Change} = \frac{\text{Actual Reputation} - \text{Perceived Reputation}}{\text{Reputation Adjustment Time}}$$

Reputation is directly affecting the external citations because reputation means being known by the other academicians. The other academicians prefer to cite from the one whom they know rather than form anyone On the other hand, reputation does not affect internal citations since internal citations are coming from the colleagues of the researcher. Reputation has also a positive effect on the *acceptance probability* of a paper by a journal.

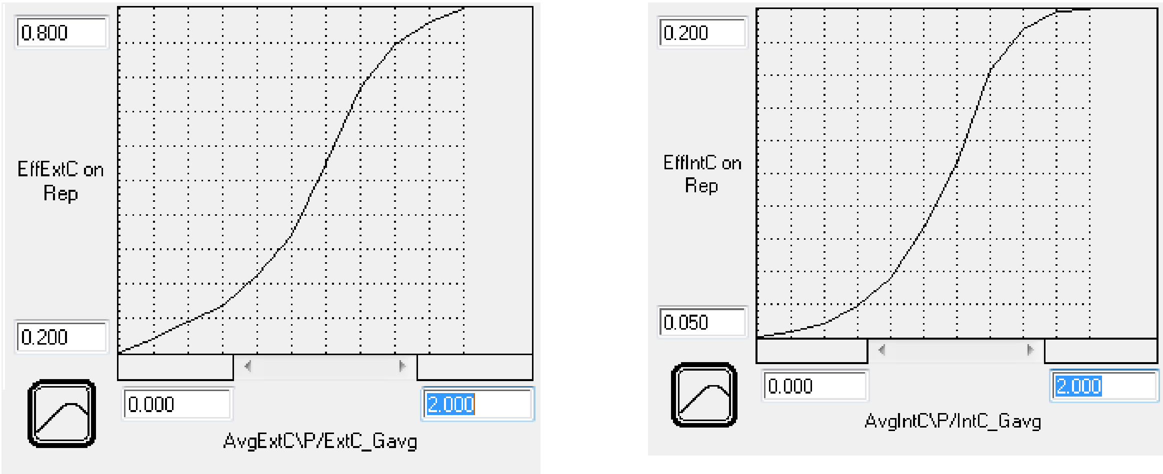


Figure 11: External and internal citation effect on reputation

3.1.5. Acceptance Probability

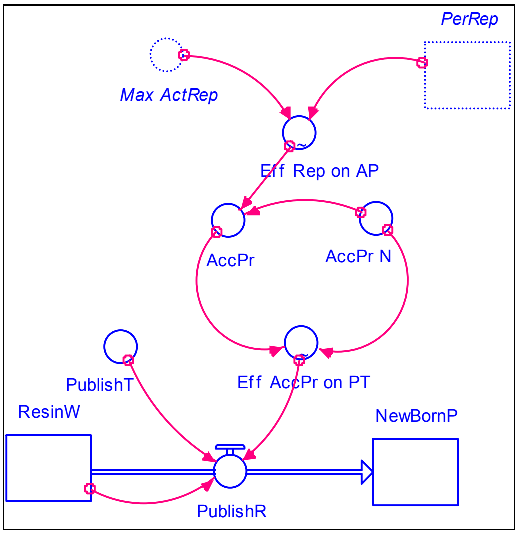


Figure 12: Acceptance probability in the model

AccPr (Acceptance Probability) is the probability that a paper is accepted by a journal. *PublishT* (Publish time) is the time that a paper waits before being published. When *PerRep* (Perceived Reputation) is close to *MaxActRep* (Maximum Actual Reputation) *AccPr* is high. In the same manner, when the perceived reputation is low, *AccPr* is low. *AccPr* has a negative effect on *PublishT* (Publish time). I.e., more reputation means more acceptance probability and more acceptance probability means less waiting time for the paper before being published in a journal.

$$\text{Publish Rate}=\frac{\text{Research in Writing}}{\text{Publish time*Effect of Acceptance Pr on Publish Time}}$$

4. Model Validation

The purpose of model validation is to assure that the model is an acceptable description of the real system behavior with respect to the dynamic problem (1). Model validation is carried out in two steps.

4.1. Structure Validity

Structure test is to check whether the structure of a model is a meaningful description of the real relations that exists in the problem or not. There are two types of structure tests: direct structure tests and structure-oriented behavior tests (1).

Direct structure tests assess the validity of the model structure by direct comparison with knowledge about real system structure. Parameter and variable confirmation, dimensional consistency and extreme condition tests are included in direct structure testing (1). In the model, all parameters and variables have real life counterparts, there is no dimensional inconsistency in equations and the model passes the extreme condition tests.

One of the tests in indirect structure testing is extreme-condition test via simulation. In order to validate the model some extreme conditions are simulated. One of our external input variables is *skill level*. The upper extreme for *skill level* is 100. When we start the simulation with a *skill level* of 100, reputation climbs up to the maximum value of 100. It is consistent in that, if a faculty consists of the most skilled faculty members in the world it becomes the most reputed one in the world.

