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ASSESSMENT OF POSSIBLE EFFECTIVE STRATEGIES IN THE TRANSITION PROCESS TO A KNOWLEDGE-BASED ECONOMY: THE CASE OF TURKEY

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The aim of this study is to introduce a framework which can be used for the assessment of possible strategies in the transition to a knowledge-based economy (KBE). For this purpose, a mixed integer programming (MIP) model is developed to determine the required levels of human resources and information and communications technology (ICT) investments for given levels of government R&D investment of the country shown to be the most significant determinant of the phenomenon. The model is solved for the case of Turkey. The results indicate that: (i) government R&D in Turkey should increase to considerable levels in order to trigger the transition to a KBE and (ii) transformation towards a KBE with an inefficient innovation system may require considerable amounts of additional resources compared to transformation with a more efficient system. The results illustrate that any improvement in the innovation system for Turkey may lead to considerable savings from the required human resources and ICT investments given same levels of R&D investment.

Keywords: Knowledge-Based Economy, Research and Development, Mixed Integer Programming

1. INTRODUCTION

The term knowledge-based economy (KBE) has been the subject of debate among many researchers during the last decade due to the rapid and simultaneous structural changes observed in economic and social activities within and among societies. It was the 8-year long continuous growth of the US economy with high GDP growth rate, low inflation and low unemployment that fuelled the debate among economists. The US experience led to some contradictions with respect to predefined concepts and relations set by economic theory.

The main concern of some of the arguments within the literature have been related to the institutional and organisational structures and the way they are to be configured (i.e. organisational diversity, knowledge diffusion within and among the economic actors, regulatory bodies…etc.). The remaining part of the literature deals with the more tangible aspect of knowledge-based economies. It is observed that in many countries some industries and service sectors have raised their share in total economic activity, gained importance in international trade and became critical due to being effective in the way they affect the operations of other sectors (i.e. information and communications technologies –ICT).

Although efforts have been made to establish frameworks for analysing different aspects of the KBE concept, a comprehensive analytic study to cover the systemic interactions among the entities and institutions of the KBE is still lacking. It is only through the development of such a framework that it may be possible to assess the effect of different strategic options towards becoming a KBE.

For this purpose in this study, a definition is proposed for the KBE phenomenon. It is defined to be the system in which there exist high levels of incentives to exploit intellectual effort and to disseminate the knowledge created with the associated mechanisms and resources supporting, sustaining and developing the attained level.

Discussing the capabilities of countries from the perspective of the knowledge-based economy requires analysing the national innovation systems of the countries comparatively. Since there does not exist normative guides to assess any nation's system of innovation, many institutions and researchers prefer to adapt *best policy approache*s. What is generally accepted is that, any system of innovation should enhance and promote the creation and the diffusion of knowledge. What is also argued within the literature is that there exist a synergistic interaction between the creation and the diffusion process in such a way that one stimulates the other.

In this study it is argued that the capabilities achievable by a nation's innovation system is reflected in the relations between the resources allocated to the creation and the diffusion activities. Making such an analysis is appropriate because it does not require normative guides for comparison. Rather, it will allow making comparisons among the countries which somehow intend to adapt the *best policy approach*.

When analysing various indicators, it is observed that the system forming the knowledge-based economy exhibits a coherent behaviour requiring to perform well in most of the aspects rather than focusing on only some subsets. Hence, a kind of *simultaneity* in the states of various aspects is worth mentioning. However, the efficiency levels (with respect to the utilisation of resources which require investment) at which that simultaneity pervades may differ.

It is argued that, due to this simultaneity aspect, by considering only a subset of the related factors, all the remaining related factors will be considered.

There are alternative indicators for knowledge creation and diffusion. Regarding the knowledge creation activity, total R&D expenditure made by government and private sectors can be considered to be the indicators of the level of knowledge created in a country. Diffusion of knowledge, on the other hand, can be measured by the level of investment in ICT. Though ICT are utilised in the diffusion of codified knowledge, the unavailability of indicators in this area imposes the use of ICT as a proxy to reflect the direct means of knowledge diffusion. What can indirectly be utilised to measure the diffusion activity is the quantity of university graduates (UG) in a country. The accumulated knowledge in the universities and institutions are transmitted to these people who are expected to take part in R&D activities. The portion of UGs who are occupied in R&D activities should also be considered. These people are referred to as researchers, scientists and engineers (RSE).

Utilising these arguments a framework is introduced that would enable the identification of the associations between some of the basic aspects of the phenomenon. The basic factors considered are the expenditure in research and development (R&D), expenditure in information and communications technologies (ICT), researchers, scientists and engineers (RSE) employed in R&D and the portion of population who are university graduates (UG). Based on these factors a framework for analysing a country from the perspective of its transformation into a KBE is introduced. The fact that the efficiency of utilisation of these basic factors differs from country to country is also taken into account. It is hoped that the framework developed will constitute a useful analytic tool in assessing some related strategic schemes. The framework and related measures are explained in Section 2.

Based on the arguments cited above, two issues are thought to be significant for identifying the structural differences between the countries. The first one is related with the state of the R&D activities (i.e. knowledge creation) and the other is the efficiency of a country in utilising its resources in conducting its knowledge-based economic activities.

It is observed that countries are in either of the two possible phases with respect to the levels of private R&D expenditure and government R&D expenditure: the phase in which private R&D of the country is dormant (i.e. insufficient private R&D) and the phase in which private R&D is at a self-sustaining state. In the study, the former phase is referred to as 1st phase and the latter as 2nd phase. In order to identify in which phase a country is, it is assumed that if government R&D expenditure of that country is higher than its private R&D expenditure the country is in 1st phase, and the reverse holds for the 2nd phase.

With respect to the utilisation of resources in conducting knowledge-based activities, the basic argument is as follows: in order to support the creation of a given amount of knowledge (measured by R&D) some level of ICT investment has to be made. It can also be inferred that without attaining a certain level of RSE, the given amount of R&D cannot be achieved. The required amount of RSE can only be obtained from the stock of UGs in the population.

Thus, in this study, using the data for OECD countries over the years a hypothetical thin boundary enveloping all the points (denoting countries) is derived and interpreted as the frontier of utilisation of RSE in R&D activities and is referred to as *envelope function*. It can be said that any country is not expected to achieve a given level of R&D activity with less than the amount of RSE indicated by the envelope function. In this sense, the points on the envelope function always reflect the best case performances for varying levels of R&D activities. Such an approach allows comparing the performances of countries in the utilisation of RSE in R&D activities with the best possible case.

It can also be observed from OECD data that there is positive correlation between RSE per population and UG per population indicating that, on the average, as the required level of RSE increases, the requirement for UG increases. Thus a country is not expected to have a given amount of RSE per population if it has UG per population less than the amount mapped by the envelope function.

Also there exists a positive correlation between per capita R&D expenditure and per capita ICT expenditure. This indicates that to support increasing levels of R&D activity, the country has to invest more in ICT. The development and interpretation of the respective envelope functions are explained in Section 3.

In order to assess the effects of alternative strategies in the transition to a KBE for the case of Turkey and to apply the framework outlined above, a mixed integer programming (MIP) model is developed. The model is presented in Section 3.

In applying the framework and the model to the case of Turkey an investment scheme for government funded research and development is set. Section 4 summarises the scheme and the results obtained by using the model. Concluding remarks are outlined in Section 5.

2. THE FRAMEWORK

Knowledge As The Basis of Analysis And Its Consequences

Currently, the widely accepted definition of the knowledge-based economy is put forward by OECD (1996) as "…*economies which are directly based on the production, distribution and use of knowledge*". It is argued that the term "*results from a fuller recognition of the role of knowledge and technology in economic growth*".

Similar to the definition of the OECD, Dyker and Radosevic (1999), articulate the activities underpinning the knowledge-based economy as:

- knowledge creation (knowledge investments),
- knowledge diffusion (knowledge distribution).

According to both these definitions, it can be said that knowledge is considered as the basic object of the phenomenon and it is to be placed in the center of the analysis. Hence, understanding the basic characteristics of knowledge and the processes associated with it will help in understanding the related arguments existing in the literature.

