**Istanbul Commerce University Journal of Science**
*İstanbul Ticaret Üniversitesi Fen Bilimleri Dergisi, 16(32), Güz 2017*
http://dergipark.gov.tr/ticaretfbd

ISTANBUL COMMERCE UNIVERSITY

*Research Article*

# SIMULATIONS OF RESEARCH PERFORMANCE IN CROSS-DISCIPLINARY CONTEXTS: A MODEL AND AN APPLICATION*

**Ahmet KARA**[1]

İstanbul Ticaret Üniversitesi, İşletme Fakültesi
İstanbul, Turkiye
kara2010@ticaret.edu.tr orcid.org/0000-0002-0162-8137

## Abstract

The purpose of this paper is to construct a model of research performance, based on a demand-and-supply set-up, in a cross-disciplinary context and simulate the trajectory of research performances. We take into account the effects of human capital and research technology as well as interactions among different disciplines/subjects so as to theorize about possible shapes of these trajectories. It turns out that, depending on the levels of human capital and technology, research performances could have different trajectories over time. Contingent upon the priority-driven amount of resources devoted to research, university administrators could choose a path among different trajectories, a path that is most compatible with their institutional objectives.

**Keywords***:* Simulations of research performances, cross-disciplinary effects, technology.

*Araştırma Makalesi*

# DİSİPLİNLERARASI BAĞLAMLARDA ARAŞTIRMA PERFORMANSI SİMÜLASYONLARI: BİR MODEL VE BİR UYGULAMA

## Öz

Bu makalenin amacı, çapraz etkileşimlerin karakterize ettiği disiplinlerarası bağlamlarda, arz ve talebe dayalı bir araştırma performansı modeli kurmak ve performansın seyrini simüle etmektir. Makalede, beşeri sermaye, araştırma teknolojisi ve disiplinlerarası etkileşimlerin dikkate alındığı bir model aracılığıyla, muhtemel performans yörüngeleri incelenmektedir. Beşeri sermayenin düzeyi ve teknolojiye bağlı olarak farklı yörüngelerin mümkün olabileceği ortaya konulmaktadır. Üniversite yönetimleri, değişik performans yörüngeleri arasında, hedeflerine uygun seçimi, araştırmaya öncelikler doğrultusunda tahsis edilmiş kaynakları kullanarak, yapabilirler.

**Anahtar Kelimeler:** Araştırma performansı simülasyonları, alanlar-arası çapraz etkiler, teknoloji.

* Received / Geliş tarihi: 05/12/2016 Accepted / Kabul tarihi: 11/03/2017
[1] Corresponding Author/ Sorumlu Yazar : kara2010@ticaret.edu.tr

## 1. INTRODUCTION

Research productivity, which is one of the key indicators of the performance of the universities in modern times, has been an active area of research in the last thirty years. Among the works exploring different dimensions of the issues associated with academic research in particular and universities in general are Abdullah, Jaafar and Taib (2013), Abramo, Cicero & D'Angelo (2012), Abramo, D'Angelo & Di Costa (2014), Adams & Clemmons (2011), Barlas & Diker (2000), Barlas, Diker, Polat (1997), Dundar & Lewis (1995), Fedderke and Luiz (2008), Grayson (2004), Ivanov, Markusova & Mindeli (2016), Jaffe (1989), Kara (2011, 2013a, 2013b, 2014), Kodama, Watatani &Sengoku (2013), Munoz (2016), Millers, Moffettt, McAdam & Brennan (2013), Neri & Rodgers (2013), Pastor & Serrano (2016), Singell and Tang (2013), Spencer (2001), and Walton, Tornatzky & Eveland (1986).

