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Research Article

Escaping Mediocre-Quality, Low-Productivity, Low-Performance Traps at Universities in Developing Countries: A Human Capital-Based Structural Equation Model with System-Dynamics Simulations

Ahmet Kara[1]
Istanbul Commerce University

Abstract

This paper develops a human capital-based structural equation model to analyze the mediocre-quality, low-productivity, and low-performance levels characterizing large subsets of universities in developing countries. Using a structural equation model, we have first specified one particular way in which overall university performance might be related to human capital, social capital, and physical capital, which are in turn related to various indicators, including teaching-quality and research-productivity levels. The structural equation-based picture of these levels is then dynamically extended to obtain their trajectories over time. We have collected data to estimate the parameters of the human capital-based structural equation model, which then serves as a basis for the system dynamics simulations of teaching quality, research productivity, and overall performance over time. We have developed an optimally-formulated subsidy/reinvestment policy that helps create a self-reproducing process of quality/productivity/performance improvements within the university system. The policy is shown to facilitate these improvements, helping universities escape the mediocre-quality, low-productivity, low-performance traps that plague many universities in developing countries.

Keywords

Quality • Productivity • Universities • Structural equation model • Simulations

1 **Correspondence to:** Ahmet Kara (PhD), Department of Economics, Istanbul Commerce University, İmrahor Cad. No: 88/2 Beyoğlu, İstanbul Turkey. Email: kara2010@ticaret.edu.tr

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The state of 21st-century scientific institutions and practices has received considerable attention in the literature, which contains a rich spectrum of works on a wide array of interrelated issues. These issues include but are not limited to incentives and inventions in universities (Lach & Schankerman, 2008); knowledge, research, development, and innovations (Simai, 2003); the problem of a market-oriented university (Hayrinen-Alestalo & Peltola, 2006); science and technology in relation to small- and medium-sized enterprises (Parilli & Elola, 2012); educational technology (Kara, 2013b); technology-induced and crisis-led stochastic and chaotic fluctuations in higher educational processes (Kara, 2015); university-industry connections (Ramos-Vielba & Fernandez-Esquinas, 2012); university as a catalyst for the science-based knowledge economy (Dzisah, 2007); university-business relations (Metcalfe, 2010); strategic university management (Barlas & Diker, 2000); the issue of networks (Hage, Mote, & Jordan, 2013); knowledge policies and universities in developing countries (Arocena, Göransson, & Sutz, 2015); analysis of structural problems in education sectors (Kara, 2013a); and performance-based resource allocation for higher education institutions (Wang, 2018). General literature also exists on the different dimensions of the resource allocation problem that explores a variety of different issues such as performance analysis and optimal resource allocation through hybrid, cognitive, Gaussian two-way relay channels (Srinath, Mishra, & Trivedi, 2018); semi-cooperative game theory analysis of resource allocation in cognitive cellular networks (Mankar, Das, Pathak, & Ghanore, 2018); the problem of stochastic nonlinear resource allocation (Cheng, Lisser, & Leung, 2016); and multi-objective optimization-oriented policies for performance and efficient resource allocation in the Cloud environment (Shrimali & Patel, 2017).

Among the institutions for which problem-centered analysis is particularly evident are universities in developing countries that have performed relatively poorly in the known history of modern universities. They have been characterized on average with consistently low ratings in the overall rankings of the world's universities (Times Higher Education, 2016, 2017). The universities in question appear to have been trapped into relatively stagnant levels of teaching quality, research productivity, and overall performance. The gap between developing and developed nations' universities has remained persistently significant over time. The special efforts made by some countries like South Korea have been unable to close the gap (Shin, 2009).

The reasons for the relatively poor performance of universities in developing countries lie in a complex set of historically contingent and interrelated economic, political, and social factors that cannot be entirely accounted for within the confines of one article. Thus, we will focus not on the entire set of relevant micro and macro dimensions of the problem but only on the subset related to the use of resources.

The resource-based reasons for universities' relatively poor performance over time can be classified under three headings:

(i) Lack of sufficient resources

(ii) Path dependence

(iii) Inefficient/dynamically suboptimal use of resources

We will assume that the amount (and origins) of resources are given. The path dependence linking past states to current ones and exploration of the particular ways in which the previous path constrains or shapes the current path is an interesting phenomenon worthy of inquiry. Attempts to transform a university (e.g., from teaching-oriented to research-oriented) would have to deal with problems related to possible path dependence. Though path dependence could be analyzed within an extended version of the analytical framework employed here, it will be left out of the chosen confines of this paper. We will instead focus on the third sub-dimension of the resource-based reasons articulated above and construct an example of dynamically efficient resource usage.