The second inference that can be drawn from the definitions is that because the terms *creation/production*, *diffusion/distribution* and *use* are directly related with the concepts of 'innovation' (in specific) and 'national innovation systems' (in general), the knowledge-based economy phenomenon requires considering both concepts.

Though not mentioned explicitly, the taxonomy of knowledge which is proposed by Lundvall and Johnson (1994) forms a common basis for most of the arguments existing in the innovation literature. Their work basically distinguishes four types of knowledge which are in continual interaction (at some pace) with each other: know-what, know-why, know-how, know-who. Lundvall and Johnson (1994) grouped them in two on the basis of the similarities of their forms in which they may be available to individuals. Consequently, know-what and know-why were regarded as codified knowledge (information) while leaving the tacit part to include know-how and know-who.

Tacit knowledge is harder to code and lies mainly in skills which are developed through time by performing some type of activity in a repeated manner. Consequently, transmitting this kind of knowledge requires a considerable amount of social interaction with the right actors possessing the skills of interest (eg. mobility of researchers, education, master-apprentice relations …etc can be considered as the means of transfer of codified knowledge). Codified knowledge, as the name implies, can be coded physically (i.e. on paper, CD…etc) and hence is referred to as information as well. As compared to tacit knowledge, codified knowledge is easier to transmit when considered the capabilities and effectiveness of ICT. However, producing and interpreting codified knowledge (especially know-why) is hard due to the fact that it requires highly specialized labour with sophisticated equipment and this process requires applying scientific and technical procedures (patents, technical papers, utilisation of cellular phones… etc can be considered as the means of transfer of codified knowledge).

"That codified and tacit knowledge are complementary is … indisputable" (Foray and Lundvall; 1996). That is, observing the four categories of knowledge throughout the activities of life will lead to the conclusion that they hardly exist in their pure individual forms and any process includes combinations of these categories with differing weights.

Note that, identifying whether a process requires tacit-intensive or codified-intensive knowledge will help in deciding in what way it is better to transfer (anywhere, anybody) how that process is conducted. (i.e. diffusion of economically useful knowledge)

The transfer of knowledge is also promoted through the *codification* process. The term *codification* can be explained as the process of transforming tacit part of knowledge to information (codified knowledge). However, it should be mentioned that codification is not the only means of creation of codified knowledge. Codified knowledge brings about its associated tacit knowledge. The dynamic nature of the codification process is explained by Foray and Lundvall (1996) as "… the spiral movement where tacit is transformed into codified knowledge, followed by a movement back to practice where new kinds of tacit knowledge are developed."

One other point worth noting is that the need for handling codified knowledge is enhancing developments in ICT and that the advances in ICT are, in turn, accelerating and enhancing the codification process. Thus, via ICT, the accessibility -and hence the diffusion- of knowledge is improved. Given the accelerated rate of change driven by the enhancements in the ICT, it is implicitly required that the associated workforce has the capability of adapting and using advanced technology.

Classifying knowledge in this way brings about the concepts of *knowledge stock* of an economy and *knowledge flows* within an economy. It is clear that new knowledge is continuously added to the knowledge stock while obsolete knowledge is dropped off.

Knowledge flow is an important factor in determining a country's innovative capability which is also emphasized implicitly in Matthew's (1996) taxonomy (with the associated concept *learning*) and within the concept of National Innovation Systems. Initially, they attempted to explain the new phenomenon with the growing importance of the process of learning which is a phenomenon highly dependent on the knowledge, its classification, and its place in various kinds of transactions.

Up to this point it has been intended to analyse the ongoing processes with respect to their knowledge content. It has also been illustrated that most of the processes contain a mixture of different knowledge types and does not consist of only a single type and identifying the tacit/codified content of required knowledge for any process will have a determining effect on how it is created and transmitted. Based on these arguments, it may be claimed that the activities mentioned above have been existent since the beginning of humanity; however, in the recent past the increased pace of knowledge creation and diffusion, the spread of knowledge utilisation and consequently the weight of knowledge within the routine economic activities emphasised the importance of knowledge. Hence, as will be shown and discussed further a significant number of countries (either intentionally or unintentionally) began to take into consideration the characteristics and requirements implied by knowledge-based activities in determining their policies.

Having mentioned the literature on knowledge related transactions, it seems appropriate to assess related strategies and policies on the basis of the extent that they promote the creation and diffusion of economically and socially useful knowledge. Such an idea will facilitate comparison of national innovation systems of different countries on common grounds.

Discussing the capabilities of countries from the perspective of the knowledge-based economy requires analysing the national innovation systems of the countries comparatively. Since there does not exist normative guides to assess any nation's system of innovation, many institutions and researchers prefer to adapt *best policy approache*s. What is generally accepted is that, any system of innovation should enhance and promote the creation and the diffusion of knowledge. What is also argued within the literature is that there exist a synergistic interaction between the creation and the diffusion process in such a way that one stimulates the other.

Clarifying The System

Based on the arguments discussed above and the findings which are to be illustrated in the following, a definition is proposed for the KBE phenomenon. It is defined to be the system in which there exist high levels of incentives to exploit intellectual effort and to disseminate the knowledge created with the associated mechanisms and resources supporting, sustaining and developing the attained level.

Once the definition of the KBE is introduced, and the ongoing basics within KBE's are illustrated, the factors involved in the system comprising KBE can be reduced to two broad sets:

- <u>Tangible factors</u> - the resources which require investment,
- <u>Contextual issues</u> - the institutional, cultural and regulational settings in which *tangible factors* are utilised.

In this study it is argued that the capabilities achievable by a nation's innovation system is reflected in the relations between the resources (tangible factors) allocated to the creation and the diffusion activities. Adopting such an approach is appropriate because it does not require normative guides for comparison. Rather, facilitating a *best policy approach*, it will allow making comparisons (among the countries) on common grounds.

The framework which will be illustrated in the following section attempts to handle the combined behaviour of the tangible factors and contextual issues reflecting both the relations among the tangible factors and between tangible factors and contextual issues.

Establishing The Framework

Firstly, an OECD-wide analysis with the following indicators was conducted to get an initial inference about the common features of the KBE. The analysis was not conducted on a systematic basis and during the analysis most recently available values were utilised: Number of granted patents per 10,000 population (1998), gross domestic expenditure on research and development as a percentage of GDP (2000), direct public expenditure for educational institutions as a percentage of GDP (1995), ICT expenditure as a percentage of GDP (1997), ratio of the population with university level education to total population aged between 25-64 (1996).

The reason that these indicators were used can be explained as that these remain as the most commonly cited indicators and also reflect the states of many other issues which are directly related with them.

Though the indicators mentioned above comprise only a limited portion of the cited indicators within the literature it can be observed that any of the indicators tend to assume high values when the others are high. That may lead to the argument that the system forming the knowledge-based economy exhibits a coherent behaviour requiring to perform well in most of the aspects rather than focusing on only some subsets. Hence, a kind of *simultaneity* in the states of various aspects is worth mentioning. However, the efficiency levels (with respect to the utilisation of resources which require investment) at which that simultaneity pervades may differ. These, in fact, were expected due to the arguments discussed in the previous section.

It may be argued that, due to this simultaneity aspect, by considering only a subset of the related factors, all the remaining related factors will be considered.

There are alternative indicators for knowledge creation and diffusion. Regarding the knowledge creation activity, total R&D expenditure made by government and private sectors can be considered to be the indicators of the level of knowledge created in a country. Diffusion of knowledge, on the other hand, can be measured by the level of investment in ICT. Though ICT are utilised in the diffusion of codified knowledge, the unavailability of indicators in this area imposes the use of ICT as a proxy to reflect the direct means of knowledge diffusion. What can indirectly be utilised to measure the diffusion activity is the quantity of university graduates (UG) in a country. The accumulated knowledge in the universities and institutions are transmitted to these people who are expected to take part in R&D activities. The portion of UGs who are occupied in R&D activities should also be considered. These people are referred to as researchers, scientists and engineers (RSE).

The relation between these factors are assumed to prevail as illustrated in Figure-1.