Topics/issues covered in the literature, which constitute a rich spectrum, include, but are not limited to, the determinants of the research output of universities (Pastor & Serrano (2016)), the system-theoretic analysis of the higher educational processes (Barlas & Diker (2000), Barlas, Diker, Polat (1997) and Kara (2011, 2013a, 2013b, 2014)), research efficiency-related issues associated with higher education institutions (Munoz (2016)), the role of human capital in the development of institutions (Fedderke and Luiz (2008)), government investments in relation to the publishing activity of higher educational institutions (Ivanov, Markusova & Mindeli (2016), the effect of human capital on job outcomes (Grayson (2004)), returns to scope of research fields (Abramo, D'Angelo & Di Costa (2014), the ranking of human capital indicators (Abdullah, Jaafar and Taib (2013)), size effects in higher education research productivity (Abramo, Cicero & D'Angelo (2012), the relation between human capital and leadership in universities (Singell and Tang (2013)), the departmental productivity in the context of the issues of economies of scale and scope (Dundar & Lewis (1995)), the relevance of university-based scientific research to private high-technology firms (Spencer (2001)), interdisciplinary issues (Kodama, Watatani & Sengoku (2013), Adams & Clemmons (20111)), real effects of academic research (Jaffe (1989)), Human capital externalities (Neri & Rodgers (2013)), topics involving research management at the university departments (Walton, Tornatzky & Eveland (1986)) and issues of intellectual capital (Miller, Moffett, McAdam & Brennan (2013)).

A comprehensive inquiry into the research performance patterns and practices may reveal some of the characteristics of the complex dynamics governing the research productivity in modern universities. Such an inquiry may take various theoretical and empirical directions and forms, one of which would be a simulation-based theory building, which we will exemplify in this paper. The particular method we choose facilitates the analysis of the intricate cause-and-effect relations behind the research performances.

To contribute to the relatively under-explored dimensions of this area, we will construct a model of research performance, based on a demand-and-supply set-up, in

a cross-disciplinary context and simulate the trajectory of research performances. We pay particular attention to the effects of human capital and research technology.

The second section of the paper will develop the model. The third section presents the simulations. Concluding remarks follow in the final section.

## **2.** THE MODEL[2]

Consider a representative institution, such as a university that engages in research in various fields. For the purpose of simplicity, we will consider two related fields/subjects, denoted by 1 and 2. The quantity demanded for the research service in a field 1 at time t ($QD_{1t}$) depends on the level of research performance for the service 1 at time t ($y_{1t}$), the relative price of the research service 1 at time t ($P_{1t}$), the level of human capital associated with service 1 at time t ($HK_{1t}$), and the level of technology associated with the service 1 at time t ($T_{1t}$),

i.e., $$QD_{1t} = g^{D_1}\left(y_{1t}, P_{1t}, HK_{1t}, T_{1t}\right)$$

which is a "peculiar" demand function for the research service 1. $P_{1t} \in (0,\infty)$, $HK_{1t} \in (0,\infty)$. By construction, observable $y_{1t}$, $y_{2t}$ ,$T_{1t}$ take on short-run values between 0 and 7, i.e., $y_{1t} \in (0,7]$, $y_{2t} \in (0,7]$, and $T_{1t} \in (0,7]$. Values exceeding 7 are considered unusually high and achievable in the long run. $QD^{T}_{1t} \in (0,\infty)$.

Let $QS_{1t}$ denote the quantity supplied for the research service 1 at time t, which is a function of the level of research performance for the service 1 at time t ($y_{1t}$), the level of research performance for the service 2 at time t ($y_{2t}$), the relative price of the service 1 at time t ($P_{1t}$), the level of technology associated with the service 1 at time t ($T_{1t}$), and the level of technology associated with the service 2 at time t ($T_{2t}$),

i.e., $QS_{1t} = \alpha o + \alpha_1 y_{1t} + \alpha_2 P_{1t} + \alpha 3\ HK_{1t} + \alpha 4 T_{1t} + u_{lt}$ , $QS_{1t} \in (0,\infty)$

We will assume that the demand and supply functions for research are of the following forms:

$$QD_{1t} = \alpha o + \alpha_1 y_{1t} + \alpha_2 P_{1t} + \alpha 3\ HK_{1t} + \alpha 4 T_{1t} + u_{lt},$$

where $T_{1t} = T_{10}(1 + a1 + z1t)^t$,

and

$$QS_{1t} = \beta_0 + \beta_1 y_{1t} + \beta_2 P_{2t} b + \beta_3\ P_{1t} + \beta_4 HK_{1t} + \beta_5 T_{1t}^{\ c} + \beta_6 T_{2t}^{\ 0.5} + v_{1t}$$

where $T_{2t} = T_{20}(1 + a2 + z2t)^t$.

