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

Research Article

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

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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
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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 σ_{u2}^2 and σ_{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.

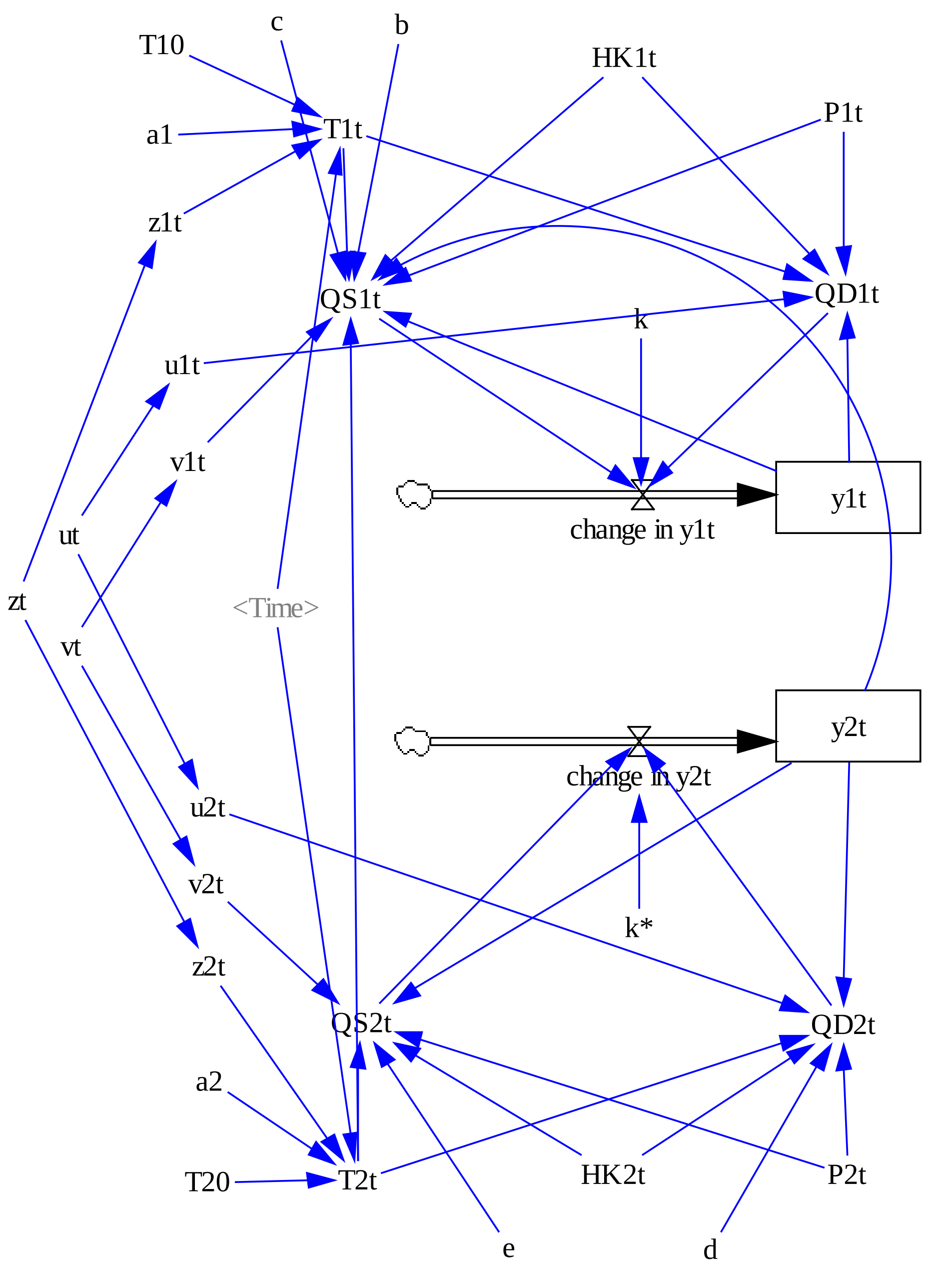
3. SIMULATIONS[3]

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: α_0 = 1, α_1 = 0.9, α_2 =-0.7, α_3 = 0.7, α_4 = 0.6, β_0 = 0.9, β_1 = 0.5, β_2 =0.3, β_3 = 0.4, β_4 = 0.4, β_5 = 0.4, β_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. θ_0 = 1, θ_1 = 0.8, θ_2 =-0.5, θ_3 = 0.4, θ_4 = 0.25, δ_0 = 0.8, δ_1 = 0.55, δ_2 =0.3, δ_3 = 0.25, δ_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} =0.6u_t, v_{1t} =0.4v_t, u_{2t} =0.5u_t, v_{2t} =0.5v_t, and z_{1t} =0.001z_t, z_{2t} =0.001z_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