For the purposes of analytical convenience, we will formulate the relevant resources in different forms of capital (i.e., physical capital, social capital, and human capital), which will be defined in the following section. Different services such as teaching services, research services, or project services provided by the university would require different combinations of physical capital, social capital, and human capital. Allocating resources (capital) in the production/provision of services is a problem to be tackled by a university in a dynamically optimal manner. In other words, resources need to be allocated so as to maximize an overall objective function or a multidimensional objective function. This in itself is a highly complicated problem in light of the many stochastic, dynamic, and strategic factors at play. We will instead choose a particular aspect of the problem relevant to optimal policy design that can facilitate creating a self-reproducing process of performance improvements.

Modeling a problem of this kind involves peculiar difficulties, for many of the variables, including performance levels, are not easily measurable. Therefore, we have used a structural equation model that allows the representation of both measurable variables as well as latent variables associated with certain observable indicators. The trajectories of these variables over time are simulated using system dynamics, which has also made possible the formulation of a process of self-reproducing mechanism for performance improvements. An optimally determined portion of the total surplus generated from teaching, research, and other activities is reinvested in a series of steps into the expansion of physical and human capital, which in turn leads to improvements in performance levels, creating a positive, self-sustaining feedback loop within the university system.

The amount of improvements targeted through such self-sustaining feedback mechanisms can differ for different dimensions of performance. Universities in developing countries appear to often achieve mediocre (and sometimes better) levels of teaching performances while research performances remain dismal. Thus these universities may want to target higher levels of research performances, which might require disproportionally higher levels of investment in particular forms of capital (such as human capital). As research performance is highly focused on human capital, human capital may have a higher impact on overall targets, which is the situation in this paper's empirical case study and why the model has been based on human capital.

Due to these background descriptions and arguments, we can make a case for, or explain in some detail, the novelty of the paper, which resides both in its theoretical and practical aspects (i.e., in the very structure of hybrid model the paper constructs and in the practical implications it generates). The main issue is the problem of resource allocation, especially in developing countries' universities with their strikingly pervasive traps, as well as a possible solution, which is the subject of our inquiry. The optimal resource allocation (and optimal decision making) in contemporary universities is a highly complicated process with intricately interwoven dynamic, stochastic (i.e., including risk and uncertainty), and strategic dimensions. Dealing adequately with these interconnected dimensions requires employing multiple hybrid methods – a practice that is rather new and hence not yet sufficiently developed in the literature. Novel attempts are needed in this area, and this paper is one such attempt. The novelty of this paper's attempt is marked by a unique combination of structural equation modeling and system dynamics modeling. What does such a combination accomplish that a simple econometric technique cannot? The answer lies in certain aspects of the resource allocation problem we are tackling. The resource-allocation/decision-making process in a university, as indicated earlier, involves observable as well as_latent factors; over time, this contributes to the evolution of certain key variables such as teaching quality and research productivity. In view of the presence of latent factors in the process, a simple econometric technique that is unable to account for latent phenomena would be inappropriate to use. A technique that lets us deal with unobservable (as well as observable) factors in a simultaneous set-up is needed. That is why, as alluded earlier, we have used structural equation modeling.

Though structural equation modeling is quite useful in describing and estimating the structure of relations among unobservable and observable factors/variables, it cannot account for the dynamic changes these factors/variables help create or the dynamic feedback loops they might be embedded in. Dynamic changes and dynamic feedback loops can be analyzed quite effectively with a system-dynamics method. This is why it has been used in this paper in combination with structural equation modeling.

Using this hybrid combination, we have accomplished two tasks: (1) demonstrating the presence in our empirical case of a low-quality, low-productivity, low-performance trap that universities may be caught in, and (2) finding/calculating the optimal value of the subsidy/reinvestment parameter that maximizes overall university performance and frees the university system from the trap in question. This is an important contribution to the practice of university management, for one of the most important problems facing university administrations is to find the optimal values of the allocation parameters that solve crucial problems and contribute to achieving the designated objectives.

The second section of the paper develops the structural equation model, which represents a picture of the variables and relations in the system. We have used the structural equation software AMOS to construct the path diagram and estimate the parameters. The third section presents a dynamic extension of this model in a revised form. The fourth section simulates the trajectories of variables and finds optimal policy parameters through system dynamics. Concluding remarks follow in the final section of the paper.