$z_{1t}$, $z_{2t}$, $u_{1t}$ and $v_{1t}$ are normally distributed white noise stochastic terms with zero means and constant variances $\sigma_{z1}^{\ 2}$, $\sigma_{z2}^{\ 2}$, $\sigma_{u1}^{\ 2}$ and $\sigma_{v1}^{\ 2}$ respectively.

[2] The model developed here benefits, in part, from Kara (2014).

To model the trajectory of research performance for service 1 over time, the movement over time of research performance for service 1 will be assumed to be proportional to the excess demand for performance,

i.e., $y_{1t+1} - y_{1t} = k(QD_{1t} - QS_{1t})$,

where $k$ is the coefficient of adjustment.

This is nothing but a dynamic adjustment equation for the research performance for service 1. Substituting the expressions for $QD_{1t}$ and $QS_{1t}$ specified above, setting the initial values of $P_{1t}$, $HK_{1t}$ , $T_{1t}$ , $T_{2t}$ to their average values $P_{1t}^{avr}$, $HK_{1t}^{avr}$ , $T_{1t}^{avr}$, *and* $T_{2t}^{avr}$ and rearranging the terms in the equation, we get,

$$y_{1t+1} + (-1 - k(\alpha_1 - \beta_1)) - y_{1t} = k(\alpha_0 - \beta_0 - \beta_2 y_{2t}^{b} + (\alpha_2 - \beta_3)P_{1t}^{avr} + (\alpha_3 - \beta_4)HK_{1t}^{avr} + \alpha_4 T_{1t}^{avr} - \beta_5 T_{1t}^{avr} - \beta_6 T_{2t}^{0.5avr} + u_{1t} - v_{1t})$$

which is one of the stochastic difference equations that we will employ in the simulations in Section III.

The quantity demanded for the research service in a field 2 at time t ($QD_{2t}$) depends on the level of research performance for the service 2 at time t ($y_{2t}$), the relative price of the research service 2 at time t ($P_{2t}$), the level of human capital associated with service 2 at time t ($HK_{2t}$), and the level of technology associated with the service 2 at time t ($T_{2t}$),

i.e., $QD_{2t} = g^{D2}(y_{2t}, P_{2t}, HK_{2t}, T_{2t})$,

which is a "peculiar" demand function for the research service 2. $P_{2t} \in (0,\infty)$, $HK_{2t} \in (0,\infty)$. By construction, observable $T_{2t}$ takes on short-run values between 0 and 7, i.e., $T_{2t} \in (0,7]$. Values exceeding 7 are considered unusually high and achievable in the long run. $QD^{T}_{2t} \in (0,\infty)$.

Let $QS_{2t}$ denote the quantity supplied for the research service 2 at time t, which is a function of the level of research performance for the service 2 at time t ($y_{2t}$), the relative price of the service 2 at time t ($P_{2t}$), the level of human capital associated with service 2 at time t ($HK_{2t}$), and the level of technology associated with the service 2 at time t ($T_{2t}$),

i.e., $QS_{2t} = g^{S1}(y_{2t}, P_{2t}, HK_{2t}, T_{2t})$, $QS_{2t} \in (0,\infty)$.

We will assume that the demand and supply functions for 2 are of the following forms:

$$QD_{2t} = \theta_0 + \theta_1 . y_{2t} + \theta_2 . P_{2t} + \theta_3 HK_{2t} + \theta_4 T_{2t^d} + u_{2t}$$

and

$$QS_{2t} = \delta_0 +_1 \delta . y_{2t} + \delta_2 . P_{2t} + \delta_3 HK_{2t} + \delta_4 T_{2t^e} + v_{2t}$$

where $u_{2t}$ and $v_{2t}$ are independent normally distributed white noise stochastic terms with zero means and constant variances $\sigma_{u2}^2$ and $\sigma_{v2}^2$ respectively.

To model the trajectory of research performance for service 2 over time, we will assume that the movement over time of research performance is proportional to the associated excess demand,

i.e., $y_{2t+1} - y_{2t} = k^*(QD_{2t} - QS_{2t})$ ,

where $k^*$ is the coefficient of adjustment.