Another extreme-condition test is applied to the *number of faculty*. When there is 1 faculty member, all publication stock levels decrease as expected. On the other hand, when we start with a faculty of 300 members publication stock levels come to equilibrium at high levels. Additionally, extreme-condition test is done with the *total research time* parameter. If faculty members allocate a very small portion of their time to research (for example 5% of a quarter) then publication stock levels decrease as expected. On the other hand, if very high portion of available time is devoted to research, publication stocks reach their equilibrium at high levels. These entire extreme-condition tests are consistent with the construction of the model.

4.2. Behavior Validity

Behavior pattern tests are designed to measure how accurately the model can reproduce the major behavior patterns of the real system (1). Real data is not available for our case; however we can judge the resulting behavior of the system. According to our assumptions, there should be a balance between the pressures and the actions of the faculty. When the behavior is examined it is seen that *time reserved for a paper* reaches its equilibrium after a set of decisions according to publication and citation pressures. This is kind of seeking a balance between number of papers published and citations received. This main behavior is consistent with our assumptions.

5. Output Analysis

5.1. Base Run

As seen in *Figure 13, new-born papers* and *research in writing* stocks reach their equilibrium after oscillation. This is a result of negative feedback loops of the model. Mainly, publication and citation pressures govern these oscillations. *Published papers* stock has also a kind of oscillation before it settles down. Because of the fact that there is not an outflow of *obsolete papers*, this stock continues to grow.

In *Figure 14* pressure effects can be seen. *Publication-pressure* increases the *total research time* while it decreases the *reserved time per paper*. In the figure, these opposite effects can be seen easily. *Effects of publication pressure* reach equilibrium after oscillations. *Effect of citation pressure* on the other hand, keeps increasing throughout the time-horizon.

In *Figure 15*, behaviors of *reserved time per paper* and *total research time per faculty* can be examined. *Reserved time per paper* is the decision of the faculty on the average time devoted to a paper as a result of the pressures. Faculty seeks equilibrium for the *reserved time per paper* and it results with a damped oscillation. *Total research time per faculty* is also the decision of the faculty in terms of the time devoted to research per faculty member per semester. Faculty seeks equilibrium for it and it results with a damped oscillation. It is seen that behavior of these two variables are in the opposite direction. This is as expected because if there is a publication pressure *total research time per faculty* will increase; however *reserved time per paper* will decrease to be able to publish more papers.

Figure 16 shows the behaviors of *average citation per paper*, *perceived reputation* and *quality*. As we have mentioned before, when citation increases reputation increases. From the figure this relation can be seen easily. *Quality* has an oscillation because it is mainly related to *reserved time per paper*. Because of the fact that *quality* is below 1 it effects citation negatively.

