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Modeling gender evolution and gap in science and technology using ecological dynamics

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ABSTRACT

In this paper a model based on population biology is proposed in order to investigate the evolution of human resources (men and women) in science and technology as a share of labor market as well as the dynamics of their gap. An analytical and a simulation method using the Artificial Bee Colony optimization algorithm are described and used for the determination of the proposed model parameters. The presented model is applied to three case studies; Greece, Portugal and Europe-27.[3] The accuracy of the obtained results is confirmed through comparison with actual data. In addition, the model can also be used to accurately forecast future trends. It is illustrated that the gender gap is continuously decreasing, while in the last years, women seem to outperform men in the field of science and technology. The estimation and forecasting ability of the model can be used as an extremely valuable tool for decision and policy makers.

1. Introduction

In the last decades, an unrelieved evolution of technologies is observed. Societies are experiencing new and rapidly changing scientific and technological (S&T) achievements. It is a common belief that the progress in science and technology is usually an indicator of economic growth, environmental well-being and social development. However, a link between the S&T evolution and the socio-economic development is required. The main candidate able to fill in the gap between these activities is the human resources of the specific field (Chou, Hsu, & Yen, 2011; Kefela, 2010). A workforce with lifelong learning (updated skills) seems to be the key ingredient for the adoption of the rapid S&T changes as well as the development and diffusion of knowledge.

Recently, there has been an increased attention for qualitative and quantitative investigation of human resources in science and technology (Chou, Sun, & Yen, 2012; Davó, Mayor, & Blazquez de la Hera, 2011). Statistical information regarding S&T human resources is of great importance and high interest for several different parties from industry, government and public sector to academics. These data are useful in determining the current status and monitoring workforce's evolution.

Special interest has also been paid for the investigation of gender gap in science and technology. As described in the following section, several studies have been conducted regarding the inequalities in education and/or the occupation of the two genders in the field of S&T. It has been shown that although the differences between males and females are marginal in younger ages, there are obvious discrepancies in older population with males outperforming females.

Although human resources in science and technology (HRST) are extremely significant, their study was incorporated for several years in research and development (R&D) related analyses, creating thus a lack of systematic mechanisms capable for in depth examination and/or future tracking of HRST based issues. It has then become evident that more effort should be made to gather and process data enhancing HSRT knowledge. This endeavor can be exemplified by the numerous programs supported by the OECD and the European Commission. Milestone to this process was the Canberra manual proposed and developed by the organization for economic co-operation and development in 1995 (Nanopoulos, Sirilli, & Tanaka, 1995).

Canberra Manual incorporates the best national and international practice as a result of a wide inventory along with the use of the main standard international classifications. In fact, it provides a framework for processing HRST data, investigating trends and preparing up-to-date series for intended users aiming in the harmonization of data and the use of HRST indicators.

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[3] Economic and political union consisting of the following 27 member states (from 1 January 2007): Belgium (BE), Greece (EL), Luxembourg (LU), Denmark (DK), Spain (ES), Netherlands (NL), Germany (DE), France (FR), Portugal (PT), Ireland (IE), Italy (IT), United Kingdom (UK), Austria (AT), Finland (FI), Sweden (SE), Poland (PL), Czech Republic (CZ), Cyprus (CY), Latvia (LV), Lithuania (LT), Slovenia (SI), Estonia (EE), Slovakia (SK), Hungary (HU), Malta (MT), Bulgaria (BG), Romania (RO).

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In this work and in contrary to the majority of previous studies that are limited to statistically analyze and forecast human resources in science and technology as a whole or the evolution of each gender separately, the evolution of "population shares" in S&T as well as gender interactions are modeled, investigated and forecasted using the evolutionary theory of population biology and dynamics. In detail, the proposed model is based on Lotka–Volterra model describing the competition between species (Begon, Townsend, & Harper, 2006; Murray, 2007). Lotka–Volterra model is a widely used model especially in biology.

However, it has also been applied in several other areas, besides biology, providing precise estimates of the dynamics under consideration (Forýs, 2009; Lee, Lee, & Oh, 2005; Ying & Shi, 2008). A typical example is telecommunications market where the L–V model is used to examine providers' competitive behavior-market share (Kim, Lee, & Ahn, 2006; Lopez & Sanjuan, 2001; Michalakelis, Christodoulos, Varoutas, & Sphicopoulos, 2012). The results obtained by the model can be supportive to other already used techniques providing a comparison reference confirming their results.