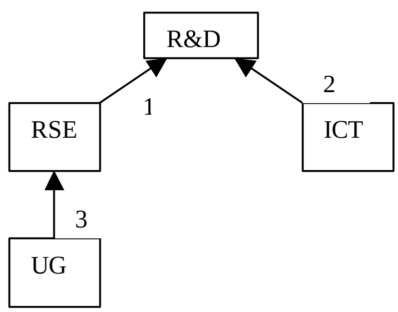

Figure-1 The Relations Between R&D, ICT, RSE And UG

Figure-1 illustrates that in order to support the creation of a given amount of knowledge (indicated by R&D) some level of ICT investment has to be made. It can also be inferred that without some level of RSE the given amount of R&D cannot be achieved. The required amount of RSE can only be obtained from the stock of UGs within the population as well. Finally, the lines connecting each factor to other indicate the relation between pairs (UG and RSE, R&D and RSE, R&D and ICT) so as to identify the magnitude of the requirement of one factor in order to achieve a given amount of the other.

The relations between these factors, which are set by lines 1, 2 and 3 in Figure-1, cannot be considered independent from each other. They are expected to reflect the capability of the country in utilising these factors.

At this point it should be noted that, the availability of the data (in terms of continuity) imposes a restriction on the attempts to perform a regression analysis based on time series data, the results of which may be utilised for making a cross-country comparison with respect to the capabilities of their national innovation systems. However, even though the familiar analysis techniques may not be sufficient for the existing data, there exists a sufficient amount of data to get inferences on performances of countries. The concern is how to obtain the information hidden in them.

As a consequence of the restrictions mentioned, the indicators are paired with respect to their corresponding years. Once the data pairs are obtained, they are plotted on a scattergram regardless of the country which they belong to and the year of observation. It should also be noted that, to be able to handle and compare different countries and various years the data were corrected to per capita (per population) and constant $ purchasing power parity (PPP) terms.

First the association between the RSE per population and per capita R&D expenditure is seeked (Refer to Figure-2).

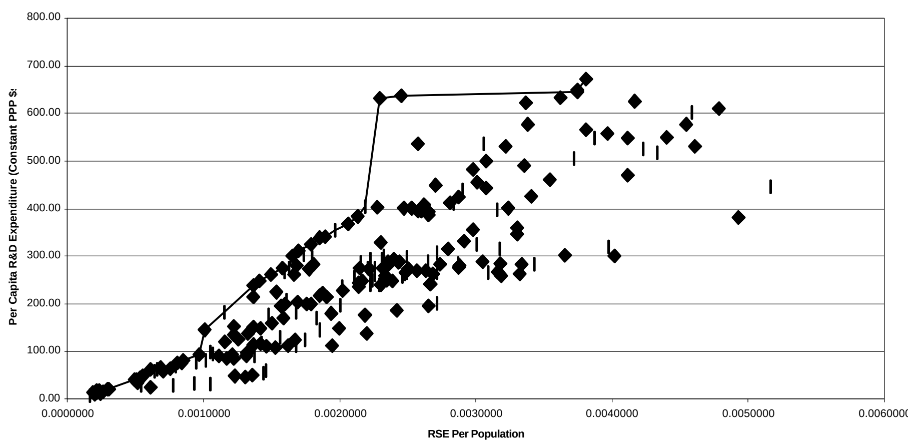

Figure-2 The Association Between RSE per population and per capita R&D Expenditure

As observed from Figure-2, there exists a positive correlation between RSE per population and per capita R&D expenditure which can be interpreted as follows: for increasing levels of R&D expenditure (indicating knowledge creation) the requirement of qualified human resources also increases. Also, the variation in the requirement of RSE per population increases as the level of per capita R&D expenditure increases. This may be because;

- The number of observations for levels of per capita R&D expenditure may be less than the number of observations for higher levels of per capita R&D expenditure.
- As the level of R&D expenditure increases, the national system of innovation may require further enhancements which possibly makes the system harder to manage.

Referring to Figure-2 again, the thin boundary enveloping all the plots can be observed. This piecewise linear line (i.e. a piecewise linear function) can be interpreted as the frontier of utilisation of RSE in R&D activities which will be referred to as *envelope function* within the following. That is to say that, for a given level of per capita R&D expenditure, there is no RSE per population figure that is smaller than the figure mapped by the envelope function. Such an argument may lead to the following interpretation: Any country is not expected to achieve a given level of R&D activity with less than the amount of RSE indicated by the envelope function; and because the plots were constructed regardless of the country and year of observation, the points on the envelope function may belong to different years of different countries. In this sense, the points on the envelope function always reflect the best case performances for varying levels of R&D activities. Such an approach allows comparing the performance of countries in the utilisation of RSE in R&D activities with the best possible case. It should be noted that such an argument is not contradicting with the *best policy approach* which was mentioned earlier. In order to illustrate these arguments Figure-3 will be utilised.

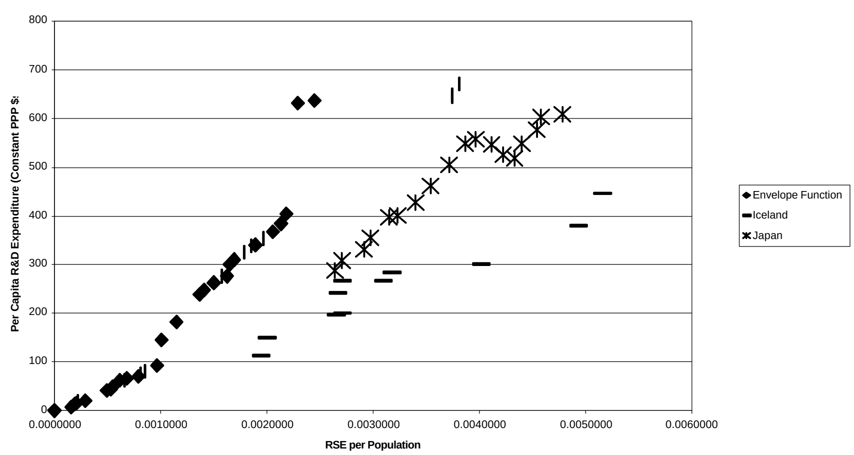

Figure-3 The Association Between RSE per population and per capita R&D Expenditure – Comparing Iceland And Japan With The Envelope Function

In Figure-3, the past performances of Japan and Iceland in utilising RSE for increasing levels of their R&D activities are observed. Referring the plots of Japan and Iceland (in Figure 3.2.2.3) as *utilisation paths* of RSE for R&D activities, one can observe the relative efficiency of each country both with respect to the envelope function (i.e. best case) and with respect to each other. Note that though Japan could have performed some PPP $ 285 (per capita) of R&D activity with 0.0016 RSE per population, it performed this amount of R&D with 0.0026 RSE per population which is higher than 0.0016 RSE per population (which has been the best possible case). The same finding can be observed all the way through the *utilisation path* of Japan. This may mean that, while increasing its R&D activity, Japan has been inefficient with respect to the utilisation of RSE in R&D activities. However, it will be, misleading at this stage, to make comments about the degree of inefficiency of that country.

Comparing the *utilisation path* of Iceland in Figure-3 with the envelope function will lead to the same findings as obtained in the case of Japan (i.e. inefficiency). However, comparing the utilisation paths of Japan and Iceland will lead to the result that Iceland has been more inefficient in utilising its RSE for its R&D activities as compared to Japan.

The reason for the difference in the efficiencies of Japan and Iceland with respect to the utilisation of RSE in R&D activities may be due to many factors (e.g. the quality of R&D projects chosen within the country, the quality of RSE with respect to their competencies in their areas of concern …etc.). Though the analysis of these factors are beyond the scope of this study, that the possible range of factors affecting the patterns of utilisation paths is directly related with the concepts involved in national innovation systems should be kept in mind.