Method and Models

The Structural Equation Model: Framework, Findings, and Discussion

Consider a representative university that engages in teaching, research, and project-related activities/services and produces the associated services. The production factors needed for efficiently providing these services take many different forms, ranging from such tangible resources as classrooms and computerized infrastructure to intangible ones such as the knowledge and know-how embodied in instruction and research. For the purposes of analytical convenience, we will divide the relevant factors of production into three different but interrelated categories: physical capital, human capital, and social capital. We will use the term "physical capital" in a broader sense so as to include physical and financial assets as well as land and natural resources. In the context of our analysis, a university's physical capital will have many components, including campuses, classrooms, laboratories, recreational and logistic facilities, and so on. On the other hand, a university's human capital represents "the knowledge, skills, competences, and attributes embodied in individuals" (Organisation for Economic Co-operation and Development, 2001, p. 18). By individuals, we mean the employees occupying teaching, research, managerial, and logistic positions. Finally, social capital will be used as a semantic equivalent of the term "network capital," which could be defined as "resources embedded in social networks, accessed and used by actors for actions. Thus, the concept has two important components: (1) it represents resources embedded in social relations rather than individuals, and (2) access and use of such resources reside with actors." (Lin, 2001, pp. 24–25). The network of relations the university is situated in will be instrumental in undertaking many service-producing activities, ranging from various forms of scientific cooperation to graduate placement.

By virtue of the difficulties associated with obtaining concrete aggregated measures of physical capital, human capital, and social capital, we will take them as latent variables representable by means of certain observable indicators. We will take basic physical resources (i.e., campus, classrooms, etc.), recreational resources (i.e., sports and entertainment facilities, etc.), and technological resources (i.e., laboratories, other information technology-related facilities, etc.) as indicators of the physical capital of the university. The indicators of universities' human capital will consist of three main components: the competences of academic, administrative, and logistic personnel. The social capital of the university will also have three components that are central to the quality, size, and effectiveness of the network the university is situated in: the levels of communication, coordination, and cooperation that the university has with all its related partners of varying degrees of interconnectivity.

The physical, human, and social capital of the university will determine the overall performance of the university, which is a difficult variable to measure. As such, overall performance is taken as a latent variable in the model, the indicators of which will be research/project performance, teaching performance, and the popularity of the university. A concise list of the concepts and variables we have so far mentioned that will form the structural equation model in this paper are as follows.

X_1: Basic physical resources/services

X_2: Recreational resources/services

X_3: Technological resources/services

X_4: Competence of academic personnel

X_5: Competence of administrative personnel

X_6: Competence of logistic personnel

X_7: Communication

X_8: Coordination

X_9: Cooperation

X_{10}: Teaching quality

X_{11}: Research productivity

X_{12}: Popularity

F_1: Physical capital

F_2: Human capital

F_3: Social capital

F_4: Overall university performance

The causally-connected diagrammatic description of the relations among these variables (factors/indicators) is given in Figure 1.

An account of university performance based on three forms of capital will enable us to test how powerful or suitable the triadic categorization of capital is in explaining a highly knowledge-intensive human endeavor. We will check and see the extent to which the fitted structural equation model that rests upon the triadic concept satisfies certain standard properties.

To estimate the model, we have collected data based on a questionnaire on indicators. As the set of data about the indicators in the model are related mainly to the supply and demand of capital, the respondents were either students or university administrators, depending on the type of question. Respondents had access to freely-available market and institutional information, and their responses are assumed to reflect their experiences and perceptions; 250 participants have been asked to provide their individual assessments/ratings concerning the indicators. Questions are rated on an ascending continuous scale between 0 and 7 (with 0 being excluded and 7 being the highest score in the short run). Through this construction, indicators take on short-term values from 0 to 7 (i.e., $X_i \in [0, 7]$, $i = 1,\ldots,12$). Values greater than 7 are considered unusually high with long-term achievability.

To assess the reliability of the relations between each latent factor and the associated indicators, we obtained Cronbach's alpha measurements for the latent factors. Cronbach's α is 0.69 for physical capital (0.96 in the absence of technology), 0.79 for human capital, 0.89 for social capital, and 0.68 for overall university performance. The values are not problematic. One of them is very close to 0.7 and the others are well over 0.7, which is considered to be an approximate threshold. The only point that may require special care in the context of reliability analysis here is the role of technology, which has conventionally been a part of physical capital. Because technology is highly correlated with many other indicators, it may be treated as a stand-alone factor separate from physical capital. This is exactly what we have done in the estimated structural equation model described in Figure 1.