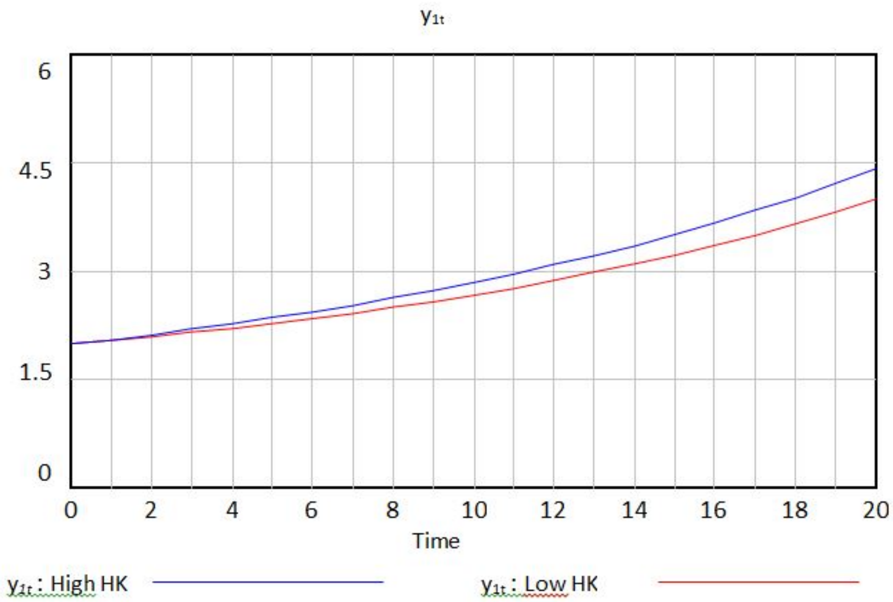
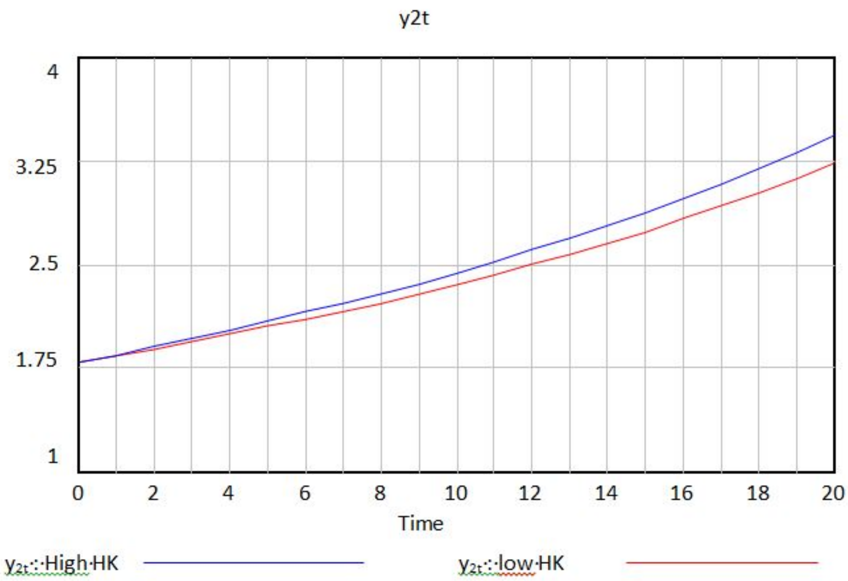
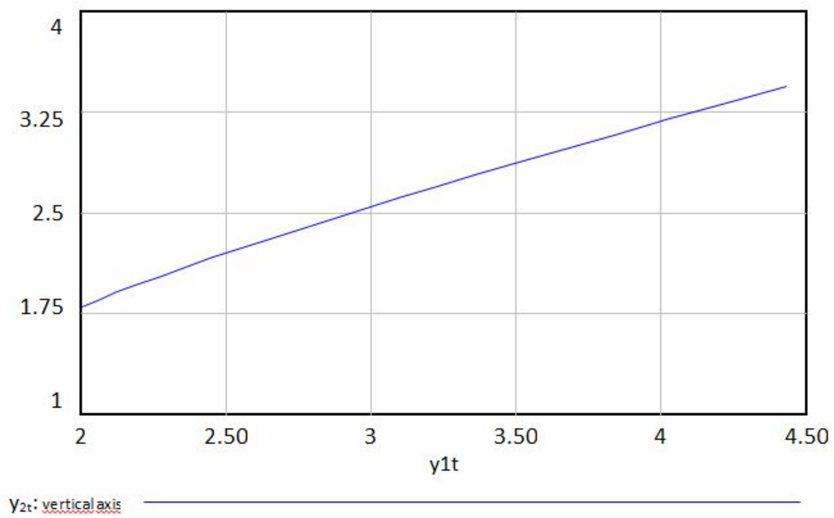


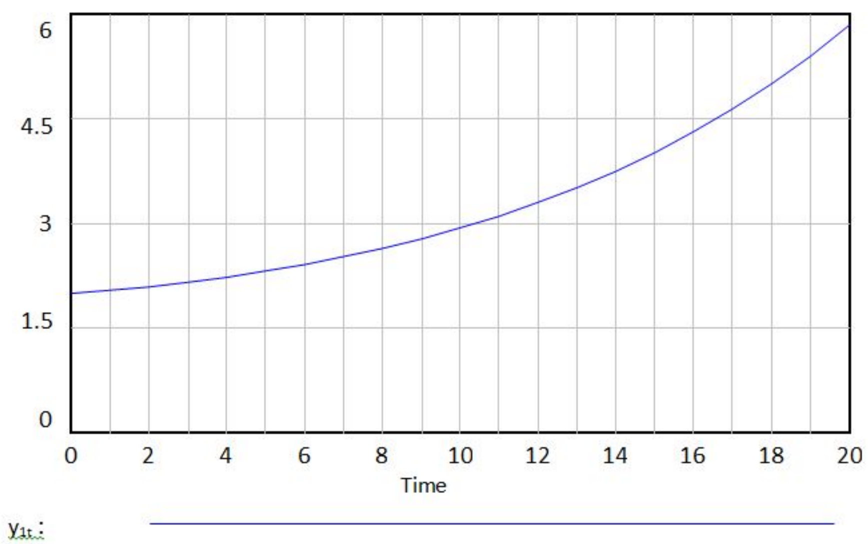
Figure 3: y_{2t} with low and high human capital





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.

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