This is of course a dynamic adjustment equation for the research performance for service 2. Substituting the expressions for $QD_{2t}$ and $QS_{2t}$ specified above, setting the initial values of $P_{2t}$, $HK_{2t}$, $T_{2t}$ to their average values $P_{2t}^{avr}$, $HK_{1t}^{avr}$ *and* $T_{2t}^{avr}$ and rearranging the terms in the equation, we get,

$$y_{2t+1}\left(-1-k^*\left(\theta_1-\delta_1\right)\right)=k^*\begin{pmatrix}\theta_0-\delta_0+(\theta_2-\delta_2)P_{2t}^{avr}+\\(\theta_3-\delta_3)HK_{2t}^{avr}+Q_4T_{2t}^{davr}-\delta_4)T_{2t}^{eavr}+u_{2t}-v_{2t}\end{pmatrix}$$

which is the stochastic difference equation describing the movement of the research performance for service 2 over time.

The two stochastic difference equations we have derived above will serve as a basis for the simulations that we will undertake in the following section.

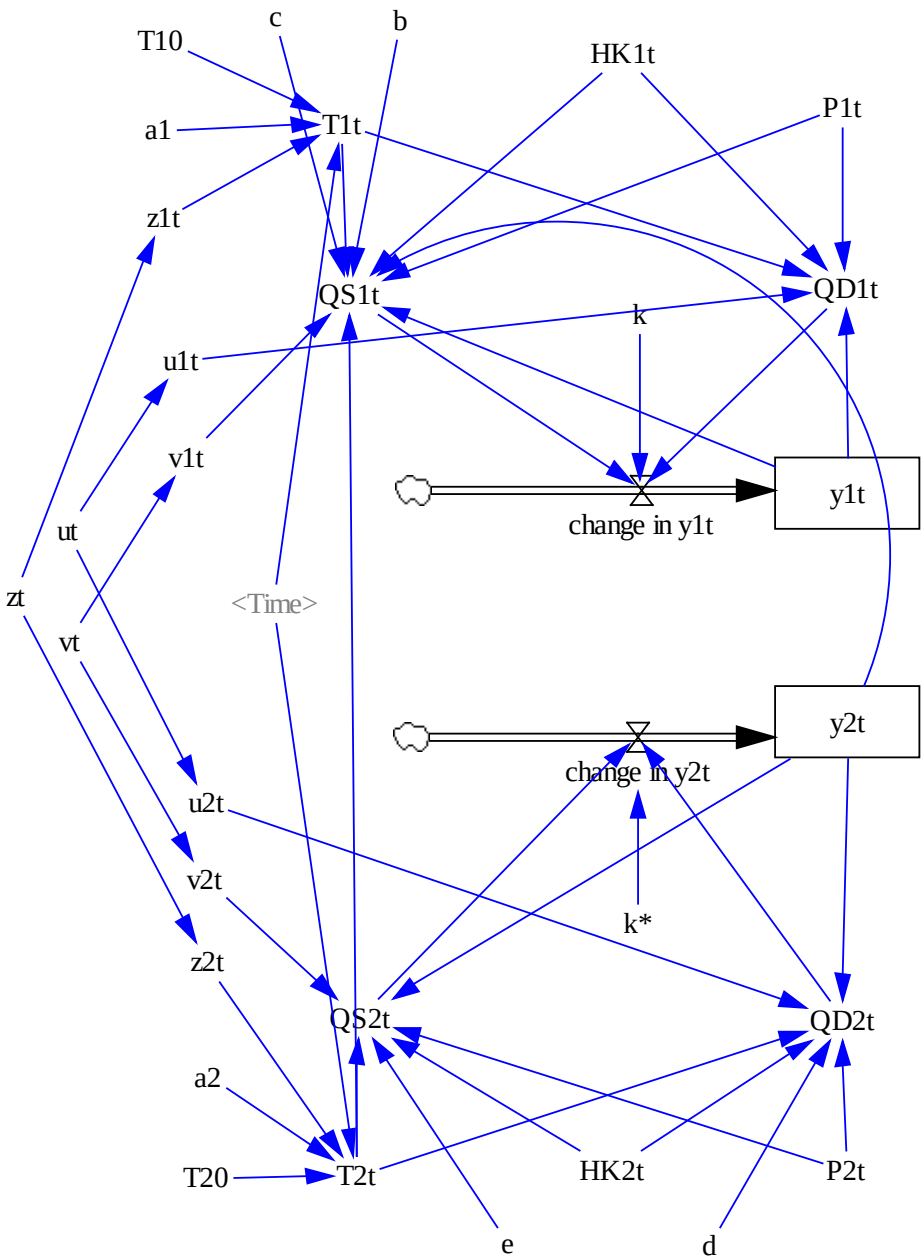
## 3. SIMULATIONS[3]