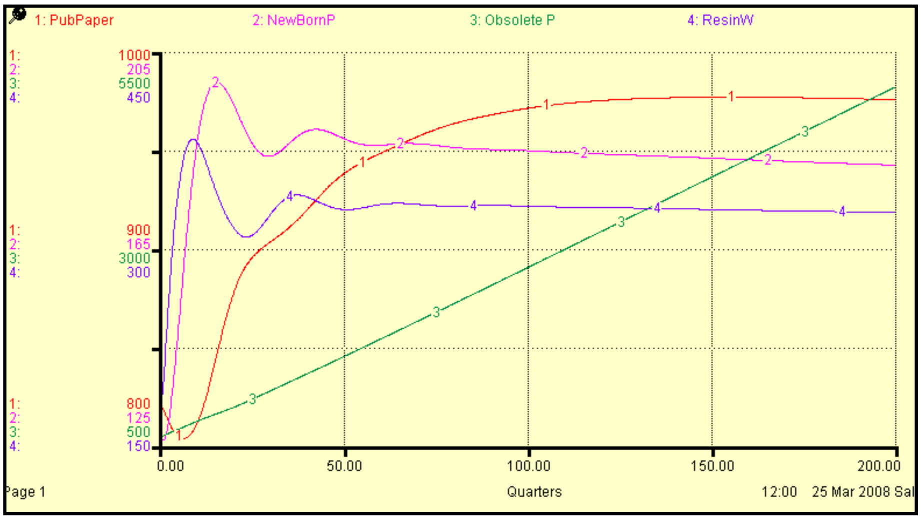


Figure 13: Paper stocks in the base model

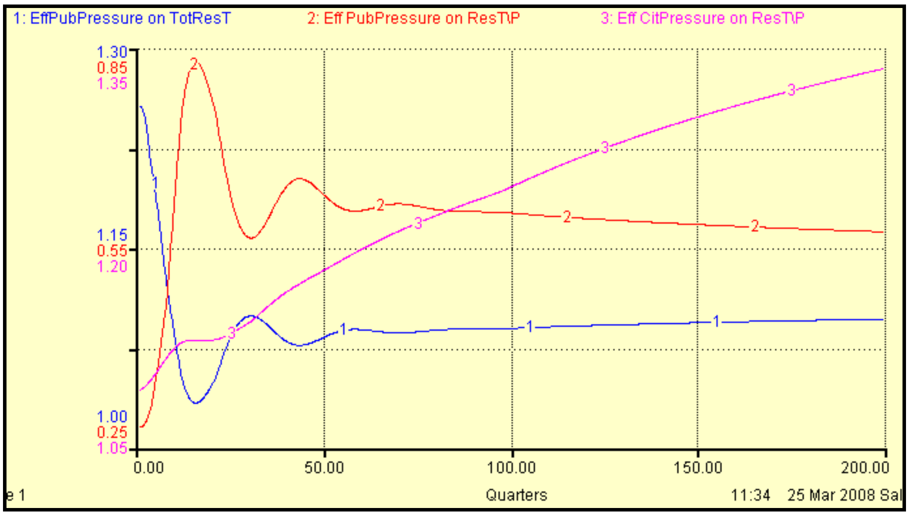


Figure 14: Pressure effects in the base model

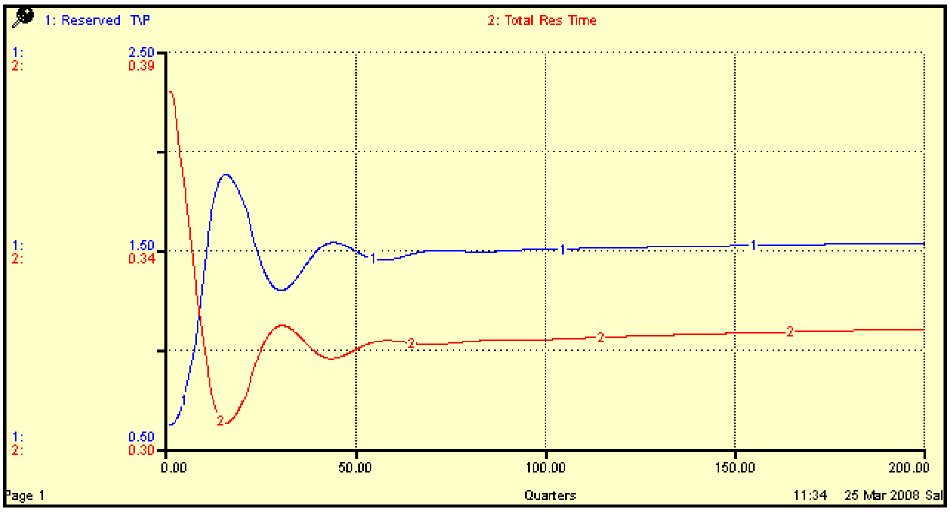


Figure 15: Reserved time per paper and total research time in the base model

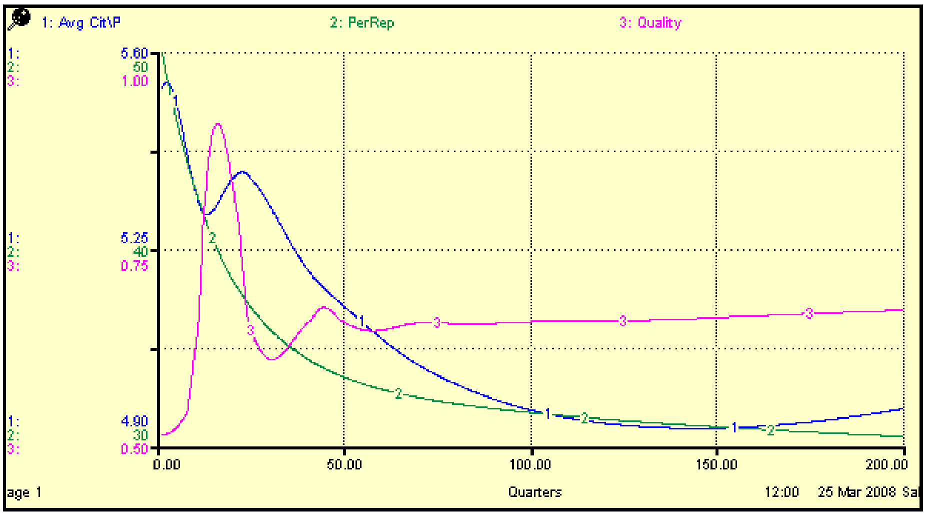


Figure 16: Average citation per paper, reputation, and quality in the base model

5.2. Scenario Analysis

5.2.1. No Publication Pressure Effect on Total Research Time

If there is no pressure effect on total research time, published paper stock reaches equilibrium at a lower level than that it does in the base model. It is expected because faculty will not be able to increase number of publications as much as that in the base model. The behavior of the paper stocks can be seen in *Figure 17.* As seen in *Figure 18*, *reserved time per paper* reaches equilibrium at a lower value compared to the base model. This is expected; faculty cannot increase *total research time* and to be able to catch the world average of the publication performance, faculty should decrease the amount of time devoted to each paper.

