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Simulations of Optimal Human Capital and Total Factor Productivity in Universities

Üniversitelerde Optimal Beşeri Sermaye ve Toplam Faktör Verimliliği Simülasyonları

Ahmet KARA

ABSTRACT

In this paper, we develop models of university capital in disaggregated and aggregated forms and simulate the trajectories of human/non-human capital and total factor productivity in universities. The capital employed by a representative university is decomposed into two composite human capital and non-human capital dimensions, each of which is further disaggregated into some sub-dimensions. We first present a sketch of a disaggregated model for illustrative purposes and then develop an aggregated model for the simulation of the key variables in the system. We incorporate an investment support (subsidy) parameter into the model, the optimal value of which is computationally determined. Based on the optimal value of this decision variable, the trajectories of human/non-human capital and total factor productivity are obtained. Though the exercise constructed in the paper is a particular or limited one, the model is highly suitable for generalized exercises with multiple decision variables and multidimensional objective functions capturing a rich variety of different possibilities in real life. The optimality and simulation exercises of this kind could help the university managers to design optimal decision systems to achieve the university objectives in a best possible manner in dynamic settings.

Keywords: Universities, Optimal capital, Total factor productivity, Simulations

ÖZ

Bu makalede, üniversitelerde sermayenin toplam ya da bileşenlerine ayrıştırılmış formlarda nasıl modellenebileceği ve beşeri sermaye ve toplam faktör verimliliği yörüngelerinin nasıl simüle edilebileceği gösterilmektedir. Temsili bir üniversitenin toplam sermayesi, beşeri sermaye ve beşeri olmayan sermaye ana bileşenleri ile temsil edilmekte ve her bir bileşen alt-bileşenlere ayrıştırılmaktadır. İlkin, alt-bileşenlerine ayrıştırılmış sermaye modellemesinin nasıl yapılabileceği gösterilmekte, ardından ana-bileşenlere dayalı bir model kurgusu sunulmaktadır. Optimal sermaye ve toplam faktör verimliliği yörüngelerinin simülasyonları, ana-bileşenlere dayalı modelden hareketle yapılmaktadır. Modele, optimal değeri hesaplanan bir yatırım desteği/sübvansiyon parametresi entegre edilmekte ve yörüngeler bu değere dayalı olarak belirlenmektedir. Makaledeki optimizasyon alıştırmasının kapsamı sınırlı olsa da, makaledeki model, reel hayatın zengin varyasyonları ve bunlarla ilişkili çoklu değişken ve çok-boyutlu amaç fonksiyonlarının temsiline oldukça müsait bir yapıdadır. Makalede örneklenen optimalite ve simülasyon denemeleri, üniversitenin amaçlarına, dinamik bir çerçevede en iyi şekilde ulaşılmasını mümkün kılacak optimal karar sistemlerinin geliştirilmesine yardımcı olabilir.

Anahtar Sözcükler: Üniversiteler, Optimal sermaye, Toplam faktör verimliliği, Simülasyonlar

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INTRODUCTION

The concept of human capital, with "the knowledge, skills, competences and attributes" (OECD, 2001: 18) it refers to, is one of the highly convenient discursive constructs that greatly facilitates the analysis of the multi-faceted processes concerning modern universities in the information age. In the literature, there are a wide range of works exploring a variety of human capital-related issues associated with the universities in particular and educational institutions in general. Among the issues covered are academic human capital in universities (Garcia-Carbonell, Guerrero-Alba, Martin-Alcazar & Sanchez-Gardey, 2021), educational technology and human capital (Kara, 2013), human capital and labor productivity (Jibir, Abdu & Buba, 2022), companies' human capital for university partnerships (Albats, Bogers & Podmetina, 2020), human capital and entrepreneurial intentions (Aboobaker & Renjini, 2020), enhancing human capital beyond university boundaries (Jakubik, 2020), the bioeconomy-related human capital development (Bejinaru, Hapenciuc, Condratov & Stanciu, 2018), quality-productivity-performance-related traps in developing countries (Kara, 2018), the human capital development-growth nexus (Barra & Zotti, 2017), the relationship between human capital components and innovation climate in public universities (Bahrami, 2017), the research efficiency of higher education institutions (Munoz, 2016), the role of human capital in university-business cooperation (Merritt, 2015), returns to scope of research fields in universities. (Abramo, D'Angelo & Di Costa, 2014), universities and regional human capital (Abel & Deitz, 2012), the university and the knowledge economy (Dzisah, 2007), strategic university management (Barlas & Diker, 2000) and departmental productivity (Dundar & Lewis, 1995).