We will make use of system dynamics method to carry out simulations for research performance. The method takes stocks, flows and auxiliary variables as the building blocks and requires that multiple causal connections among the variables be specified mostly in the form of feedback relations or structures. In our model we take the designated research performances as the stocks, the change of which are described as the flow variables. Other variables are of the auxiliary type playing key roles in specifying the feedback relations within the system.

The simulation diagram describing the stochastic-equation-based causal connections and feedback-relations within the system is as follows:

[3] Programs ranging from NET LOGO to VENSIM could be used for simulation purposes. We have used VENSIM. MATLAB could be used as well. The description of the system dynamic processes in this section is similar to the one in Kara (2016).

**Figure 1: Simulation Diagram**



Research performances evolve over time through demand and supply and the adjustment dynamic specified in the model.

For simulation purposes, let: $\alpha_0$ = 1, $\alpha_1$ = 0.9, $\alpha_2$ =-0.7, $\alpha_3$ = 0.7, $\alpha_4$ = 0.6, $\beta_0$ = 0.9, $\beta_1$ = 0.5, $\beta_2$ =0.3, $\beta_3$ = 0.4, $\beta_4$ = 0.4, $\beta_5$ = 0.4, $\beta_6$ = 0.3, k = 0.1, $P_{1t}^{avr}$ = 1, $a_1$ = 0.03, $HK_{1t}^{avr}$ = 2.5 and $T_{10}$ = 2.

The initial $y_{1t}$ = 2, the initial $y_{2t}$ = 1.8. $\theta_0$ = 1, $\theta_1$ = 0.8, $\theta_2$ =-0.5, $\theta_3$ = 0.4, $\theta_4$ = 0.25, $\delta_0$ = 0.8, $\delta_1$ = 0.55, $\delta_2$ =0.3, $\delta_3$ = 0.25, $\delta_4$ = 0.1, k* = 0.1, $a_2$= 0.04. $P_{2t}^{avr}$ = 1.1, $HK_{2t}^{avr}$ = 2.5 and $T_{20}$ = 2. $u_{1t}$ =0.6$u_t$, $v_{1t}$ =0.4$v_t$, $u_{2t}$ =0.5$u_t$, $v_{2t}$ =0.5$v_t$, and $z_{1t}$ =0.001$z_t$, $z_{2t}$ =0.001$z_t$, $z_t$ is a random variable that takes a value between zero and one. $u_t$ and $v_t$ are random variables with zero mean and standard deviation of 0.1. The simulated stochastic trajectories of $y_{1t}$, $y_{2t}$ and $y_{1t}$-$y_{2t}$ relations are as follows: Figure 2 and 3 illustrate the research performances with the initial (low) and increased (high) human capital. Figure 4 display the cross-evolution of the performances in question.