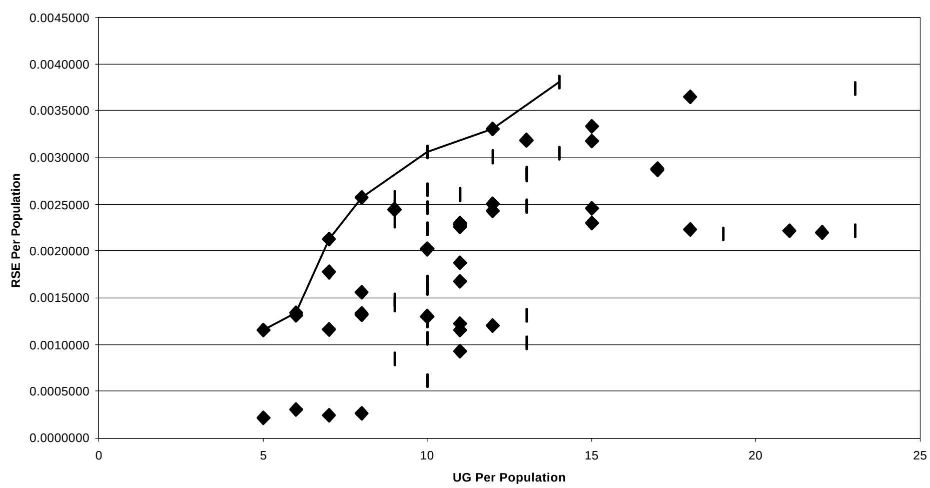

Figure-4 The Association Between RSE per population and UG per Population

With respect to Figure-4, it can be said that all the arguments put forward in Figure-3 also hold for Figure-4 which reflects the relation between RSE per population and UG per population. That is, the same arguments with respect to the efficiency comparisons (i.e. utilization paths) are also valid for them. The same is said for Figure – 5 which attempts to illustrate the relation between the per capita ICT expenditure and per capita R&D expenditure.

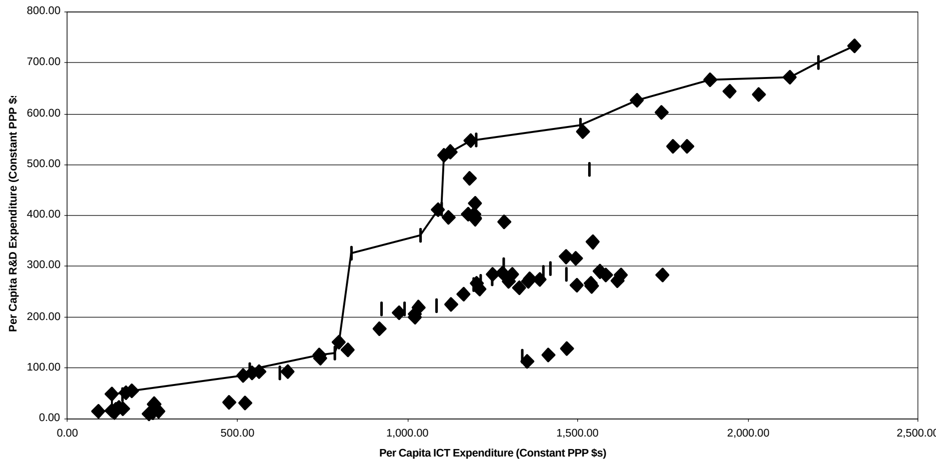

Figure-5 The Association Between per capita ICT investment and per capita R&D investment

While adapting the approach discussed in this part, it has been implicitly assumed that the size of the country (i.e. with respect to its economy, population and area) has no effect on the observed performance of the country in utilising its RSE, UG and ICT in R&D activities. However, it should be noted that the effects of the size of the country on the performance of its utilising UG, RSE and ICT in R&D activities require extensive further research.

In the arguments cited above, there exist one more issue which remains to be clarified: the state of the R&D activities (i.e. knowledge creation).

R&D

Kim (2000) states that "where demand for technology from the private sector is still dormant, … government R&D expenditure has to be made for a certain period of time, as a necessary condition for indigenous private R&D…" to take off.

Kim (2000) illustrates the relation between the development pattern of demand for technology with respect to the pattern of supply of technology for the case of Korea. It is supposed that the economy's total demand for and supply of technology is negligible until a certain time T_1 at which government starts allocating national resources to the supply of technology. Assuming that appropriate market environment is satisfied, at time $T_2 > T_1$, demand from firms is realised. Finally, at time $T^* > T_1 > T_1$, both the demand and supply reach a point where they are equal which is claimed to be the "… starting point for the economy to be self sustaining".

In investigating his arguments for the case of Korea, Kim (2000) used government R&D expenditure to measure supply of technology and private R&D expenditure to measure demand for technology. The investment level at which private R&D equals government R&D is defined to be the self-sustaining point.

Adapting Kim's (2000) approach, the relation between government and private R&D expenditure is analysed for OECD countries. The scatter plots of government and private R&D of OECD countries are formed. Three basic patterns were observed:

- There exist countries whose private R&D expenditure has been higher than their government R&D expenditure for the period analysed, which are said to be in a *self-sustaining* state. These countries are Austria, Belgium, Czech Republic, Denmark, Finland, Germany, Japan, Netherlands, Norway, Spain, Sweden, Switzerland and UK.
- Greece, Mexico, Poland and Turkey are the countries in which private R&D expenditure has remained negligible for the period analysed compared to the countries mentioned above. Also in these countries, it is observed that government R&D expenditure is stable at relatively low levels which can be interpreted as insufficient supply for stimulating firms to invest in R&D.
- In the figures for Australia, Canada, France, Iceland, Ireland and the US, the point at which the countries start to be self-sustaining can be observed.

Based on the discussions outlined above, it can be claimed that countries may be in two possible phases with respect to the levels of private and government R&D expenditures: the phase in which private R&D expenditure of the country is dormant (i.e. insufficient government R&D) and the phase in which private R&D expenditure is at a self-sustaining state. Within the following, the former phase will be referred to as 1^{st} phase and the latter as 2^{nd} phase. In order to identify in which phase a country is, it will be assumed that if government R&D expenditure of that country is higher than its private R&D expenditure the country is in 1^{st} phase and the reverse holds for the 2^{nd} phase.

3. THE MODEL

Incorporating the abstractions and generalisations mentioned above, a model is constructed with the idea that there exists a minimum required level for each of the main factors (of the KBE phenomenon) in order to achieve a given level of the other.

Let RSE be the number of researchers, scientists and engineers per population , and UG be the number of university graduates aged between 25-64 per population, and ICT be the per capita expenditure on information and communications technology, and PRIRD be per capita private expenditure on R&D, and GOVRD be per capita government expenditure on R&D. Suppose that f is a function where $f(RSE) = R\&D_{RSE}$ and $R\&D_{RSE}$ is the maximum amount of R&D that can be achieved by RSE; g is a function where $g(ICT) = R\&D_{ICT}$ and $R\&D_{ICT}$ is the maximum amount of R&D that can be achieved by ICT; and h is a function where $h(UG) = RSE$ and RSE_{UG} is the maximum amount of RSE that can be achieved by UG. Then the model in compact form can be expressed as:

Max. R&D

subject to

$PRIRD_t = m(GOVRD_t , PRIRD_{t-1})$ (a)
$h^{-1}(RSE_{UG}) < UG$ (b)
$g^{-1}(R\&D_{ICT}) < ICT$ (c)
$f^{-1}(R\&D_{RSE}) < RSE$ (d)

Constraint (a) determines the relation between R&D expenditure of government and private sectors. Constraint (b) determines the minimum required level of UG per population in order to achieve a given level of RSE per population. Constraint (c) reflects the minimum required amount of ICT expenditure per population in order to supply the corresponding amount of R&D expenditure per population. Hence, in order to achieve some level of R&D investment the constraints force the country to invest at least that amount in ICT. Constraint (d) determines the minimum required RSE per population for a given amount of R&D expenditure per population. Constraints (b), (c) and (d) are constructed with the help of *utilisation paths* methodology. I*n* addition, the model outlined above covers a period of 23 years in each of which the values of RSE, UG, ICT, PRIRD and GOVRD are determined in order to maximise the terminal year total R&D value.