The issues are fairly complex with micro and/or macro-academic dimensions. Understanding of each of these dimensions would be greatly facilitated by system-theoretic modeling and examinations that have not yet appeared in the literature in fully-fledged forms. In this paper, we will contribute to the system-theoretic inquiry into one particular aspect of university modeling. We will first present an exemplary sketch of a disaggregated system dynamics model of capital and then go one step further to develop an aggregated model for human capital and total factor productivity simulations in universities. Through the models we develop, we find out the optimal values of policy variables such as subsidies that lead to optimal aggregated human capital, non-human capital and total factor productivity trajectories over time. Though there are works in the literature, such as Berde (2014) and Fethke (2011), which deal with the issue of university-related subsidies, the works in question do not explore the crucial question of optimality in a simulative framework, which we examine in this paper. Similarly, Barlas & Diker (2000) undertakes simulations for university-related variables involving teaching and research, but they do not explore the issue of the optimal levels of the underlying capital and total productivity variables in a dynamic-stochastic framework as we analyze in this paper. In some limited contexts, however, the issue of optimization for some university-specific processes has received some attention in the literature (Ma, 2022, Flood, 1985). Finding the optimal values of decision variables that enable the universities to achieve the objectives they set out to pursue in a dynamic-stochastic framework, as exemplified in this paper, could be considered a worthwhile contribution to the theory and practice of university management.

The second section of the paper puts forward the method and the model of the paper. The third and fourth sections contain, respectively, the findings and the discussion about the findings. The concluding remarks are presented in the fifth section.

THE METHOD/THE MODEL

Consider a higher education institution (a university) which employs various forms of capital to produce teaching, research and project-related services. For reasons of analytical convenience, we will decompose the capital employed by the university into two composite forms, namely "human capital" and "non-human capital". The overall form of human capital will include the sub-forms of "teaching-oriented human capital" (HK_1), "research-oriented human capital" (HK_2) and "managerial capital" (HK_3). The non-human capital will include various sub-forms of physical capital, such as infrastructure (PK_1) and technology (PK_2) as well as particular forms of social/network capital (SK) involving, among other things, the relations of the institution with the social and scientific ecosystem. We will conceive the aggregated human capital and non-human capital as the two composite factors that can be constructed from their sub-components.[1]

We can develop models of human capital in either disaggregated or aggregated forms, each of which could shed a peculiar light on human capital processes. We will first sketch a disaggregated model to illustrate a possible way in which it can be constructed and then proceed to develop an aggregated one to exemplify human and non-human capital simulations. Let D^i_t, i=1,…,6, represent, respectively, the quantity demanded of teaching-oriented human capital, research-oriented human capital, managerial human capital, infrastructure-related physical capital, technology-related physical capital and social capital. Similarly, let S^i_t, i=1,…,6, represent the quantity supplied of the respective forms of capital. For simplicity, suppose that D^i_t depends on the prices of each form of capital, p_i, =1,…,6, as well as the total value of the university's services (V_t). S^i_t, on the other hand is conveniently assumed to depend only on the price of the relevant form of capital. That is to say,

$$D^i_t = f_i(p_1,\dots,p_6, V_t), \quad (1)$$

$$S^i_t = g_i(p_i), \quad (2)$$

i=1,…,6.

1 We will not be dealing with the ways in which composite factors could be constructed. Let us just note that in the context of our model, where prices are fixed, the usual problems associated with the construction of composite goods or factors do not arise.

Each variable, the measurement of which will not be explored in detail in this paper, takes on nonnegative real values. Some issues associated with measurement are pointed out in the appendix.

The change, over time, of each form of capital will be assumed to be proportional to the excess demand for the relevant form of capital. It is possible to postulate a different change dynamic as well, which will be exemplified in the aggregated model below.

Using the method of system dynamics, we will now present a sketch of the simulation diagram for the disaggregated model in which, the quantity of each form of capital is a stock variable. The change, over time, of each of those quantities is a flow variable. Other variables are assumed to be auxiliary variables (Figure 1).[2]