**Figure 2:** $y_{1t}$ with the initial (low) and increased (high) human capital

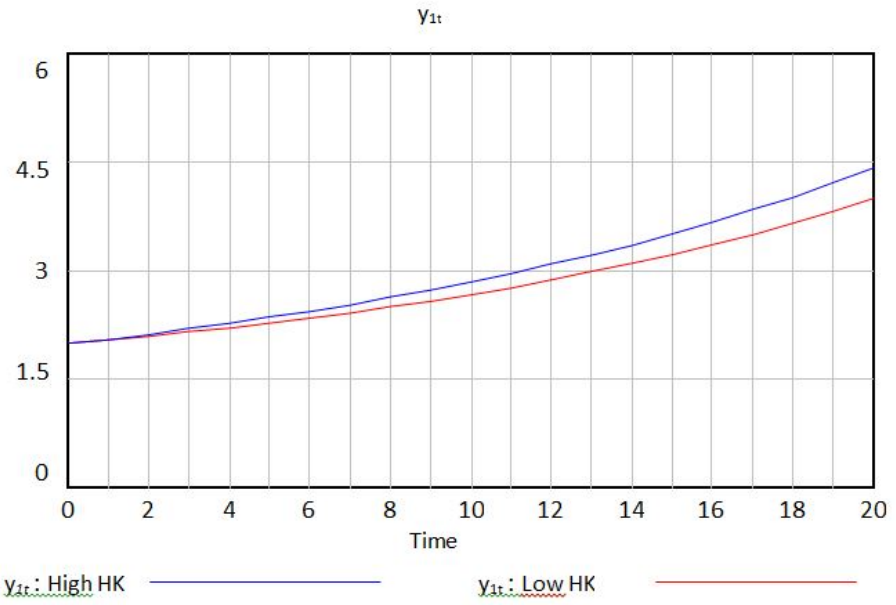
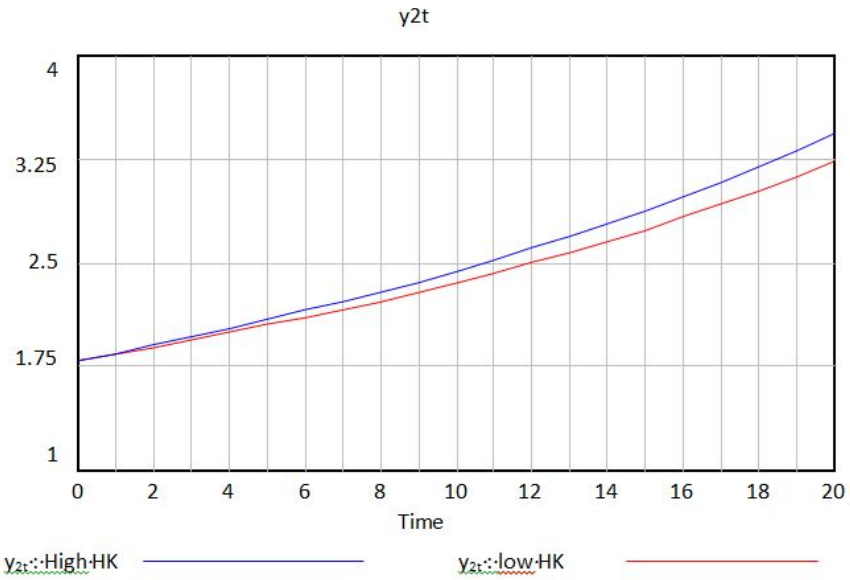
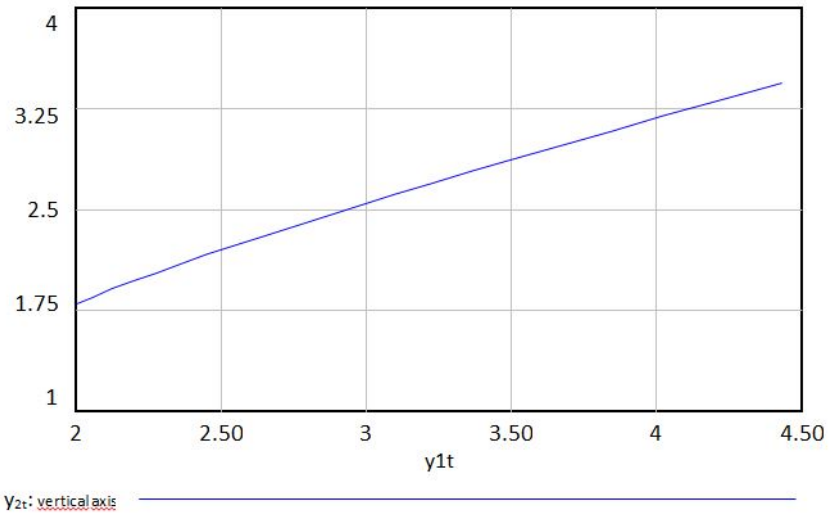