The variables used in the model are as follows:

GRD_t : Amount of per capita GOVRD in year *t* (in constant 1995 PPP $’s);
PRD_t : Amount of per capita PRIRD in year *t* (in constant 1995 PPP $’s);
$GRD1_t$: The amount of GRD_t if $GRD_t > PRD_t$ (i.e. phase 1);
$GRD2_t$: The amount of GRD_t if $GRD_t < PRD_t$ (i.e. phase 2);
$PRD1_t$: The amount of PRD_t if $GRD_t > PRD_t$ (i.e. phase 1);
$PRD2_t$: The amount of PRD_t if $GRD_t < PRD_t$ (i.e. phase 2);
$PRD1A_t$: Value of $PRD1_t$ if *t* is not the period just before transition to phase 2;
$PRD1B_t$: Value of $PRD1_t$ if *t* is the period just before transition to phase 2;
y_t = 1 if $GRD_t > PRD_t$
0 otherwise ;
ICT_t : Per capita ICT expenditure in year *t* ;
RSE_t : Share of RSE in total population in year *t*;
UG_t : Share of UG in total population in year *t*;

The parameters are as follows:

$PRD1_{init}$: Amount of PRIRD in year 2000 if the country is in phase 1 in that year;
$PRD2_{init}$: Amount of PRIRD in year 2000 if the country is in phase 2 in that year;
G1 : Coefficient of contribution of GRD_t to PRD_t in phase 1;
G2 : Coefficient of contribution of GRD_t to PRD_t in phase 2;
P1 : Coefficient of contribution of PRD_{t-1} to PRD_t in phase 1;
P2 : Coefficient of contribution of PRD_{t-1} to PRD_t in phase 2;
CON1 : Constant term in the estimation of PRD_t in phase 1;
CON2 : Constant term in the estimation of PRD_t in phase 2;
M : Any number quite larger than the maximum value which GRD_t or PRD_t can assume;
B_ICT : Coefficient determining the increase in R&D when ICT is increased by 1;
B_RSE: Coefficient determining the increase in R&D when RSE is increased by 1;

B_UG : Coefficient determining the increase in RSE when UG is increased by 1;
C_ICT : Constant term in the relation between ICT and R&D;
C_RSE: Constant term in the relation between RSE and R&D;
C_UG : Constant term in the relation between UG and RSE;
POP_t : The projected population of the country in year t;
GDP_t : The projected gross domestic product of the country in year t;
GDP_{2000} : The gross domestic product of the country in year 2000;
SRD_t: Maximum allowed share of GDP_t allocated to government R&D (i.e. GRD_t);
$KGDP_t$: Annual average growth rate of GDP;

Currently the model is as follows:

Max. $GRD_{2023} + PRD_{2023}$

<u>subject to</u>

$GRD1_t > PRD1_t$	for $\forall\ t$	(1)
$PRD2_t > GRD2_t$	for $\forall\ t$	(2)
$GRD1_t \quad M * y_t$	for $\forall\ t$	(3)
$GRD2_t \quad M * (1 - y_t)$	for $\forall\ t$	(4)
$PRD1_t \quad M * y_t$	for $\forall\ t$	(5)
$PRD2_t \quad M * (1 - y_t)$	for $\forall\ t$	(6)
$GRD_t = GRD1_t + GRD2_t$	for $\forall\ t$	(7)
$PRD_t = PRD1_t + GRD2_t$	for $\forall\ t$	(8)
$PRD1_t = PRD1A_t + PRD1B_t$	for $\forall\ t$	(9)
$PRD1B_t < M * (y_t - y_{t+1})$	for $\forall\ t < 2023$	(10)
$y_t \geq y_{t+1}$	for $\forall\ t < 2023$	(11)

$PRD_t = CON1 * y_t + CON2 * (1-y_t) + G1 * GRD1_t + G2 * GRD2_t + P1 * PRD1A_{t-1} + P2 * PRD1B_{t-1} + P2 * PRD2_{t-1}$ for $t = 2002,..,2023$ (12)

$PRD_t = CON1 * y_t + CON2 * (1-y_t) + G1 * GRD1_t + G2 * GRD2_t + P1 * PRD1_{t-1} + P2 * PRD2_{t-1}$ for $t = 2001$ (13)

$PRD_t + GRD_t = B\_ICT * ICT_t + C\_ICT$	for $\forall\ t$	(14)
$PRD_t + GRD_t = B\_RSE * RSE_t + C\_RSE$	for $\forall\ t$	(15)
$RSE_t = B\_UG * UG_t + C\_UG$	for $\forall\ t$	(16)

$GRD_t = (SRD * GDP_t) / POP_t$		(17)
$GDP_{t+1} = KGDP * GDP_t$	for $\forall\ t > 2001$	(18)
$GDP_t = KGDP * GDP_{2000}$	for $\forall\ t = 2001$	(19)

and
$GRD_t, PRD_t, GRD1_t, GRD2_t, PRD1_t, PRD2_t, PRD1A_t,$
$PRD1B_t, ICT_t, RSE_t, UG_t \quad 0$ and $y_t = 0/1$ (20)

The model maximises the terminal year (year 2023) total R&D expenditure for Turkey given annual government R&D expenditures throughout the planning horizon and determines the required levels of human resources and information and communications technology (ICT) investments for the given levels of government R&D expenditures.

4. APPLICATION OF THE FRAMEWORK: TURKEY

Setting The Scheme

In applying the framework and the model to the case of Turkey an investment scheme for government funded research and development is set by us. The reason for doing this is that Turkey is a country whose R&D expenditures are the least among the OECD countries and have been stable at the level of 20.61 PPP $ per capita until 1997. Since in the model private R&D expenditures at time t are assumed to be a function of government R&D expenditures in t and private R&D expenditures in t-1, when government R&D expenditures are held constant at their 1997 level or slightly increased, the model projects increasing levels of total R&D expenditures. This imposes a requirement for the level of ICT expenditures and number of RSE and UG to increase. The natural pace of increase of these factors in Turkey results in an infeasible solution.

In the developed scheme, the annual government R&D expenditure is set as a constant percentage of annual GDP of Turkey. In obtaining a meaningful scheme, the government investment levels of OECD countries as a percentage of their GDPs were traced for the available years. It was observed that 0.6 % has been the highest share of GDP devoted to R&D by the OECD governments since 1981. Assuming that the GDP of Turkey will increase 4 % annually and the percentage of GDP devoted to R&D will be 0.6 %, the pattern that government R&D and private R&D expenditure will follow is illustrated in Figure-6, and used as such in the model.

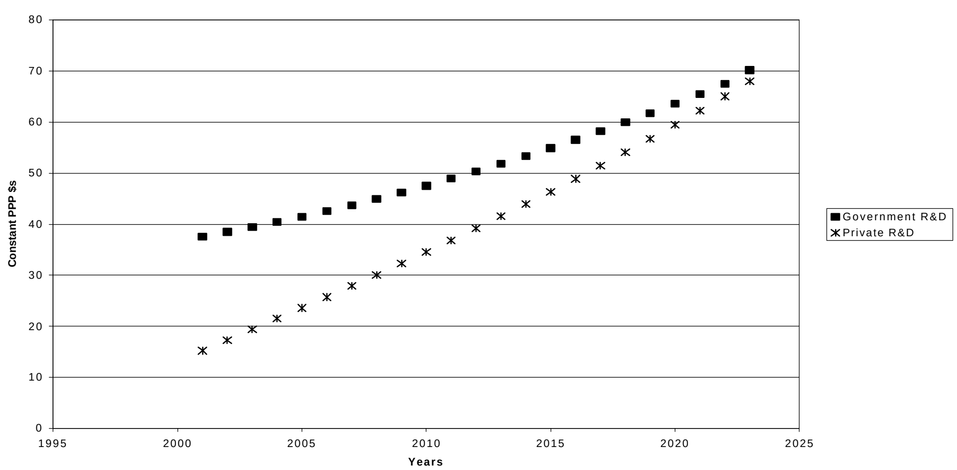

Figure-6 The Projected Government And Private Per Capita R&D Expenditures With 4% Annual GDP Growth and 0.6 % of GDP Allocated To Government R&D

It should also be noted that with such a scheme, Turkey is projected to achieve PPP $ 138.2 worth of total per capita R&D activity while remaining in phase 1. Then the requirements imposed by that scheme are analysed considering various scenarios in which Turkey exhibits an efficient utilisation of RSE, UG and ICT, as well as the case in which factors are assumed to be used inefficiently (derived by using the envelope functions explained above).