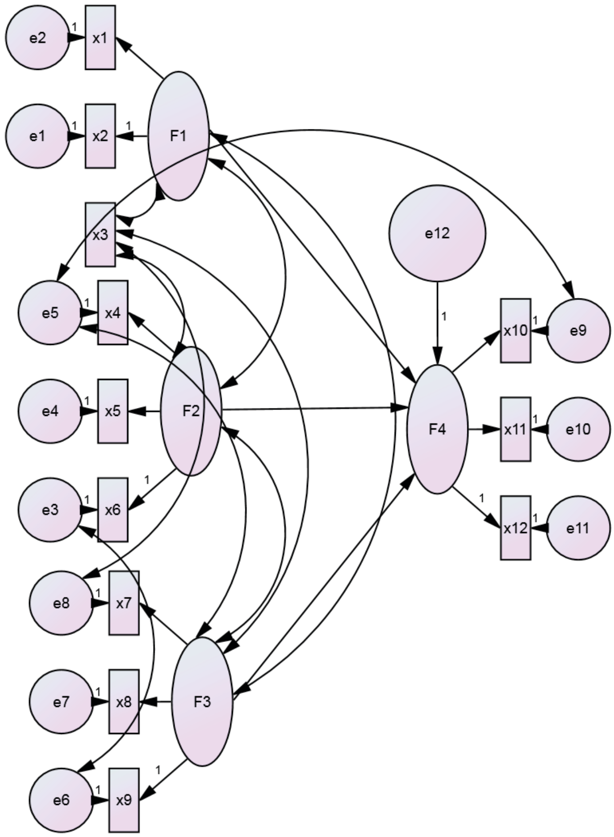

Figure 1. Diagram.

Regarding the goodness-of-fit measures, we have obtained the following values Chi-square related value of $p = 0.08$, , $GFI = 0.095$, $AGFI = 0.92$, $NFI = 0.96$, $TLI = 0.98$, $CFI = 0.99$, $RMSEA = 0.03$. In the standard practice of structural equation modeling (SEM) estimation, a *p*-value in terms of the chi-square greater than 0.05; *GFI*, *AGFI*, *CFI*, *NFI*, *TLI*, and *CFI* values greater than 0.9; and an *RMSEA* value less than 0.05 are considered indicators of very good fit. Thus the obtained goodness-of-fit measures are quite good.

Though we have obtained very good overall fit, some estimated relations do not precisely fit into the overall SEM framework. To give an example, not correlating e3 and e6 would have been better for they were the error terms associated with indicators of different latent factors (i.e., human capital and social capital). Though having entirely distinct factors/constructs would have been nice for the idealized workings of the model, this cannot always hold in practice. For instance, despite the fact that human capital and social capital could be justifiably treated as distinct constructs in this particular case as they are in the literature, the items and properties associated with them need not be, and in reality are not totally unrelated. By virtue of these types of complexities, some correlations may be unavoidably present. However, this does not undermine the overall usefulness of the model, for the main structure of the model remains intact, the model's overall fit is good, and the relevant relations are mostly statistically significant, as will be elaborated below. The regression weights and associated levels of statistical significance are shown in Table 1.

Table 1
Inter-factor and Factor-Indicator Regression Weights

			Estimate	*SE*	*CR*	*p*
F_4	<---	F_1	.148	.062	2.383	.017
F_4	<---	F_2	.605	.282	2.150	.032
F_4	<---	F_3	.216	.243	.893	.372
X_2	<---	F_1	1.000			
X_1	<---	F_1	1.159	.060	19.355	***
X_6	<---	F_2	1.000			
X_5	<---	F_2	1.047	.092	11.394	***
X_4	<---	F_2	.985	.104	9.499	***
X_9	<---	F_3	1.000			
X_8	<---	F_3	1.062	.071	15.031	***
X_7	<---	F_3	1.039	.072	14.464	***
X_{10}	<---	F_4	.737	.097	7.599	***
X_{11}	<---	F_4	.782	.100	7.792	***
X_{12}	<---	F_4	1.000			

Table 2
Standardized Regression Weights

			Estimate
F_4	<---	F_1	.180
F_4	<---	F_2	.588
F_4	<---	F_3	.231
X_2	<---	F_1	.941
X_1	<---	F_1	.994
X_6	<---	F_2	.733
X_5	<---	F_2	.800
X_4	<---	F_2	.724
X_9	<---	F_3	.816
X_8	<---	F_3	.893
X_7	<---	F_3	.871
X_{10}	<---	F_4	.600
X_{11}	<---	F_4	.615
X_{12}	<---	F_4	.706

As the numbers in the table above indicate, the only regression weight that is not statistically significant is the one between social capital and overall performance. The effects of physical capital and human capital on overall performance are statistically significant. Moreover, all indicators have statistically significant relationships with the relevant latent factors.

The effect of human capital is considerably greater than that of physical capital in terms of magnitude. In view of the dominant empirical role human capital plays in the case under investigation, we can say the resulting structural equation model should be based on human capital. Up to now the model has been static and hence has presented a picture at a single point in time. Static as it may be, however, the model and the resulting estimates may serve as a basis for a dynamic extension of the analysis. We will make use of the estimated dominant role of human capital as well as the subsidiary role of physical capital in developing a follow-up model that will make possible a dynamic analysis of the system over time. We will use the estimated relations obtained from the structural equation model above as a reference point for a system dynamics model of this kind, which we will develop next.

A Dynamic Extension: Model, Findings, and Discussion

Based on the results concerning the degree of the statistical and magnitude-wise significance of the impacts of physical, human and social capital on the university performance, we will take the statistically significant factors, human capital and physical capital, as elements of the joint basis for the dynamic extension of the model.