The proposed model was applied in the case of two European countries; Greece and Portugal as well as in the case of Europe-27. It was shown that the model gives very good interpolation of the statistical data providing at the same time an accurate forecasting (It was compared to actual data of 2011) using the parameters obtained from both the analytical and simulation methods. The results showed that in the case of Greece and Portugal, human resources of the two genders in S&T as a share of active population will continue to increase in the following years tending to a steady-state. On the other hand human resources in the case of Europe-27 revealed a decreasing oscillatory behavior, possibly due to the contribution of countries with different characteristics, leading again to a steady-state.

Good performance of the proposed methodology would result in a twofold contribution. On the one hand, it would provide an alternative analysis and interpretation method of HRST data as well as of the interaction of the two genders in this area. On the other hand, it would act as valuable tool for policy and decision makers saving money from expensive and frequently unnecessary training of S&T skills.

This paper is organized as follows. At first a literature review is introduced regarding gender inequalities in HRST. Then the proposed model describing the relationship and the evolution of the two genders regarding human resources in science and technology is presented. Subsequently the solution procedure of the set of the nonlinear differential equations is described and details are given for the analytical method for the determination of model coefficients is given and the simulation method based on Artificial Bee Colony optimization algorithm. The linearization of the nonlinear problem as well as a closed form formula for the evolution of males and females in S&T is derived the following subsection. The results obtained by the application of the described model along with the two solving methods are finally presented and discussed before the concluding remarks.

2. Literature review and definition

Gender inequality has existed since the ancient times. Women were not involved in paid labor (Rossi, 1988) until 1830. Women began to participate in labor after the first industrial revolution that generated a great need for manpower (Ruskin, 2002). However, both technological revolutions brought up once again gender inequality issues.

The European Union (EU) since its establishment anticipated these gender inequality issues and therefore took steps towards equal rights between men and women. Nevertheless the two genders have not yet achieved to be equal to each other and it is a fact that women are still employed in inferior and less paid jobs. Gender inequality was extensively studied by Helgesen (1990) and many more researchers earlier than him.

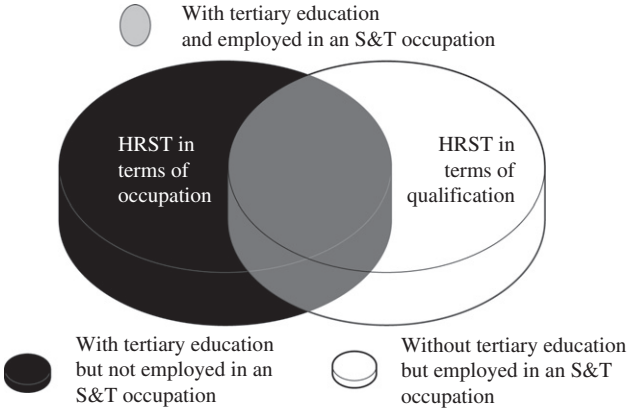

Fig. 1. Components of HRST.

In the last decades it was realized that the existing inequality between men and women that use new technologies and are employed to jobs related to science and technology (i.e. sciences related to mathematics, chemistry, engineering and biology etc.[4]) was not only due to gender differences but also due to age differences. More specifically, men and women between the ages of 16 and 24, have the same education and should therefore share the same labor opportunities but in contrast to that, when it comes to older people men outperform women.

Even though both genders equally use new technologies, fewer women chose to study in the field of natural sciences. At this point, it should be noted that between the ages of 25 and 64 over the years 2006–2008 in EU-27 there has been an increase of people related to science in new technologies of about 11% while at earlier ages this increase was even greater. Women working in R&D seem to be a minority in EU-25 with a percentage of only 28% that drops to 22.3% when regarding the field of technology and natural sciences in general (European Commission, 2008).

Before further analyzing women's disadvantages in labor over men it would be significant to define the term human resources in science and technology (HSRT). According to Eurostat:

"*This indicator gives the percentage of the total labor force in the age group 25–64, that is classified as HRST, i.e. having either successfully completed an education at the third level*[5] *in an S field of study or is employed in an occupation where such an education is normally required*".

As shown in Fig. 1, HSRT has two components; one consists of the people who work in fields related to new technologies without having a relevant educational background and the other of the people who work in related fields without tertiary education in the specific field. The rest are people that have studied fields related to science and technology and work in related issues (Nanopoulos et al., 1995).

In previous years, there is an increased interest of girls for tertiary education. This can also be proved by Eurostat statistical data showing that in the last two decades more women have graduated tertiary education. In 2007, 21.1% of women aged from 15 to 64 hold a degree, while the corresponding percentage of men is 20.1%. However the percentage of women choosing the field of

[4] http://www.uis.unesco.org/ScienceTechnology/Documents/38235147.pdf.

[5] ISCED levels 5, 6, 7 and 8, which are labeled as shortcycle tertiary, bachelor level or equivalent, master level or equivalent and doctoral level and equivalent, respectively.