Because determining the efficient and inefficient requirement patterns of RSE, UG and ICT are topics which require further research, past performance of OECD countries, whose development patterns with respect to R&D expenditure have been similar to Turkey's projected R&D expenditure pattern were analysed. The efficient and inefficient countries were identified with respect to their performances in utilising each of the RSE, UG and ICT. These countries are identified as follows:

- Ireland is supposed to reflect the efficient utilisation of RSE in performing R&D activities whereas Poland and Iceland are supposed to reflect the inefficient utilisation.
- Ireland is supposed to reflect the efficient utilisation of ICT in performing R&D activities whereas New Zealand is supposed to reflect the inefficient utilisation.
- Ireland is supposed to reflect the efficient utilisation of UG in deriving RSE whereas Spain is supposed to reflect the inefficient utilisation.

In order to use the findings summarised above in the model, the utilisation paths should be defined mathematically. Note that, the slope of the function (i.e. utilisation path) defining the additional requirement of the independent variable (e.g. ICT) in order to increase the dependent variable by one unit (e.g. R&D) can be used for defining the related utilisation paths. Simple linear regression is utilised for estimating these slopes using the data of the countries noted above.

Table-1 The Estimated Slopes For Utilisation Paths

	R&D vs. RSE	R&D vs. ICT	RSE vs. UG
Efficient Case	109,794.40	0.280505	0.000145
Inefficient Case	50,849.12 for 0 < R&D < 100 95,657.35 for 100 < R&D < 200	0.131871	0.000107

In constructing the constraints (14), (15) and (16), the utilisation paths will be assumed to start from the most recent RSE, UG and ICT values of Turkey while having the slopes illustrated in Table-1. The equations of utilisation paths for corresponding cases are given in Table-2.

Table-2 The Estimated Equations For Utilisation Paths

	Efficient Case	Inefficient Case
R&D vs. RSE	R&D = (109,794.40) * RSE - 12.5168	(5.23081 ; 0) ; (100 ; 0.001864) ; (200 ; 0.002909)
R&D vs. ICT	R&D = (0.280505) * ICT - 25.0391	R&D = (0.131871) * ICT - 0.84996
RSE vs. UG	RSE = (0.000145) * UG - 0.00057	RSE = (0.000107) * UG - 0.00034

It should be mentioned that, while comparing the efficient and inefficient cases, the only monetary costs (due to being inefficient) which can be identified are the costs associated with ICT expenditure.

With respect to the utilisation of human resources, it can be claimed that education constitutes the most important issue in the quality of human resources (which, in turn, is supposed to affect the utilisation of UG and RSE in knowledge-based activities). So, the level of education expenditures can be said to reflect the efficiency of utilising human resources in performing R&D activities. Considering this argument, it is proposed that the monetary costs of realising an inefficient utilisation of UGs in deriving RSEs is the additional expenditure made per university student. Because these costs cannot be determined by the model, they are calculated exogenously.

In order to handle this situation, the model assumes inefficient utilisations of RSE in performing R&D. Based on the resulting RSE's the inefficient utilisation of UG in deriving RSE will be compared with the efficient utilisation of UG. This difference can be interpreted as the increased amount of educational expenditure per university student starting from 2001. However, because the effects of well-trained students who start education in 2001 can be realised only after they are introduced to the market the system will be assumed to be efficient after 2006. So, the model is adjusted in such a way that until 2006, the UG will be utilised inefficiently and after 2006 they will be utilised efficiently. This case is referred to as *educational enhancement case*.

Analysing The Results

In order to compare the levels of projected requirements of RSE, UG and ICT expenditure of efficient and inefficient cases, Table-3 will be utilised.

Table-3 The Results of Model Runs For The Efficient And Inefficient Cases

	R&D Exp. (Million Constant PPP $)	NUMBER OF RSE		NUMBER OF UG		ICT EXPENDITURE (Constant PPP $)	
		Efficient Case	Inefficient Case	Efficient Case	Inefficient Case	Efficient Case	Inefficient Case
2001	3,499	39,434	61,636	5,323,871	7,899,317	18,388,595,225	26,957,886,450
2002	3,753	41,844	66,869	5,531,186	8,389,616	19,384,714,950	28,893,753,500
2003	4,016	44,377	71,960	5,743,125	8,895,972	20,412,807,724	30,897,082,696
2004	4,289	46,957	77,223	5,961,036	9,418,395	21,471,365,160	32,968,054,644
2005	4,570	49,649	82,655	6,183,311	9,957,203	22,560,975,075	35,108,426,950
2006	4,860	52,361	88,287	6,408,471	10,510,519	23,677,267,014	37,314,690,420
2007	5,160	55,173	94,069	6,638,821	11,080,788	24,824,378,172	39,592,206,984
2008	5,469	58,095	100,081	6,873,716	11,669,280	26,005,022,812	41,945,118,264
2009	5,789	61,131	106,261	7,115,269	12,276,402	27,221,858,855	44,377,702,505
2010	6,120	64,279	112,675	7,362,296	12,902,847	28,475,151,060	46,891,554,820
2011	6,462	67,451	119,377	7,614,050	13,548,231	29,763,301,796	49,485,899,928
2012	6,815	70,751	126,195	7,873,266	14,215,746	31,095,058,599	52,172,989,693
2013	7,182	74,182	133,359	8,140,831	14,907,287	32,472,213,634	54,956,729,846
2014	7,561	77,747	140,722	8,416,890	15,622,482	33,896,603,542	57,840,813,614
2015	7,955	81,369	147,422	8,701,585	16,276,103	35,370,109,443	60,829,491,254
2016	8,363	85,206	152,403	8,995,059	16,760,418	36,894,736,269	63,926,800,519
2017	8,785	89,184	157,455	9,298,256	17,259,948	38,472,536,608	67,137,352,076
2018	9,224	93,224	162,657	9,611,343	17,773,338	40,105,691,628	70,465,625,012
2019	9,678	97,490	168,094	9,933,670	18,303,254	41,796,433,328	73,916,281,800
2020	10,149	101,820	173,606	10,267,030	18,849,156	43,547,127,050	77,494,502,313
2021	10,638	106,383	179,359	10,611,614	19,412,972	45,360,108,841	81,205,253,925
2022	11,145	111,097	185,359	10,967,611	19,994,172	47,237,933,781	85,053,948,431
2023	11,620	115,387	190,321	11,266,170	20,458,409	48,933,914,547	88,661,376,725

While comparing the results with respect to the differences between efficient and inefficient cases, it should be kept in mind that, in each year, the efficient and inefficient case values of each factor (e.g. RSE, UG, ICT) correspond to the same R&D expenditure. That is, PPP $ 6,120 millions worth of R&D expenditure can be conducted with 64,279 RSE and 112,675 RSE depending on the efficient or inefficient utilisation of the RSE resources in performing R&D activities.

In order to compare the significant differences between the requirements of both cases, the results which were tabulated in Table-3 are represented as bar charts in Figures-7, 8 and 9.

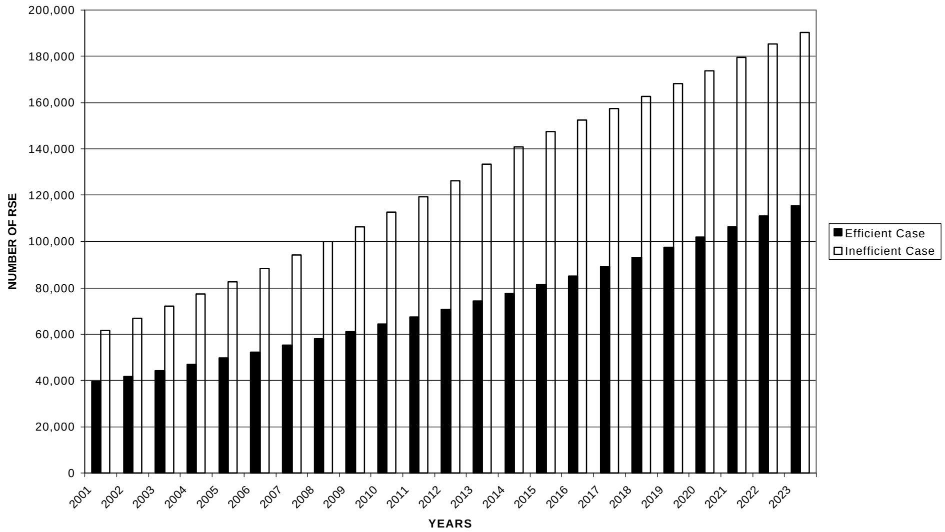

Figure-7 The Comparison of Efficient and Inefficient Cases With Respect to RSE Requirement

As observed from Figure-7, the additional requirement of RSE due to inefficiency assumes a range of values between 22,202 (in year 2001) and 74,934 (in year 2023). Also, the calculations with the figures obtained from Table-3 suggest that due to being inefficient in utilising RSE resources of the country in performing R&D activities, Turkey should create, on the average, 5,000 RSE per year (assuming that the rate of death of RSE is negligible compared to its rate of birth). This figure appears to be (on the average) 3,000 RSE for the efficient case.