To construct the dynamic model, we will begin with a dynamic supply-and-demand structure for human and physical capital¸ which is simple but highly hybrid in nature. Suppose that the quantity demanded for the human capital at time t (DHC_t) depends on the level of human capital at time t-1 in the previous period (HC_{t-1}), the level of teaching quality at time t ($X_{10,t}$), the level of research performance at time t ($X_{11,t}$), the relative price of the human capital at time t (PHC_t) and the human capital subsidy at time t (SH_t),

i.e., $DHC_t = g^{DHC} (HC_{t-1}, x_{10,t}, x_{11,t}, PHC_t, SH_t)$ (1)

which is a hybrid demand function for human capital. Relative price, quantity demanded, and subsidy take on positive real values. Here we assume higher levels of teaching quality, research performance, and human capital subsidy will drive demand up while higher levels of prices and previous human capital will drive demand down.

Similarly, suppose that the quantity supplied for human capital at time t (SHC_t) depends on the level of human capital at time t_1 (i.e., in the previous period¸ (HC_{t-1}), the level of overall university performance at time t ($F_{4,t}$), and the relative price of human capital at time t (PHC_t),

i.e., $SHC_t = g^{SHC} (HC_{t-1}, F_{4,t}, PHC_t),$ (2)

which is a hybrid supply function for human capital. Quantity supplied takes on positive real values. Here, we assume that higher levels of overall university performance (which could presumably attract further human capital) and prices will drive supply up while higher levels of previous human capital (which could reduce the need for prospective human capital employment) will drive supply down.

We will assume that the demand and supply functions for human capital have the following forms:

$$DHC_t = \alpha_0 + \alpha_1 HC_{t-1} + \alpha_2 X_{10,t} + \alpha_3 X_{11,t} + \alpha_4 PHC_t + \alpha_5 SH_t + u_{1t}, \qquad (3)$$

and

$$SHC_t = \beta_0 + \beta_1 HC_{t-1} + \beta_2 F_{4,t} + \beta_3 PHC_t + v_{1t}, \qquad (4)$$

where and are normally-distributed, white-noise, stochastic terms with zero means and constant variances σ_{u1}^2 and σ_{v1}^2 respectively.

To model the trajectory of human capital over time, human capital's movement over time will be assumed proportional to the excess demand for human capital,

i.e., $HC_t - HC_{t-1} = k\,(DHC_t - SHC_t),$ (5)

where k is the coefficient of adjustment.

This is nothing but a dynamic adjustment equation for human capital. Substituting the expressions for DHC_t and SHC_t specified above, setting the initial values of $X_{10,t}$, $X_{11,t}$ and PHC_t to their averages $X_{10,t}^{avr}$, $X_{11,t}^{avr}$ and PHC_t^{avr} and rearranging the terms in the equation, we get,

$$HCt + (-1-k(\alpha_1 - \beta_1))\,HC_{t-1} = k(\alpha_0 - \beta_0 + \alpha_2 X_{10,t}^{avr} + \alpha_3 X_{11,t}^{avr} + (\alpha_4 - \beta_3)\,PHC_t^{avr} + \alpha_5 SH_t - \beta_2 F_{4,t} + u_{1t} - v_{1t}). \qquad (6)$$

This is one of the stochastic difference equations that will be employed in the subsequent simulations.

Suppose that the quantity demanded for physical capital at time t (DPC_t) depends on the level of physical capital at time t-1 in the previous period¸ (PC_{t-1}), the level of teaching quality at time t ($X_{10,t}$), the level of research performance at time t ($X_{11,t}$), the relative price of human capital at time t (PPC_t) and the physical capital subsidy at time t (SP_t),

i.e., $DPC_t = g^{DPC}(PC_{t-1}, x_{10,t}, x_{11,t}, PPC_t, SP_t),$ (7)

which is a hybrid demand function for physical capital. The quantity demanded and subsidy take on positive real values. Here, we assume higher levels of teaching quality, research performance, and physical capital subsidy to drive demand up while higher levels of prices and previous physical capital drive demand down.

Similarly, suppose that the quantity supplied for physical capital at time t (SPC_t) depends on the level of physical capital at time t-1 in the previous period, PC_{t-1}) and the relative price of physical capital at time t (PPC_t),

i.e., $SPC_t = g^{SPC} (PC_{t-1}, PPC_t),$ (8)

which is a hybrid supply function for human capital. The quantity supplied takes on positive real values. Here, we assume higher prices to drive supply up while higher levels of previous human capital, which could reduce the need for additional physical capital, drive supply down.