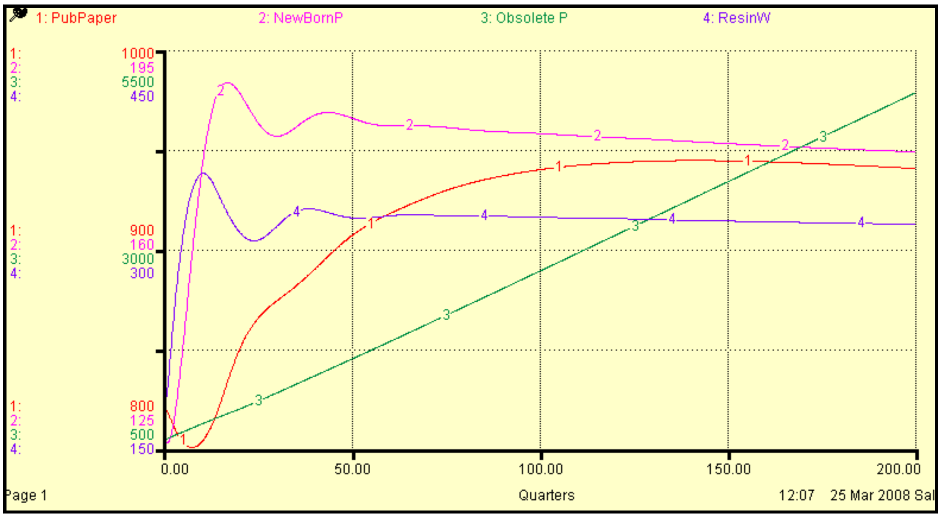


Figure 17: Paper stocks in scenario 1

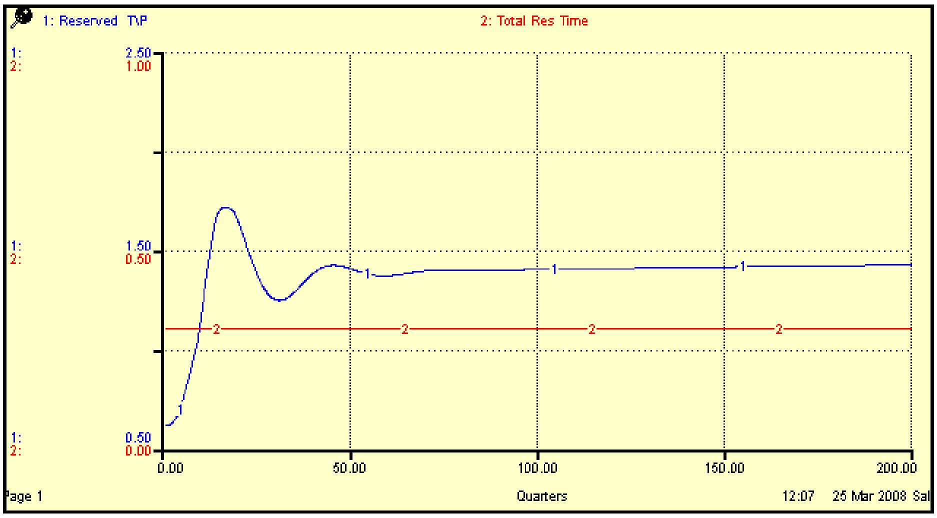


Figure 18: Reserved time per paper and total research time in scenario 1

5.2.2. No Citation Pressure

Everything being equal, if there is no citation pressure, the faculty does not keep track of the citations received and so does not care about quality. The main effect is on *reserved time per paper* and on *total research time per faculty* which can be seen in *Figure 20*. As expected, *reserved time per paper* reaches equilibrium at a lower level than that in the base model. Besides *total research time*'s equilibrium value is lower than its being in the base model because of the same reason. In *Figure 19*, it is seen that paper stock values are higher compared to the base model as a result of devoting less time to each paper in the absence of the citation pressure.