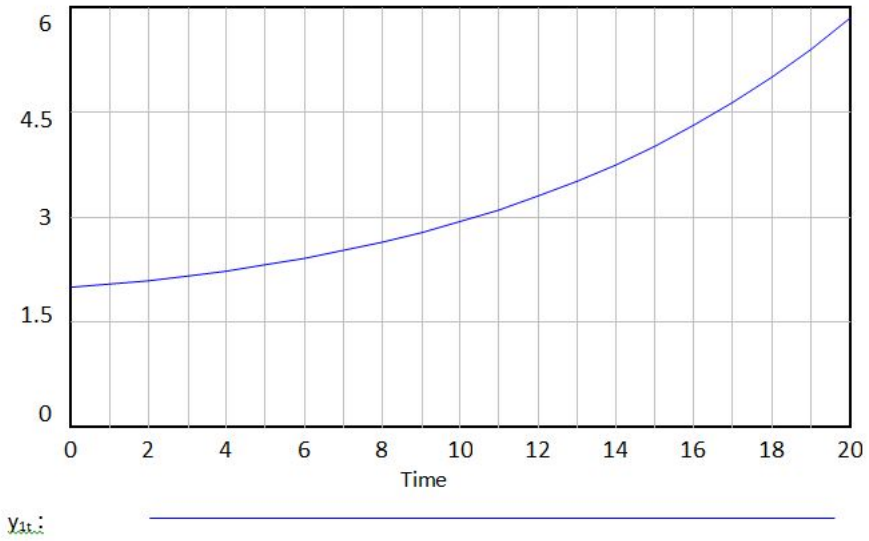
**Figure 3:** $y_{2t}$ with low and high human capital






Similarly, we can simulate the trajectory of research performances with an improved research technology. For instance, an increase in the technological growth parameters ($a_1$ and $a_2$) would considerably improve the research performance $y_{1t}$, as illustrated in Figure 5 below.

**Figure 5:** $y_{1t}$ with rapidly evolving technology (with $a_1=a_2=0.07$)



Clearly there are, in the model, many deterministic and stochastic factors influencing the trajectories of the variables. Their presence leads to stochastic fluctuations around the deterministic trends of the variables in question. In the simulation set-up, stochastic factors are kept small in magnitude; graphs do not discernably reflect their effects. On the other hand, the steepness of the graphs clearly depends on the values of a variety of parameters representing, for instance, the technological growth or the degree of complementarity between subjects.

Graphs display a number of features of the performance trajectories. First increases in the human capital employed in research lead to upward shifts in the trajectories of research performances (Figure 2 and 3). Second, changes in the research performance for subject 2 are positively associated with the changes in the research performance for subject 1, demonstrating, within the causal structure of the model, the positive cross-influence of $y_{2t}$ on $y_{1t}$ (Figure 4). Third, technological growth, as illustrated in Figure 5, positively influences the relevant research performance.

## 4. CONCLUDING REMARKS

Results above exemplify the possibility of improvement in research performance due to improved human capital and intra-or-cross-disciplinary research technology. There are, of course, many other sources of improvement, and the extraordinary richness in sources is mostly in the details of performance-generating processes. For instance, the intricate ways one research area (research in one discipline) depends on another could contain new possibilities for performance improvements. A striking example would be the dependence of economics on computational science/computational methods. With improved computational methods (and hence an improved research technology), the extent and depth of economic research has gone well beyond what could have been achieved in the past. With the introduction of these methods, the dimensions, reach and complexity associated with market analysis have improved quite dramatically in the last quarter of a century.

With proper investments in the research technology and human capital, different evolutionary trajectories/paths for research could be obtained. University administrators could optimally choose the path that is most conducive to their overall objectives.

The author acknowledges financial support from the Istanbul Commerce University Research Fund.

## REFERENCES

**Abdullah, L., Jaafar, S., Taib, I.,** (2013), Ranking of Human Capital Indicators using Analytic Hierarchy Process, Procedia-Social and Behavioral Sciences 107, 22-28.

**Abramo, G., Cicero, T., D'Angelo, C.A.,** (2012), Revisiting size effects in higher education research productivity, . Higher Education,3 (6), 701-717.