We will assume the demand and supply functions for human capital to have the following forms:

$$DPC_t = \theta_0 + \theta_1 PC_{t-1} + \theta_2 X_{10,t} + \theta_{3\ X11,t} + \theta_4 PPC_t + \theta_5 SP_t + u_{2t}, \quad (9)$$

and

$$SPC_t = \delta_0 + \delta_1 PC_{t-1} + \delta_2 PPC_t + v_{2t}, \quad (10)$$

and u_{1t} and v_{1t} are normally distributed white noise stochastic terms with zero means and constant variances σ_{u1}^2 and σ_{v1}^2 respectively.

To model the trajectory of physical capital over time, physical capital's movement over time will be assumed proportional to the excess demand for physical capital,

$$PC_t - PC_{t-1} = k^* (DPC_t - SPC_t), \quad (11)$$

where k^* is the coefficient of adjustment.

This is nothing but a dynamic adjustment equation for physical capital. Substituting the expressions for DPC_t and SPC_t specified above, setting the initial values of $X_{10,t}$, $X_{11,t}$, and PPC_t to their averages $X_{10,t}^{\text{avr}}$, $X_{11,t}^{\text{avr}}$, and PPC_t^{avr} and rearranging the terms in the equation, we get

$$PC_t + (-1-k(\theta_1 - \delta_1)) PC_{t-1} = k(\theta_0 - \delta_0 + \theta_2 X_{10,t}^{\text{avr}} + \theta_3 X_{11,t}^{\text{avr}} + (\theta_4 - \delta_3) PPC_t^{\text{avr}} + \theta_5 SP_t + u_{2t} - v_{2t}). \quad (12)$$

The simulations that will be undertaken in the following section will make use of the two stochastic difference equations (Equations 6 & 12) derived above.

System Dynamics Simulations

We will employ a system dynamics procedure to simulate the trajectories of teaching quality, research productivity and university performance and explore the possibilities of optimal policies that can get the university out of possible low-quality-low-productivity-low-performance traps.

System dynamics is a flexible method that enables us to weave stocks, flows, and auxiliary variables into a dynamic whole and to properly specify the feedback relations/structures involving these variables for simulation purposes. In our model, we choose the human capital and physical capital as the stock variables. Flow variables are the changes in the stock variables. Using the variables of the original model above, we have formulated auxiliary variables to help specify the causal connections as well as the feedback relations within the system.

To design policies for performance improvements, we will assume that a fraction of the surplus generated out of the university activities is invested for the purpose of improving human and physical capital, which in turn, influences university performance, teaching quality, and research productivity, generating a positive feedback loop within the university system.

Let the total surplus in the university have three components, namely (a) surplus from teaching activities, (b) surplus from research and project-related activities, and (c) performance-proportional public and private aid, net of other expenditures. Let p_t and p_r represent the returns on a unit of teaching quality and research performance respectively. Let all surplus components be defined in "revenue minus cost" terms. Revenues are defined in the usual way. Suppose that the cost functions in terms of teaching quality and research productivity are of quadratic forms, i.e.,

Cost of teaching$_{10,5\,pt} = c_1.X_{10,t}^{\,2}$

and

Cost of research$_{\mathrm{t}} = c_2.X_{11,t}^{\,2}$

where c_1 and c_2 represent the positive, real-valued cost parameters.

Suppose that a fraction of the total surplus, say z, is reinvested for the purpose of expanding the human capital and physical capital in the university. Assume that r is the fraction of the total surplus that is reinvested in the human capital, and z-r is the fraction for physical capital. Thus,

Human capital investment (human capital subsidy) at time t (SH_t) is: SH_t = r. Total surplus at time t. (13)

Similarly, physical capital investment (physical capital subsidy) at time t (SP_t) is: SP_t = (z-r .Total surplus at time t. (14)

The representative university may have a number of goals to achieve, but for present purposes, let us assume that it attempts to find the optimal value of r that maximizes overall university performance. Optimization has been carried out through a module built in the program VENSIM.

In this process, an optimally reinvested fraction of the total surplus generated from teaching, research, and other activities will lead to the expansion of physical and social capital in a series of steps, which in turn lead to improvements in performance levels, creating a positive, self-sustaining feedback loop within the university system.

The simulation diagram describing the feedback relations embodied in the model is given in Figure 2.