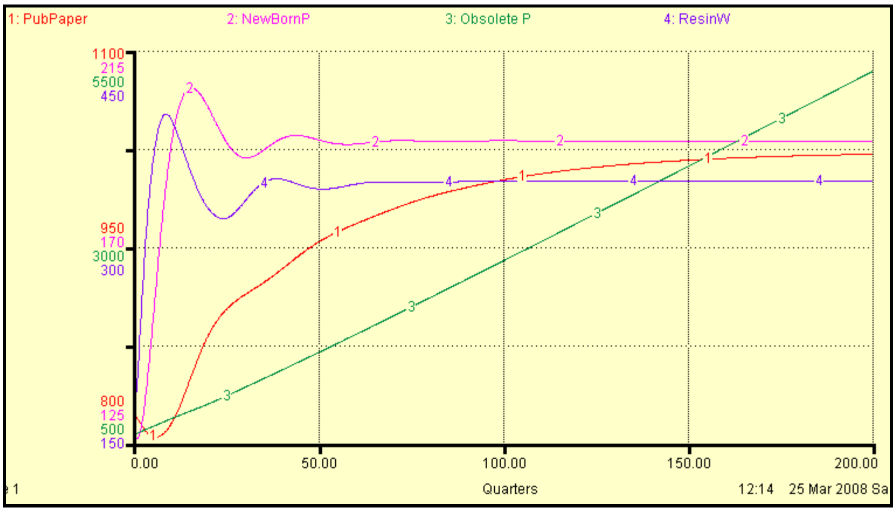


Figure 19: Paper stocks in scenario 2

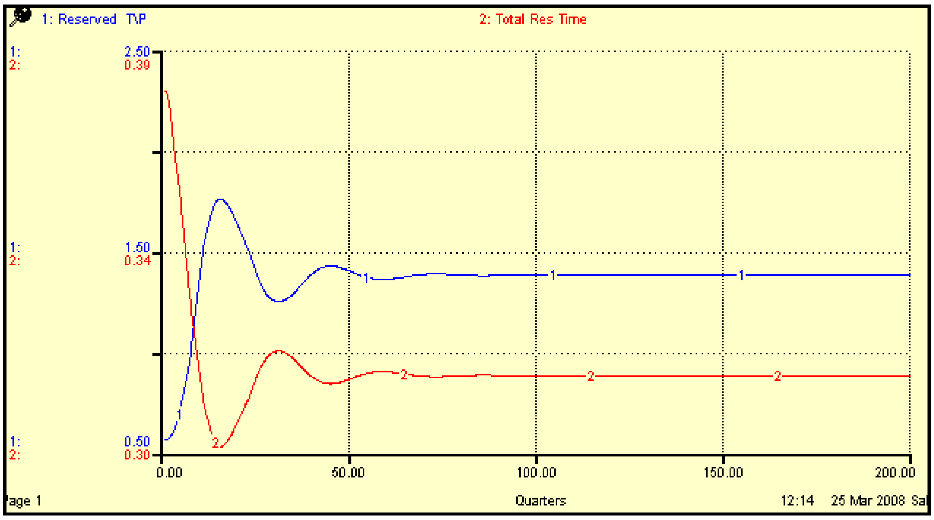


Figure 20: Reserved time per paper and total research time in scenario 2

5.2.3. Lower Skill Level

Skill level is an input for the quality, as stated before. In the base model it was 50 (normal value for the quality). Different scenarios are created with different values of skill level. One of them is carried out with a skill level of 20. In this case paper stock levels decrease as expected (*Figure 21*). Besides, because of the fact that quality of the papers is low, citation pressure occurs. Compared to the base model *reserved time per paper* reaches equilibrium at a higher level (*Figure 22*). Quality decreases and this decrease effects the citation and reputation negatively (*Figure 23*).