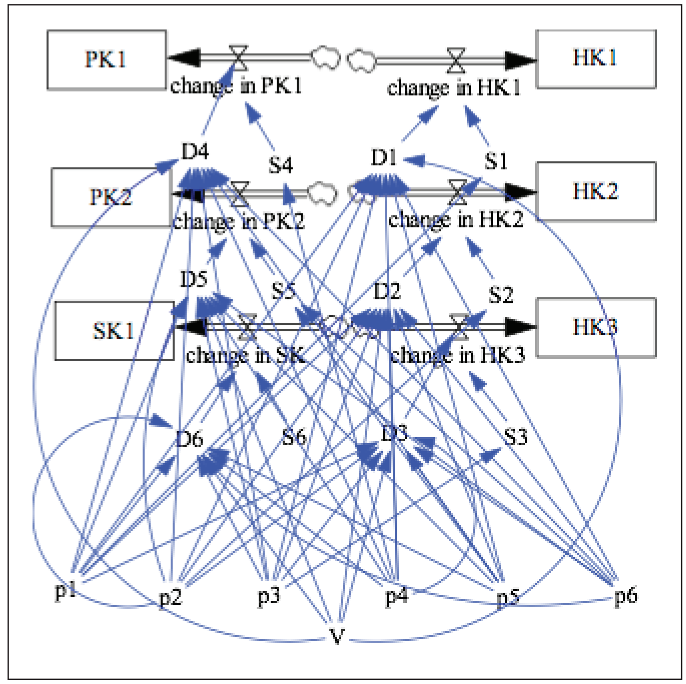

Figure 1: The simulation diagram for the disaggregated model.

The disaggregated model and the diagram, which could be extended to include stochastic and strategic terms and various interdependencies, could be used for simulation purposes. However, because of the highly tedious nature of the background details of a disaggregated set-up, we will use a condensed, aggregated version of it with some additional complexities. The aggregated set-up is as follows. We will posit the following demand function for the aggregated human capital at time t (D_{HK}^t),

$$D^{HK}_t = f^{HK}_t(p^{HK}_t, P^{NHK}_t, s^{HK}_t, s^{NHK}_t, V_t, u_{1t}), \quad (3)$$

where D_{HK}^t, p^{HK}_t, P^{NHK}_t, s^{HK}_t, s^{NHK}_t and u_{1t} represent, respectively, the quantity demanded for the aggregated human capital at time t (HK_t), the composite price of HK_t at time t, the composite price of the aggregated non-human capital (NHK_t) at time t, the aggregated human capital subsidy variable at time t, the aggregated non-human capital subsidy variable at time t and a human-capital-demand-related stochastic factor. D_{HK}^t is assumed to be of the following explicit form.

$$\ln D^{HK}_t = \ln V_t/(c_1+c_2+r_1+r_2)-\ln A_t/(c_1+c_2+r_1+r_2)-((c_2+r_2)/(c_1+c_2+r_1+r_2)).\ln(P^{HK}_t)+((c_2+r_2)/(c_1+c_2+r_1+r_2)).\ln(P^{NHK}_t)+((c_2+r_2)/(c_1+c_2+r_1+r_2)).\ln(c_1+r_1)-((c_2+r_2)/(c_1+c_2+r_1+r_2)).\ln(c_2+r_2)+u_{1t}, \quad (4)$$

where A_t is the university-specific total factor productivity term. c_1+r_1 and c_2+r_2 are the exponents of the aggregated human capital and non-human capital inputs in the aggregate production function, which is of the following form.

$$V_t = A_t HK_t^{c_1+r_1 NHK_t^{c_2+r_2}} \quad (5)$$

r_1 and r_2 are the subcomponents of the exponents of HKt and NHKt that have stochastic parts and depend on policy variables s^{HK}_t and s^{NHK}_t as well as on the overall level of capital investment (I), which is a function of the total value of the aggregated human and non-human capital. For the sake of simplicity, let us assume the following forms for r_1 and r_2.

$r_1 = a.s.\ln I+z_1$

$r_2 = b.(q-s).\ln I+z_2$,

where a and b are coefficients. q is an overall subsidy parameter to be administratively determined. s is a proxy for s^{HK}_t and (q-s) is a proxy for s^{NHK}_t. We will assume that I depends on the value of total capital in the following manner.

$\ln I = \alpha.\ln(P^{HK}_t.HK_t+P^{NHK}_t.NHK_t)$, $0<\alpha<1$.

The supply function for the aggregated human capital at time t (S_{HK}^t) is as follows.

$$S^{HK}_t = g^{HK}_t(p^{HK}_t, v_{1t}), \quad (6)$$

where v_{1t} is a human-capital-supply-related stochastic factor. A possible explicit form for S^{HK}_t could be designated as:

$\ln S^{HK}_t=\ln(c-d/(2P^{HK}_t))+v_{1t}$.