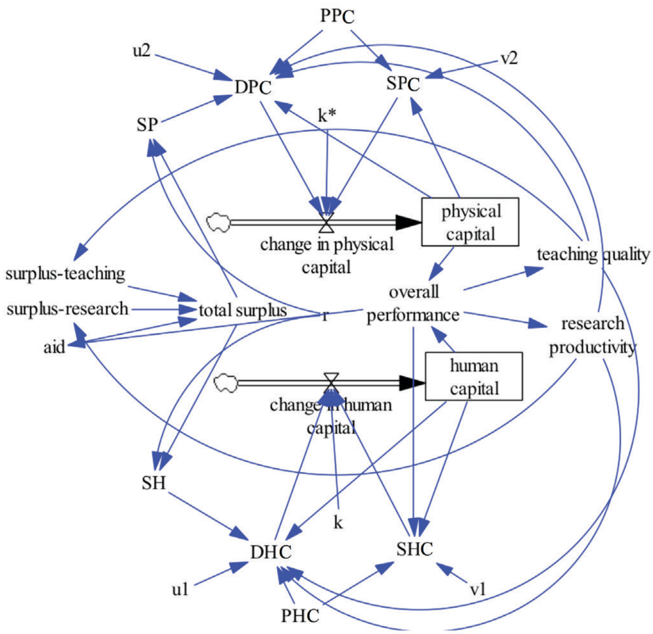

Figure 2. Simulation diagram.

The physical capital and human capital evolve over time through demand and supply and the adjustment dynamic specified in the model. For simulation purposes, let: $\alpha_0 = 2$, $\alpha_1 = 0.6$, $\alpha_2 =0.6$, $\alpha_3 = 0.7$, $\alpha_4 = - 0.8$, $\alpha_5 = 0.9$, $\beta_0 = 1$, $\beta_1 = -0.4$, $\beta_2 =0.3$, $\beta_3 = 0.5$, k = 0.1, $X_{10,t}^{initial} = 2$, $X_{11,t}^{initial} = 2$, and PHC_t avr =1. Initial $HC_t = 2$, initial $PC_t = 2$. $\theta_0 = 2$, $\theta_1 = -0.5$, $\theta_2 =0.4$, $\theta_3 = 0.5$, $\theta_4 = -0.6$, $\theta_5 = 0.8$, $\delta_0 = 1$, $\delta_1 = -0.3$, $\delta_2 = 0.6$, k* = 0.1, $PPC_t^{avr} = 1$. u_{1t}, v_{1t}, u_{2t}, and v_{2t} are random (normal) variables with zero mean and a standard deviation of 0.2. The simulated stochastic trajectories of teaching quality, research productivity and overall university performance (both with and without subsidies) are given in Figures 3, 4, and 5, respectively.

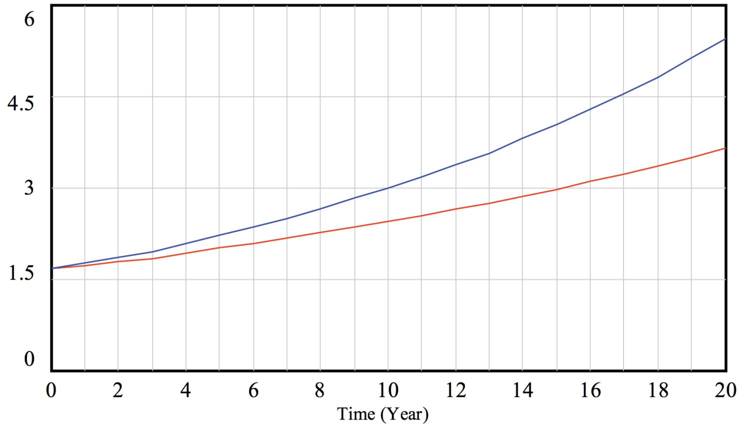

Figure 3. Teaching quality with and without subsidies.

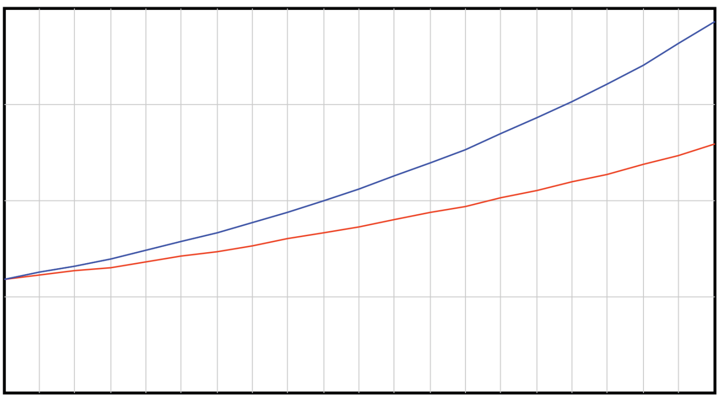

Figure 4. Research productivity with and without subsidies.