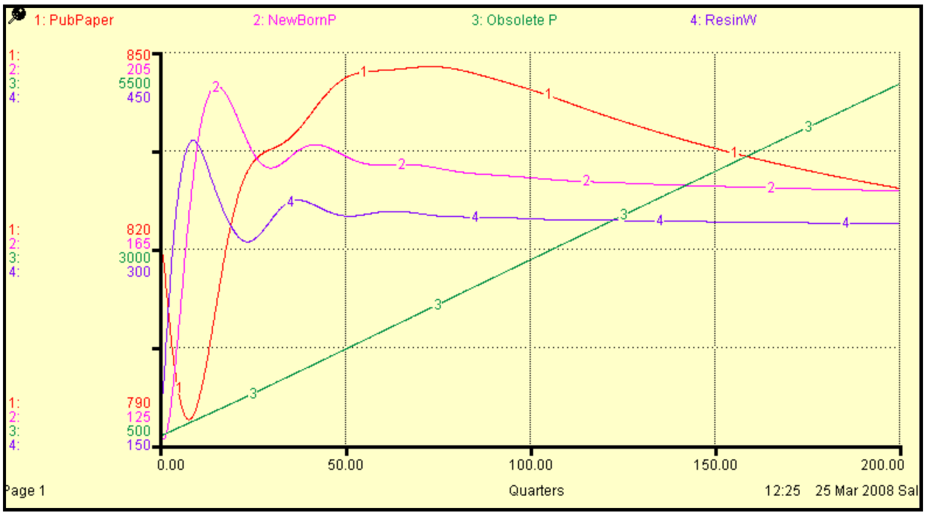


Figure 21: Paper stocks in scenario 3

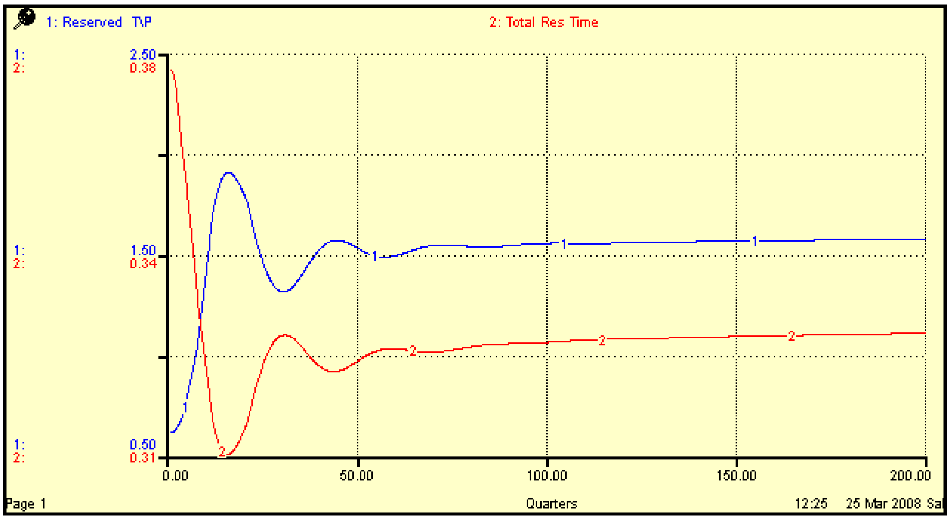


Figure 22: Reserved time per paper and total research time in scenario 3

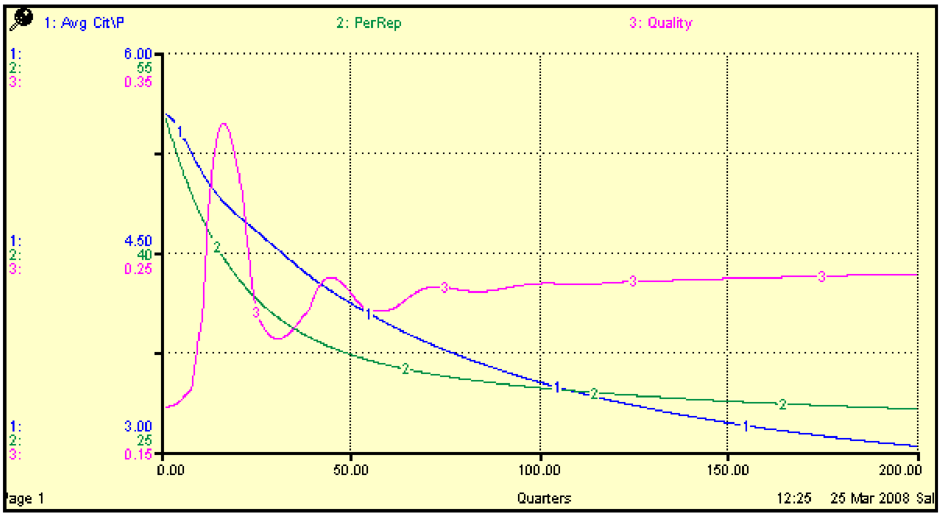


Figure 23: Average citation per paper, reputation, and quality in scenario 3

5.2.4. Higher Skill Level

In this case skill level is increased to 80 and as a result paper stock levels increased as seen in *Figure 24*. Because of the fact that quality of the papers is high, *citation pressure* is not effective. As a result compared to the base model *reserved time per paper* reaches equilibrium at a lower level. Parallel to that *total research time* has a lower equilibrium than that of the base model. These behaviors can be seen in *Figure 25*.

In *Figure 26*, it is seen that *quality* increases with the high skill level. As a result of the higher quality compared to the base model, average citation values increase and *reputation* increases.