To theorize about the dynamics of the aggregated human capital over time, we will assume that the ratio of the aggregated human capital at t+1 to the aggregated human capital at t is proportional to the ratio of the aggregated human capital demand to the aggregated human capital supply at t, i.e.,

$$\frac{HK_{t+1}}{HK_t} = \left(\frac{D_t^{HK}}{S_t^{HK}}\right)^{k1} \quad (7)$$

2 Note that, here, we will not explain the method of system dynamics, the detailed description of which would takes us beyond the scope and limits of this paper. There are both theory-focused as well as practice-oriented works in the literature which the readers might take a look at for deailed accounts of the steps and issues associated with system dynamics as a simulation method. For theory-related issues, see Sterman (2020). For practical examples, see Garcia (2022).

where k1 is the coefficient of adjustment. Taking the logarithms of each side and substituting the terms for the demand and supply functions, we get a dynamic of adjustment equation for the aggregated human capital, a numerical version of which will be used in the simulation process.

Regarding the aggregated non-human capital, we will posit the following demand (D^{NHK}_t) and supply (S^{NHK}_t) functions.

$D^{NHK}_t = f^{NHK}_t(p^{HK}_t, P^{NHK}_t, s^{HK}_t, s^{NHK}_t, V_t, u_{2t})$, (8)

$S^{NHK}_t = g^{NHK}_t(p^{NHK}_t, v_{2t})$, (9)

where u_{2t} and v_{2t} are, respectively, the stochastic terms for the aggregated non-human capital demand and supply.

The explicit forms for D^{NHK}_t and S^{NHK}_t are as follows:

$$\ln D^{NHK}_t = \ln V_t/(c_1+c_2+r_1+r_2)-\ln A_t/(c_1+c_2+r_1+r_2)+((c_1+r_1)/(c_1+c_2+r_1+r_2)).\ln(P^{HK}_t)-((c_1+r_1)/(c_1+c_2+r_1+r_2)).\ln(P^{NHK}_t)+((c_1+r_1)/(c_1+c_2+r_1+r_2)).\ln(c_2+r_2)-((c_1+r_1)/(c_1+c_2+r_1+r_2)).\ln(c_1+r_1)+u_2. \quad (10)$$

$$\ln S^{NHK}_t = \ln(-1.5+2.P^{NHK}_t)+v_2. \quad (11)$$

The dynamic adjustment equation for the aggregated non-human capital has the same form as the aggregated human capital.

$$\frac{NHK_{t+1}}{NHK_t} = \left(\frac{D_t^{NHK}}{S_t^{NHK}}\right)^{k2} \quad (12)$$

where k_2 is the coefficient of adjustment.

The equations (7) and (12), which make use of the other relations in the model, will be used for the purpose of simulating the aggregated human and non-human capital. Simulations in question are key to the decision making processes within the university. Combining with optimization, simulations of the variables of the system will tell us, at different points in time, the optimal levels of the variables such as human and non-human capital and total factor productivity that facilitate the efficient achievement of the university's objectives. Thus such simulations, the construction of which is a practically-significant contribution of this paper to the literature, are key parts of the optimal decision support systems of efficiently-managed universities.

FINDINGS

For system dynamics simulations, we will choose HK_t and NHKt as stock variables. Changes in those variables will represent the flow variables. Other variables will be designated as the auxiliary variables. The diagram portraying the relations among the variables in the aggregated model is as follows (Figure 2).

For simulation purposes, the following values for parameters will be used:

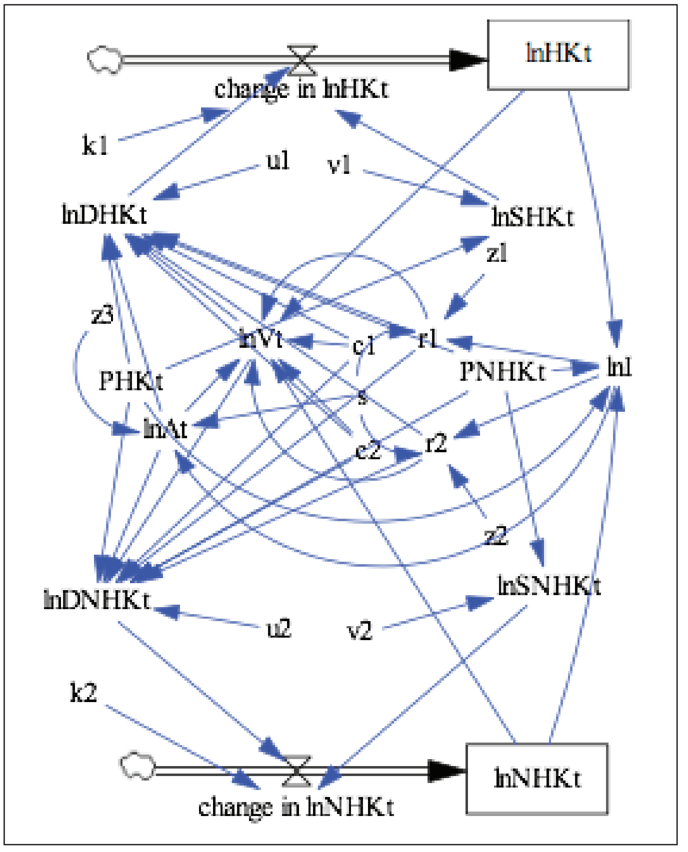

Figure 2: The simulation diagram for the aggregated model.