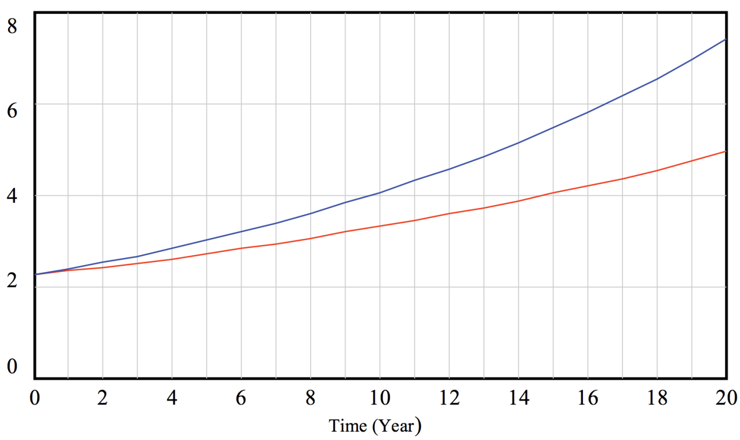

Figure5. Overall performance with and without subsidies.

In the simulation diagrams above, the lower trajectories represent the ones without subsidies. The upper trajectories represent the ones with optimal subsidies. Trajectories with no subsidy or (re)investment are relatively flat with relatively stagnant levels of quality, productivity, and overall performance over time and indicate a low-quality, low-productivity, low performance trap for the universities in question. This is the first important result of the paper. To elaborate briefly, if the university begins with low levels of quality, productivity, and performance, it becomes more or less stuck there; namely the university is likely to remain at those levels without significant improvements over time. This is exactly what we mean by the low-quality, low-productivity, low-performance trap. The reason for this trap may lie in the minimal requirements for different forms of capital in providing educational and research services. Certain minimally required levels of capital that are necessary to generate a surplus my indeed exist, which could eventually serve as a source for a self-reproducing growth process.

To get out of this trap, we need a jump, the effects of which are illustrated in Figures 3, 4, and 5. This jump can be induced through a subsidy or reinvestment into human and physical capital. A subsidy/reinvestment policy appears to be fairly effective at shifting performance trajectories upwards, leading to higher teaching quality, higher research productivity, and higher overall performance levels. But what are the optimal levels of those subsidies that maximize overall university performance? The answer to this question is the second contribution of this paper. Constructing a model, simulated using the system-dynamics software VENSIM, which includes an optimization module, we have shown a simple way to calculate these optimal levels. In our particular case, the optimal subsidy parameter, determined through simulation, indicates a corner solution assigning the entire subsidy to human capital. This, however, is not surprising in view of the fact that through the data-based structural equation modeling analysis in our empirical case in the second section of the paper, human capital is shown to be magnitude-wise much more significant than physical capital. This of course does not always have to be the case. Depending on the particularities of the empirical case, one may end up with different allocations of subsidies between different forms of capital. The key here is the instrumental role the subsidies play in generating a self-reproducing feedback loop within the university system. Such a subsidy/reinvestment policy with optimally-adjusted parameters could prove to be an effective mechanism that can help free the system from the low-quality, low-productivity, low-performance trap.

Concluding Remarks

A considerable subset of universities in developing countries appears to be trapped in low-to-mediocre values for teaching quality, research productivity, and overall performance. Strategies/policies able to free these universities from this trap can take many different forms and directions, one of which has been explored in this paper. By hypothesizing that different forms of capital in its physical, social, and human varieties to be among the key determinants of the quality, productivity, and performance in universities, creating self-reproducing mechanisms/processes based on these forms of capital can effectively help these universities escape the trapped levels of quality, productivity, and overall performance. The subsidy/reinvestment policy described and modeled in this paper is a possible example of such mechanisms. The dynamic effects of this policy, the parameters of which may be optimally determined in a time-dependent framework, can feedback on itself so as to generate a process of sustainable improvements over time.

To our knowledge, the model we have developed here is the first dynamic, computational model of a university based on a structurally-constructed triadic concept of capital with optimally-driven feedback loops. We do think this to be a novel direction with many innovative possibilities that are hybrid in nature. Modeled and analyzed in a dynamic framework, self-reproducing improvement mechanisms in universities are likely to involve multiple intricately-interwoven dimensions that might require combining multiple and even hybrid methods. In this paper, we have employed a combination of the methods of structural equation modeling and system dynamics. We have used the structural equation modeling method to take the picture of a multiplicity-dominant phenomenon with latent dimensions, the dynamics of which have been explored through system dynamics. Of course, the combination we employed has not exhausted all the productive possibilities. Depending on the particularities of the wide range of problems and processes in universities, one could explore many important issues that we have not, with many different creative combinations of methods. Different issues may require different combinations of methods. Namely, the choice of method combination may be issue and purpose specific; one particular combination may not suit all purposes. For example, the combination we employed in this paper does not properly take into account the strategic interplay of the units and actors in universities. Multidimensional strategic interactions are critical to the evolution of many processes in universities, which can be effectively modeled using different methods. One could, for instance, construct a combined "agent-based-system-dynamics" model so as to explore the possible trajectories of strategic interactions and improvement possibilities, which would be worthy of future research.

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