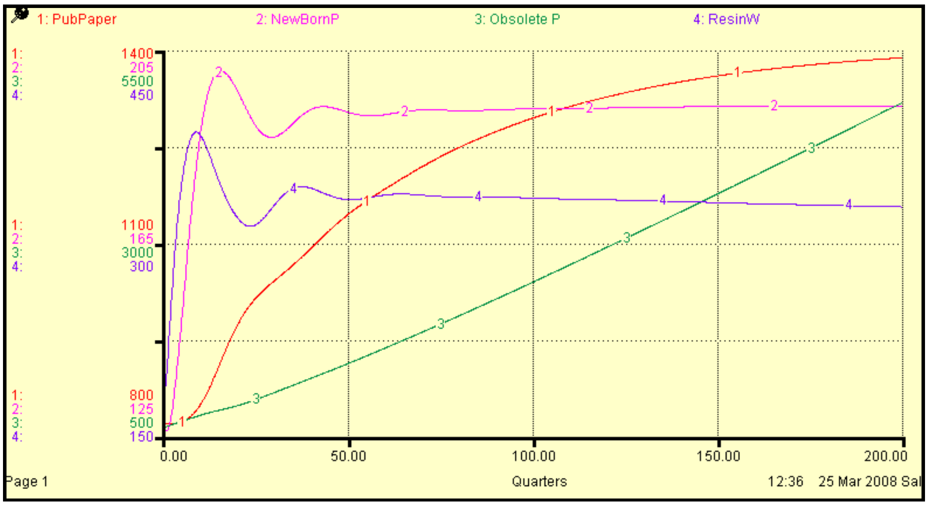


Figure 24: Paper stocks in scenario 4

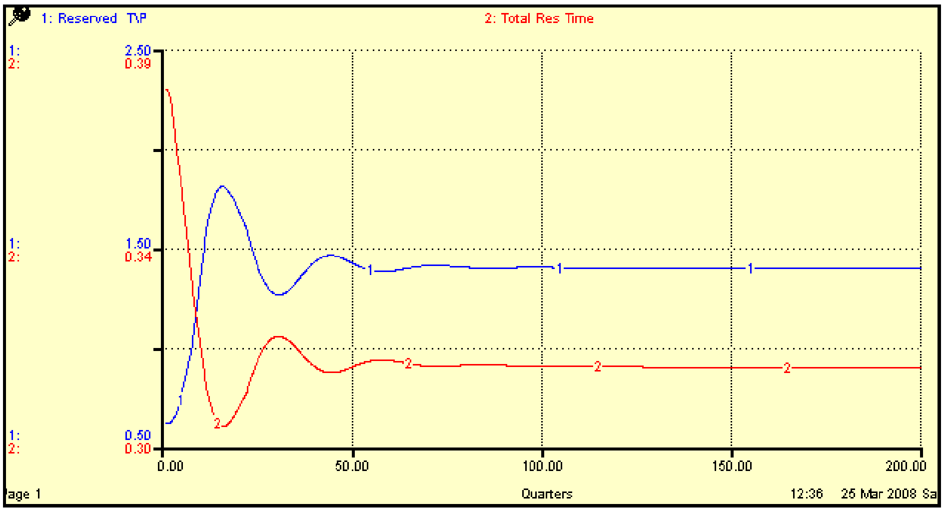


Figure 25: Reserved time per paper and total research time in scenario 4

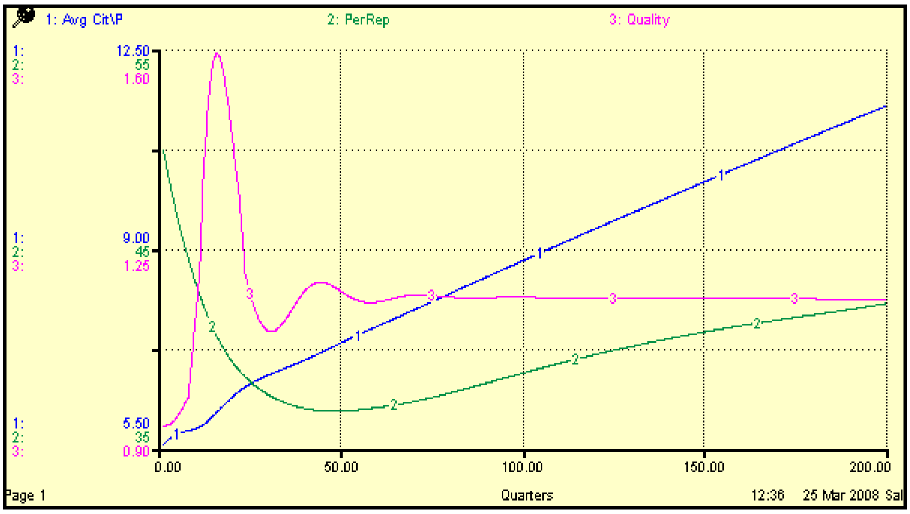


Figure 26: Average citation per paper, reputation, and quality in scenario 4

5.2.5. Lower Initial Reputation and Higher Skill Level

To be able to show the effect of the initial population and the skill level together, these last two scenarios are created. In our base model we have taken initial reputation as 50. In this case initial reputation is 20 and the skill level is 80. As seen in *Figure 27*, because of the high skill value quality is high, and reputation climbs up together with citation.