c1= 0.4, c2=0.6, a=0.1, b=0.155, q=0.2, α=0.5, k1=0.1, k2=0.05, PHKt=2, PNHKt=3,

u1=RANDOM NORMAL(-0.5, 0.5, 0, 0.5, 0), v1= RANDOM NORMAL(-0.5, 0.5, 0, 0.5, 0), u2=RANDOM NORMAL(-0.5, 0.5, 0, 0.5, 0), v2=RANDOM NORMAL(-0.5, 0.5 , 0, 0.5, 0), z1=RANDOM NORMAL(-0.003, 0.003, 0, 0.003, 0), z2=RANDOM NORMAL(-0.003, 0.003, 0, 0.003, 0), z3=RANDOM NORMAL(-0.001, 0.001, 0, 0.001, 0), lnAt =4*(1+0.044*s*lnI+z3). Initial HKt=2. Initial NHKt=3.

By virtue of multidimensional relations between university's revenues and the capital stock, we can hypothesize that investment in capital is a function of revenues or the capital stock itself.[3] The levels of HKt and NHKt influence the overall level of investment in HKt and NHKt, which influences the university-specific total factor productivity as well as the exponents of HKt and NHKt in production function, which influence the overall level of the production of services, which influences the conditional demands for HKt and NHKt, which in turn influence the levels of HKt and NHKt, completing a positive feedback loop involving the variables in question.

Here one of the key questions is to determine the optimal value of the subsidy variable "s", which governs the relative

3 The universities may need, in additional to the conventional methods, innovative ways of financing investments which may involve, for instance, profit-and-loss-sharing arrangements. The general problems with such arrangements should, however, be properly taken into account (Kara, 2001).

investment support for HKt and NHKt. Assuming that the university tries to maximize the overall value of the services, we find, by means of a mathematical program (VENSIM DSS), the value of s that maximizes the value in question.[4] Given the chosen set of parameter values, the optimal value of s turns out to be approximately 0.19. We incorporated this value into the simulation set-up and obtained the simulated trajectories of the optimal aggregated human capital, the aggregated non-human capital and the university-specific total factor productivity over time, which are as follows (Figure 3, Figure 4 and Figure 5).

Clearly, finding the optimal levels of decision variables is key to the efficiency and effectiveness with which the university objectives could be achieved. In the exercise above, we have found the optimal level of subsidy that maximizes the overall value of the services produced by the university and determined the optimal subsidy-induced trajectories of human capital, non-human capital and total factor productivity over time. Thus this exercise would enable us to find the amounts of (and hence the levels of investment into) the various dimensions of capital to achieve the university objectives.

Here, the constructed exercise is a specific one focusing on subsidies. We can of course have more general cases making use of a number of decision variables and more complicated and perhaps multidimensional objective functions. Nevertheless, the system dynamics formulation proposed in this paper can handle such cases as well.

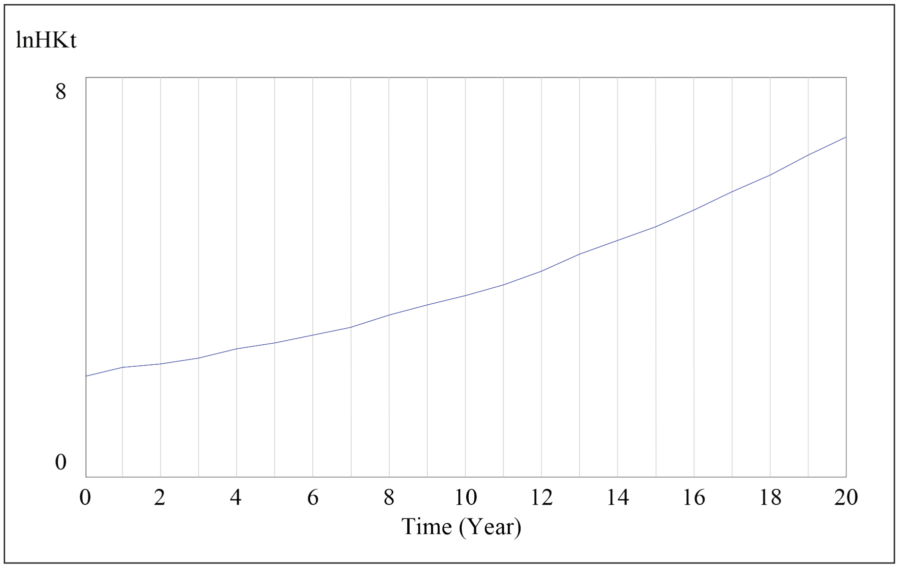

Figure 3: The trajectory of optimal aggregated human capital (logarithmically transformed values).