**Abramo, G., D'Angelo, C.A., Di Costa, F.,** (2014), Investigating returns to scope of research fields in universities. Higher Education 68 (1), 69-85.

**Adams, J.D., Clemmons, J.R.,** (2011), The role of search in university productivity: Inside, outside, and interdisciplinary dimensions. Industrial and Corporate Change, 20 (1), 215-251.

**Barlas, Y., Diker V.,** (2000),. A Dynamic Simulation Game for Strategic University Management, Simulation and Gaming, 31(3), 331-358.

**Barlas, Y. , Diker, V. & Polat, S. (eds.),** (1997), Systems Approach to Learning and Education into the 21st Century (Proceedings of 15th International System Dynamics Conference. Istanbul: Boğaziçi University Press.

**Dundar, H., Lewis, D.R.,** (1995), Departmental productivity in American universities: Economies of scale and scope. Economics of Education Review 14 (2), 119-144.

**Fedderke, J. W., Luiz, J. M.,** (2008), Does Human Capital Generate Social and Institutional Capital? Exploring Evidence from South African Time Series Data, Oxford EconomicPapers, 60 (4), 649-682.

**Grayson, J. P.,** (2004), Social Dynamics, University Experiences, and Graduates' Job Outcomes, British Journal of Sociology of Education, 25 (5), 609-627.

**Ivanov, V. V., Markusova, V.A., Mindeli, L. E.,** (2016), Government investments and the publishing activity of higher educational institutions: Bibliometric analysis, Herald of the Russian Academy of Sciences 86 4, 314-321.

**Jaffe, A.B.,** (1989), Real Effects of Academic Research, The American Economic Review, 79 (5), 957-970.

**Kara, A.,** (2011), Modeling social processes, Istanbul Commerce University, Mimeo.

**Kara, A., (**2013a), Dynamics of Performance and Technology in Higher Education: An Applied Stochastic Model and a Case Study. Hacettepe Journal of Mathematics and Statistics 42 (1), 87-99.

**Kara, A.,** (2013b), Educational Technology and Human Capital," Procedia – Social and Behavioral Sciences, 106, 970–979.

**Kara, A.,** (2014), A System Dynamics-Based Decision Support Model for Universities. Istanbul Commerce University, Mimeo.

**Kara, A.,** (2016), "Simulations of information technology-induced teaching performance in cross-disciplinary settings: a model and an application", The International Conference on Intercultural Education, Education, Health And Ict: From A Transcultural Perspective, Almeria, Spain, June 2016.

**Kodama, H., Watatani, K., Sengoku, S.,** (2013), Competency-based assessment of academic interdisciplinary research and implication to university management. Research Evaluation, 22 (2), 93-104.

**Miller, K., Moffett, S., McAdam, R., Brennan, M.,** (2013), Intellectual capital: A valuable resource for university technology commercialisation?. Proceedings of the European Conference on Knowledge Management, ECKM, Volume1, 429-437.

**Munoz, D.A.,** (2016), Assessing the research efficiency of higher education institutions in Chile: A data envelopment analysis approach, International Journal of Educational Management 30 ( 6), 809-825.

**Neri, F., Rodgers, J.R.,** (2013), Eagles and Turkeys: Human Capital Externalities, Departmental Co-authorship and Research Productivity. Australian Economic Papers 52 (3-4), 171-189.

**OECD,** (2001), The Well-Being of Nations: The Role of Human and Social Capital. OECD, Paris.

**Pastor, J.M., Serrano, L.,** (2016), The determinants of the research output of universities: specialization, quality and inefficiencies**,** Scientometrics 109 (2), 1255-1281.

**Singell, L.D., Tang, H-H.,** (2013), Pomp and circumstance: University presidents and the role of human capital in determining who leads U.S. research institutions, Economics of Education Review, 32, 219–233.

**Spencer, J. W.,** (2001), How Relevant Is University-Based Scientific Research to Private High-Technology Firms? A United States-Japan Comparison, The Academy of Management Journal, 44 (2), 432-440.

**Walton, A. L., Tornatzky, L. G. & Eveland, J. D.,** (1986), Research Management at the University Department, Science &Technology Studies, 4 (3/4), 35-38.