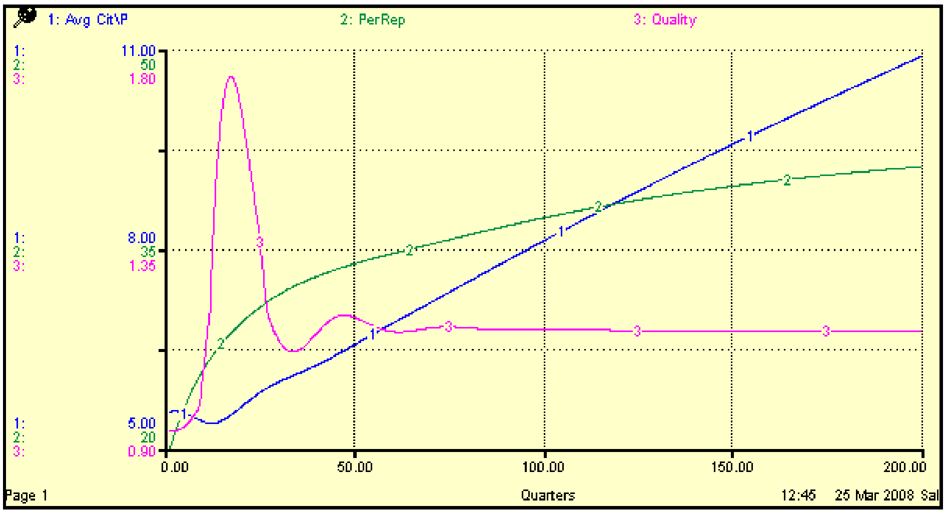


Figure 27: Average citation per paper, reputation, and quality in scenario 5

5.2.6. Higher Initial Reputation and Lower Skill Level

In this last scenario, initial reputation is taken as 100 and the skill level is 20. As seen in *Figure 28*, because of the low skill value quality is low, and reputation goes down together with citation.

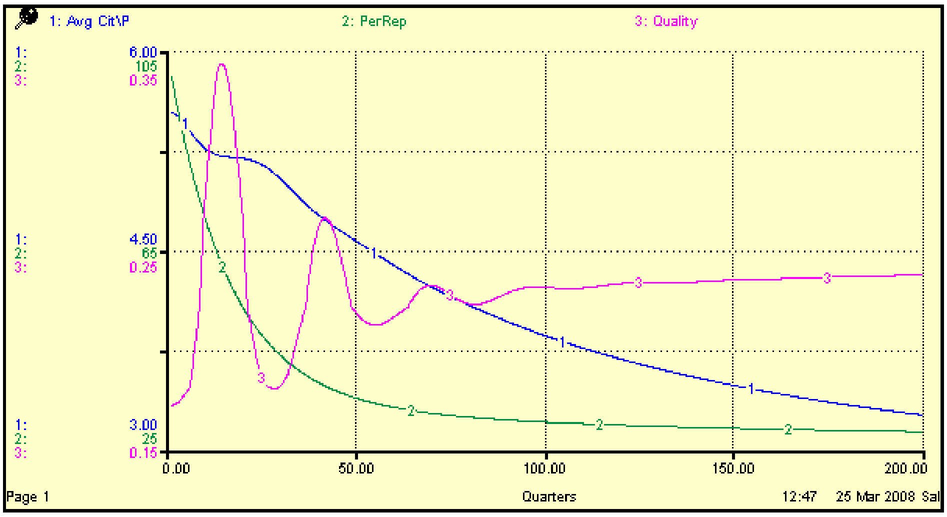


Figure 28: Average citation per paper, reputation, and quality in scenario 6

6. Discussion and Conclusion

The conventional wisdom in the field which is that 10% of the journals get 90% of the citations is a striking signal of a problem in science policy. The evolution of scientometrics, which uses number of publications and citations as measure, has to change its direction and find new comprehensive measures in order to make publication again the way of communication among scientific peers. For such a new comprehensive measure it is needed a systemic analyze of the situation in order the grasp the roots of the problem. This study is an initial effort of such an analysis.

The aim of the study which is to examine the behaviors of researchers in response to dynamics of publication and citation pressures is achieved as a model including researchers in a department, their publications, citations and the factors such as reputation, quality, pressures on researchers and their skill levels.

The main decision of the department (accumulated faculties) is the allocation of time to produce in high quality or low quality papers and this decision creates the dynamics. In the base run, quality of publication, reputation of the department, publication and citation pressures are understood as main factors. High skill and much time results in high quality papers which get more citations. As papers get more citation the reputation increases and increasing reputation results in more citation. The positive feedback loop between reputation and citation is very strong but other feedback mechanism balances it. Publication and citation pressures act in opposite way. While former causes producing more papers in shorter times (low quality); the latter tries to make high quality papers in longer times (few paper). These opposite effects make model reach equilibrium after some oscillations between low and high reserved time values.

In the scenario analysis, when citation pressure is removed the paper stocks reach equilibrium at higher levels with low quality, less-cited papers. Additionally, the system is very sensitive to the skill level which is modeled as an exogenous factor. And lastly, when the reputation and skill level analyzed together, it is seen that the skill level is decisive factor. A skilled department obtains reputation, regardless of the initial level of reputation.

As further research, in order to better grasp the decision mechanism of the researchers, this model can be widened by including the other pressures (such as career, financial…etc). Or with an agent based approach the interrelations between multiple departments can be analyzed with a multi-level model. Furthermore, the network structure between people is a necessary research topic in understanding today's problem of science. All in all, this study is an initial effort and will achieve its goal if it can stimulate any further research.

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