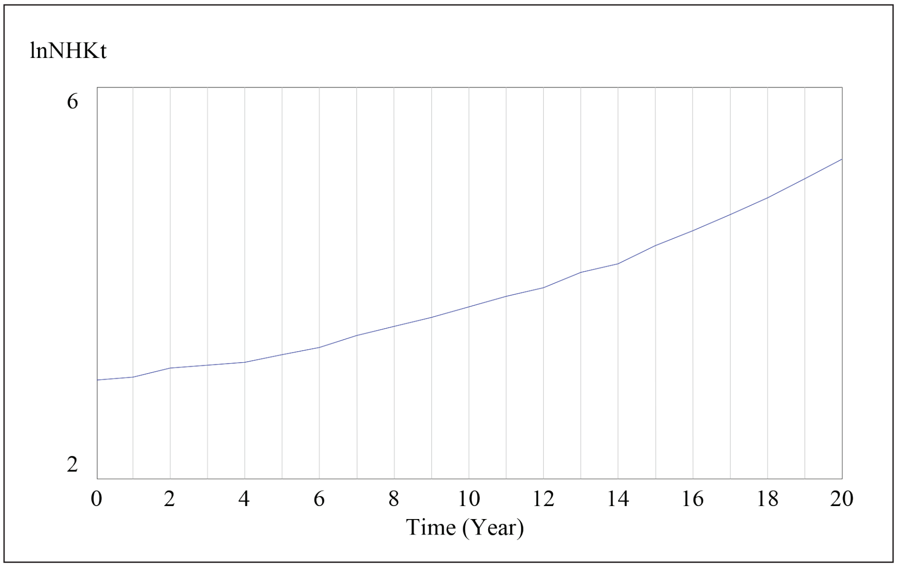

Figure 4: The trajectory of optimal aggregated non-human capital (logarithmically transformed values).

4 The university may have multiple objective functions with multiple preferences, a proper and sufficiently informative account of which could not be taken up within the confines of this paper. For a general description of multiplicity of preferences, see Kara (2009).

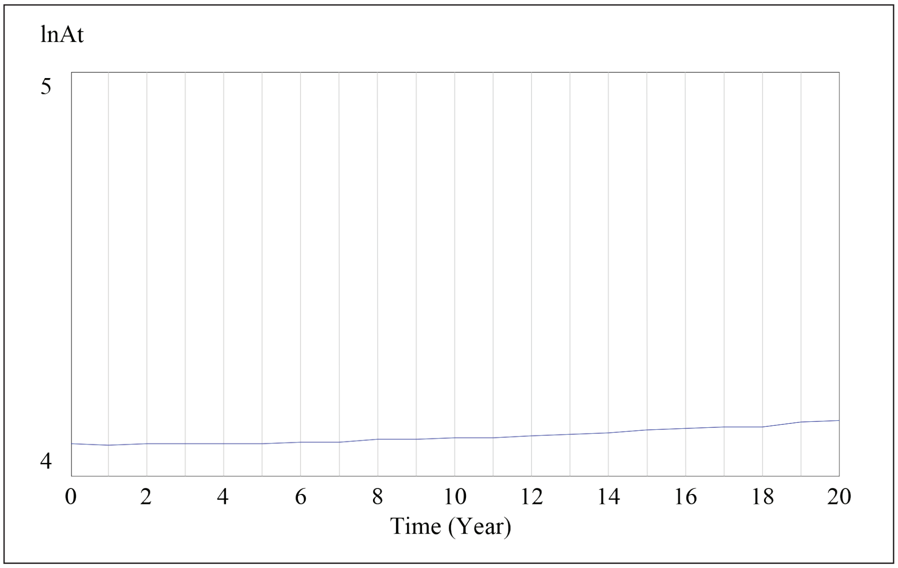

Figure 5: The trajectory of the university-specific total factor productivity (logarithmically transformed values).

DISCUSSION

The trajectories above display short-run fluctuations as well as long-run upward trends over time. Short-run fluctuations, which are not easily discernible in the long-term trajectory but can easily be identified in table of simulated values,[5] are mainly due to the stochastic factors influencing demand, supply, exponents of capital inputs and the university-specific total factor productivity. The long-run upward trends may be, in part, attributed to the subsidy-mediated investment support helping to improve the total factor productivity and increase the exponents of the aggregated human and non-human capital inputs. The supply-and-demand dynamics also plays a role in the capital accumulation in question.