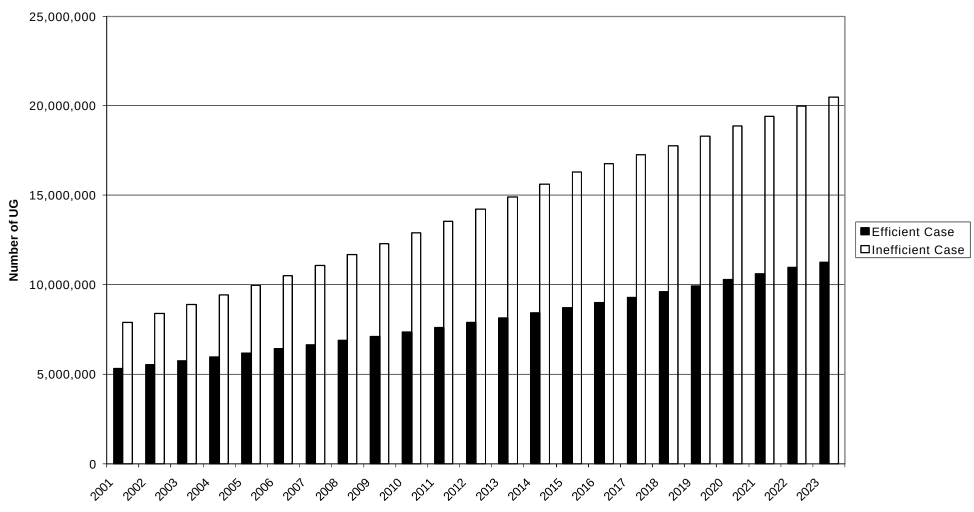

Figure-8 The Comparison of Efficient and Inefficient Cases With Respect to UG Requirement

The additional UG requirement due to being inefficient rises up to 9,192,239 in year 2023 from 2,575,446 in year 2001. Also, as can be calculated from Table-3 if Turkey were efficient, on the average, it would require 250,000 graduates (also post graduates) each year from universities in order to support the annual requirement of RSE due to the annual increase in R&D activities whereas in the inefficient case this figure rises up to some 500,000 (on the average) which will possibly require extra fixed costs (building, equipment …etc.) beside the variable costs (instructor, overhead …etc.).

In fact the inefficiency of the country with respect to utilising UG may be due to several reasons. One of the reasons may be the lack of sufficient level of training such that 1 RSE can only be obtained from 2 UGs though the same level of RSE can be obtained from only 1 sufficiently trained UG. One other reason may be that the economic conditions may not be appropriate to invest in R&D activities and hence existing UG can hardly be converted to RSE.

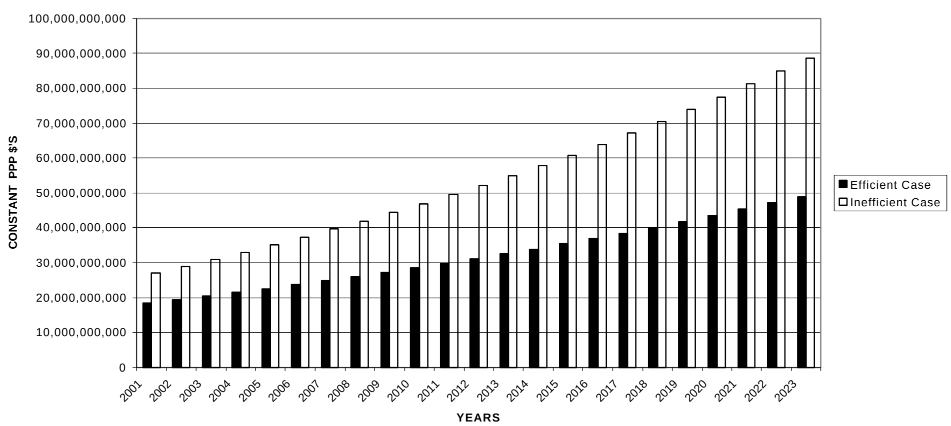

Figure-9 The Comparison of Efficient and Inefficient Cases With Respect to The Requirement of ICT Expenditure

It can be seen in Figure-9 and calculated from Table-3 that through the year 2023 in the efficient case, the country gradually doubles the ICT expenditure to support the same level of R&D expenditure when compared with the efficient case. The total amount of additional spending (from 2001 to 2023) sums up to PPP $ 511 billions due to being inefficient in utilising information and communications infrastructure in R&D activities. This amount is more than the current GDP of Turkey even though the calculation does not represent the net present value of annual expenditures. Note that PPP $ 511 billions means, on the average, PPP $ 22 billions of yearly savings, part of which can be allocated to R&D. However, allocating some amount of Savings from ICT expenditures will lead to increases in R&D which in turn will require more ICT expenditures. That is, improving the system will possibly require investing some amount to various aspects of the system leaving only some portion of the savings to allocate to R&D.

After illustrating the individual direct effects of improving the relation between per capita ICT expenditure and per capita R&D expenditure, the individual effect of improving RSE per population and UG per population is illustrated considering the educational enhancement case explained above.

The projected UG requirements for the educational enhancement case that correspond to number of RSE's in the inefficient case are illustrated in Table-4.

Table-4 The UG Requirements For Inefficient Case And Educational Enhancement Case

	Required Number of UG	
	Inefficient Case	**Educational Enhancement Case**
2001	7,899,317	7,899,317
2002	8,389,616	8,389,616
2003	8,895,972	8,895,972
2004	9,418,395	9,418,395
2005	9,957,203	9,957,203
2006	10,510,519	10,510,519
2007	11,080,788	10,966,263
2008	11,669,280	11,433,839
2009	12,276,402	11,914,333
2010	12,902,847	12,409,194
2011	13,548,231	12,915,925
2012	14,215,746	13,439,690
2013	14,907,287	13,980,006
2014	15,622,482	14,538,689
2015	16,276,103	15,052,431
2016	16,760,418	15,440,275
2017	17,259,948	15,839,248
2018	17,773,338	16,249,539
2019	18,303,254	16,671,340
2020	18,849,156	17,104,841
2021	19,412,972	17,551,066
2022	19,994,172	18,011,070
2023	20,458,409	18,353,361

The results of inefficient case and educational enhancement case with respect to UG requirements are illustrated in Figure-10.

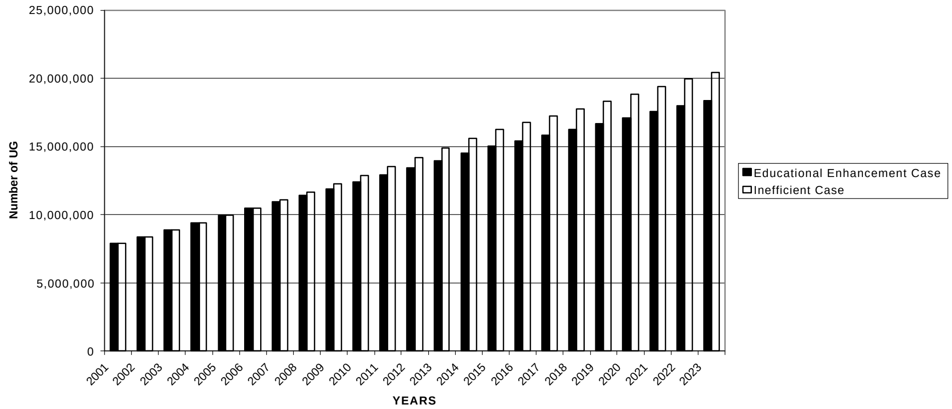

Figure-10 The Comparison of Inefficient And Educational Enhancement Cases With Respect to UG Requirement

As can be observed from Figure-10, the UG requirement starts to differ for the two cases in year 2007. The additional UG requirement (due to not investing in education) appears to be 114,525 in 2007 (i.e. calculated using Table-4) and rises up to 2,105,048 in 2023. Also, in the educational enhancement case, starting from 2007, the additional required UG drops from some 460,000 to 342,000 in 2023. However, in the inefficient case, this requirement is sustained around the value of 500,000. This may be interpreted as follows: investing in education increases the quality of human resources in such a way that supporting increasing levels of R&D requires less amount of UG compared to the case of poorly qualified human resources.