Here, of course, finding the optimal levels of the decision variables and simulating the optimal values-incorporated trajectories are among the key tasks of practical significance. The correctly identified optimal levels of decision variables and the associated trajectories greatly facilitate the tasks of university managers in achieving the university's short-run and long-run goals. The modeling procedure outlined and exemplified in this paper is very likely to enable the university managers as well as researcher to undertake optimization and simulation exercises concerning concrete/real-life cases of different universities. The model here could also contribute to the simulation-based pedagogical improvements implied by the simulation inquiry of the kind exemplified by Gaintza-Jauregi (2020).

Nevertheless, the example given in this paper is just for illustration purposes. There may well be many other uses of subsidies or, as indicated above, many other decision variables that may need to be taken into account for the purpose of achieving the university's multidimensional objectives involving, for instance, research and development (R & D), innovation, teaching effectiveness and regional development . In the literature, there are works that explore the effects of public subsidies on innovation and university-industry undertakings (Song et.al. 2022), the effects on R & D (Cheng et.al., 2022) and the statistical analysis of subsidies (Sanusi & Oyama, 2008). The policy-exercise-inclusive simulation modeling we present in this paper has the potential of extending the results of these works to a dynamic-stochastic setup where the effects on innovation, R & D and university-industry relations could be simulated and the optimal trajectories could be found. Similarly, the mode of modeling developed in this paper could be combined with the strategic considerations and simulative formulations of Barlas & Dicker (2000) so as to open up an avenue for optimality-targeting dynamic-stochastic-strategic analysis of university processes. This type of modeling can also facilitate the explorations of the efficiency of alternative policy options involving mechanisms such as incentive systems, work reorganizations and systems of cooperation, which could be instrumental in achieving the university objectives.

CONCLUSION

This paper exemplifies modeling options for human capital in both disaggregated and aggregated forms, which could prove to be valuable for a variety of different purposes. Disaggregated modeling options would be useful for analyzing especially the micro-level interactions within the university system. Aggregated modeling exercises, on the other hand, could prove to be instrumental in effectively and concisely describing the state and evolution of the macro components of the system and analyzing the system's interactions with the scientific ecosystem.

Both modeling tracks enable us to simulate the trajectories of the key variables of the university system and undertake optimality exercises for the purpose of achieving the university's

5 For example, the simulated values for HKt for 10 periods are 2, 2.172, 2.249, 2.363, 2.541, 2.682, 2.826, 2.985, 3.217 and 3.433.

objectives. This paper has presented a sketch of the disaggregated modeling but worked out examples of simulation (and an example of optimization) for aggregated capital-related processes. Similar exercises could also be formulated in disaggregated forms, which may generate different insights into the complex processes characterizing modern universities. The mode of modeling and simulation presented in the paper could also be used for the dynamic and stochastic extensions of the works in the literature on innovation, R&D and university-industry relations.

Appendix

Since this paper is designed as a theoretical work, the variables in the paper are theoretical constructs, the empirical measurement of which has not been addressed/explored within the text. For illustrative guidance purposes that can be of assistance to the empirical researchers, it might be useful to touch upon some of the issues relevant to the empirical measurement. Some of the variables used in the paper, such as human capital and non-human capital are composite constructs with multiple dimensions which might even have multiple sub-dimensions. For instance, the dimensions of human capital such as the "teaching-oriented human capital" (HK_1), the "research-oriented human capital" (HK_2) and the "managerial capital" (HK_3) are heterogeneous in nature, and as such, possible forms of empirical measures, such as "labor hours", which could be used for the empirical measurement of these multiple dimensions are not of the same kind and cannot be meaningfully aggregated. These dimensions might even have sub-categories representing, for instance, different qualities and types, which render the process of aggregation even more complicated. Thus, when aggregated measures are needed, market-mediated measures (such as monetary values) could be used for each component or sub-component so that we can meaningfully aggregate them so as to obtain the aggregated measure in question. Such an aggregation could be used for the dimensions of both human capital as well as non-human capital. On the other hand, for sufficiently disaggregated analyses where each sub-dimension is distinctly used, "labor hours" could be used for the measurement of some of the categories. For the various forms of non-human capital, monetary values and quantities might be used for measurement purposes.

REFERENCES

Abel, J. R. & Deitz, R. (2012). Do colleges and universities increase their region's human capital? *Journal of Economic Geography*, 12 (3), 667-691.

Aboobaker, N. & Renjini, D. (2020). Human capital and entrepreneurial intentions: Do entrepreneurship education and training provided by universities add value? *On The Horizon*, 28 (2), 73-83.

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.

Albats, E., Bogers, M. & Podmetina, D. (2020). Companies' human capital for university partnerships: A micro-foundational perspective. *Technological Forecasting and Social Change*, 157, Article Number: 120085. DOI: 10.1016/j.techfore.2020.120085.

Bahrami, S. (2017). The relationship between human capital components and innovation climate in public universities. *International Journal of Advanced and Applied Scien*ces, 4 (5), 86-90.

Barlas, Y. & Diker V. (2000). A dynamic simulation game for strategic university management. *Simulation and Gaming*, *31*(3), 331–358.

Barra, C. & Zotti, R. (2017). Investigating the human capital development-growth nexus: Does the efficiency of universities matter? *International Regional Science Review*, 40 (6), 638-678.

Bejinaru, R., Hapenciuc, C.V., Condratov, I. & Stanciu, P. (2018). The university role in developing the human capital for a sustainable bioeconomy. *Amfiteatru Economic*, 20,538-598.

Berde, E. (2014). Should universities be subsidized? - A reference point view. *Procedia Social and Behavioral Sciences*, 143, 838-842.

Cheng, H. et.al. (2022). Government support, different types of collaborative R&D input, and performance: evidence from China. *International Journal of Technology Management*, 88(1), 51-70.

Dzisah, J. (2007). Institutional transformations in the regime of knowledge production: The University as a catalyst for the science-based knowledge economy. Asian Journal of Social Science, Vol. 35, No. 1, pp. 126-140.

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

Fethke, G. (2011). A low-subsidy problem in public higher education. *Economics of Education Review*, 30 (4), 617-626.

Flood, M.M. (1985). An optimization procedure for a university. *Behavioral Science*, 30(2); 57-97.

Gaintza- Jauregi, Z. (2020). Simulation as a methodological strategy in the faculty of education at the University of the Basque Country**.** *Revista Electronica Educare*, 24(3). DOI: 10.15359/ree.24-3.11.

Garcia, J.M. (2022). *System dynamics modeling with vensim: A quick guide to building causal loops and stock and flow diagrams*. Juan Martin Garcia Publ. Kindle edition.

Garcia-Carbonell, N., Guerrero-Alba, F., Martin-Alcazar, F. & Sanchez-Gardey, G. (2021). Academic human capital in universities: Definition and proposal of a measurement scale. *Science and public policy***,** 48 (6), 877-888.

Jakubik, M. (2020). Enhancing human capital beyond university boundaries. *Higher Education Skills and Work-Based Learning*, 10 (2), 434-446.

Jibir, A., Abdu, M. & Buba, A. (2022). Does Human Capital Influence Labor Productivity? Evidence from Nigerian Manufacturing and Service Firms. *Journal of the Knowledge Economy*, DOI**:** 10.1007/s13132-021-00878-8.

Kara, A. (2001). On the efficiency of the financial institutions of profit and Loss sharing. *Journal of Economic & Social Research,* 3(2), 99-104.

Kara, A. (2013). Educational technology and human Capital. *Procedia – Social and Behavioral Sciences*, *106*, 970 – 979.

Kara, A. (2009). Implications of multiple preferences for a deconstructive critique and a reconstructive revision of economic theory. *Journal of Economic & Social Research*, 11(1), 69-78.

Kara, A. (2018). Escaping Mediocre-Quality, Low-Productivity, Low-Performance Traps at Universities in Developing Countries: A Human Capital-Based Structural Equation Model with System-Dynamics Simulations. *Educational Sciences: Theory & Practice*, 18(3), 541-559.

Ma, N. (2022). Optimization simulation system of university science education based on finite differential equations. *Applied Mathematics and Nonlinear Sciences*. DOI: 10.2478/amns.2022.2.0177

Merrit, H. (2015). The role of human capital in university-business cooperation: The case of Mexico. *Journal of the Knowledge Economy*, 6 (3), 568-588.

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.

OECD (Organization for Economic Cooperation and Development). (2001). *The well-being of nations: The role of human and social capital*. Paris, France.

Sanusi, A., Oyama, T. (2008). Statistical data analysis for investigating Japanese government subsidy policy for private universities. Higher Education, 55 (4), 407-423.

Song, Y. et.al. (2022). The effects of government subsidies on the sustainable innovation of university-industry collaboration. *Technological Forecasting and Social Change*, 174, Article Number, 121233.

Sterman, J. (2000). *Business Dynamics: Systems Thinking and Modeling for a Complex World*. McGraw-Hill Education; HAR/CDR edition.