In order to estimate the levels of educational expenditures per university student associated with the inefficient case, and educational enhancement case Table-5 will be used.

In Table-5 it can be observed that the higher the per capita R&D expenditure, the higher the expenditure per university student. So, it can be inferred from Table-5 that attaining high levels of R&D activity requires considerable investments in education which means qualified human resources. In order to make a rough calculation to get inference about the cost of the trade-off between improving the efficiency of the system and leaving it on its own, the expenditure per university student of a country which is around the level of Turkey’s projected per capita R&D expenditure will be considered as the cost per student to have an efficient system with respect to the relation between UG and RSE. Spain seems to be appropriate for such an assumption, which on the average spend some PPP $ 5300 per university student. Mexico which invests PPP $ 4,600 can also be assumed to represent the current situation of Turkey.

Table-5 Expenditures Per University Student For Various OECD Countries (Constant PPP $s)

	Expenditure Per University Student (Constant PPP $s)			Per Capita R&D Expenditure (Constant PPP $s)		
COUNTRY	**1993**	**1994**	**1995**	**1993**	**1994**	**1995**
Iceland	6,252	..	..	265.73	284.59	301.12
US	..	..	20,946	644.64	637.04	671.43
Switzerland	..	18,913	18,998	..	..	..
Canada	11,688	12,328	13,311	269.85	283.97	281.54
Australia	11,529	12,199	12,866	..	259.86	..
Japan	8,078	9,500	9,747	525.26	517.68	549.24
Netherlands	9,082	8,824	9,550	255.96	268.82	275.65
Germany	..	9,050	9,399	..	..	411.33
Czech R.	..	7,772	9,151	..	..	119.41
N. Zealand	7,654	8,157	8,340	123.90	..	124.74
Austria	8,951	8,616	7,954	206.90	216.21	216.04
Finland	..	..	7,733	325.15	..	359.98
Hungary	10,346	8,459	6,344	..	..	..
Korea	..	6,300	6,271	..	..	..
Spain	..	..	5,326	90.23	84.89	92.77
Italy	..	5,020	5,038	..	..	..
Mexico	6,150	7,098	4,698	8.43	12.94	12.86
Greece	..	3,118	3,334	28.78	..	32.14

In order to calculate the costs of being inefficient with respect to utilising UG in deriving RSE, it will be assumed that each additional UG (i.e. $\Delta UG = \Delta UG_t - \Delta UG_{t-1}$) added to the stock of succeeding year will be the product of an educational system in which PPP $ 4,600 is spent per university student. This figure is realised as PPP $ 5,300 additional UG in the educational enhancement case, however, it will be assumed for this case that this amount will have been spent for the ΔUG who started education in 2001 and introduced to the market in year 2006.

The cumulative number of ΔUG from 2007 to 2023 appears to be 7,842,842 for the educational enhancement case and 9,947,890 for the inefficient case. Assuming that these people have been educated for 5 years, the associated costs for each case are PPP $ 229 billions for the inefficient case and PPP $ 208 billions for the inefficient case. The difference appears to be PPP $ 21 billions for the total of 23 years which results in PPP $ 912 millions per annum which can also be allocated to R&D activities or utilised for the betterment of educational system.

5. CONCLUSION

Though not proved appropriately, due to the insufficiency of the data, two basic characteristics of the knowledge-based economy phenomenon have been illustrated in this study. These characteristics are *simultaneity* and *differences in efficiency*. Being a knowledge-based economy imposes on a country the requirement to perform well *simultaneously* at a broad set of aspects, noting that the relations between these aspects in terms of efficiency of utilisation of them may differ from one innovation system to the other.

Also, it is implicitly put forward that, for the countries which are at the very initial step of being knowledge-based, government expenditure in R&D forms the vital element in stimulating the entities within the economy for taking part in the production of knowledge. It should be noted that, knowledge creation is a process which goes hand-in-hand with knowledge-diffusion. Hence, in this sense, stimulating the creation also means stimulating the diffusion. Both these points are illustrated in applying the model for the case of Turkey. It is observed, for projected R&D levels of the country, that the required ICT investment rose in relation to the level of R&D investment.

Envelope functions, constituting a reference point for comparing the countries with respect to the capabilities of their innovation systems allowed the researcher to distinguish various OECD countries with respect to their utilising RSE, UG and ICT in performing knowledge creation activities. They were assumed, in fact, to reflect the *best policy* approach which the researchers prefer to adapt when considering national innovation systems. However, it was noted that, in analysing the efficiencies of countries with respect to the envelope functions in utilising RSE, UG and ICT, slight deviations of utilisation paths from the envelope function due to the differences in the populations, geographical dispersions and size of the economies should be taken into consideration which may mislead the researcher. These effects on the utilisation paths should also be considered while comparing countries with each other with respect to the efficiencies in utilising RSE, UG and ICT.

Related with the envelope functions, the utilisation paths remain as the issue which needs extensive research. Basically, the factors which affect the behaviour of the functions for different levels of R&D and RSE, R&D and ICT, RSE and UG should be investigated by the researcher who aims to test different development scenarios in the transition process to a knowledge-based economy. Because the aim of the current study is mainly to introduce a framework which is to be used in the assessment of various strategies in transforming to a knowledge-based economy, Section 4 should be treated as a first application of the framework proposed. However, with respect to the application efforts there exist much to be studied. One important area closely related with this issue is analysing the trade-offs between enhancing the system of innovation (i.e. the shape of the utilisation paths) or investing in R&D.

The initial results indicate that: (i) government R&D in Turkey should increase to considerable levels in order to trigger the transition to a knowledge-based economy and (ii) transformation towards a knowledge-based economy with an inefficient innovation system may require considerable amounts of additional resources. It is illustrated for the case of Turkey that any improvement in the innovation system (moving towards the enveloping frontier) may lead to considerable savings in the required human resources and ICT investments, given the same levels of R&D investment.

The costs of transforming the country to an efficient state from an inefficient state with respect to the utilisation of ICT infrastructure and human resources are also investigated. It is found that due to inefficient utilization of ICT infrastructure in the creation of knowledge (i.e. R&D activities) Turkey has to pay PPP (purchasing power parity) $ 20 billions every year for 23 years on the average over the period analysed. On the other hand, with respect to the utilization of human resources, it is assumed that the investment in university level education has been the determining factor in the utilization of UGs in knowledge creation activities, and the results indicate that Turkey could have yearly savings of PPP $ 900 millions if she diverts her resources to obtain qualified UGs. In addition to this, Turkey might have the capability of conducting the same level of R&D activities with less UG if they are sufficiently well trained.

The results of the analysis also lead to the conclusion that the possible savings arising from efficient utilisation of human resources and ICT infrastructure can be used to increase investments in R&D. This may lead to the policy implication that efficient utilisation of ICT infrastructure should be encouraged. Further policy implications may be derived considering the fact that investing additional amounts in R&D would lead to increased ICT expenditure, noting the fact that possible savings arising from efficient utilization of ICT can only be partly allocated to R&D, the remaining of which should be allocated to ICT again and to other aspects of the innovation system (such as betterment of educational system in order to support the increased level of knowledge creation activities). This is an outcome of the assumption of simultaneity reinforcing the point that if Turkey is to increase her knowledge-based activities, she should perform well in all of a broad set of areas rather than in only a part of these. So further research is required in order to decide on which resources the estimated savings should be allocated to. Also, the obstacles in projecting the utilisation patterns of UG, RSE and ICT are topics which require further investigation.

Nevertheless, it can be concluded from the study that, Turkey, if she intends to transform to a knowledge-based economy, should allocate much higher amounts of her resources to R&D activities compared to its current level. While doing so, she should prefer to invest in enhancing her innovation system rather than wasting money and time to support an inefficient system.

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