Depletion of Non-renewable Energy Sources and Environmental Taxation

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The need to limit consumption of fossil fuels is determined by evaluating three factors in the global economy: population size, fossil fuel stocks and pollution emitted from fossil fuels. A corrective tax is seen as a possible solution for decision makers. Optimal control theory is used to analyze a dynamic model that aims to correct for the exhaustion of non-renewable energy sources combined with stock externality. The time horizon used is divided in two periods: one with extraction of fossil fuels and one when the economy has switched to an alternative technology. The thesis describes possible ways to influence the consumption of fossil fuels and decrease pollution at the same time. An optimal corrective tax is estimated. The model suggests that the optimal tax should be approximately 28 % of the optimal price per unit of fossil fuel in the first period. It decreases slowly over time to about 20 % after 28 years. At that time the economy switches to an alternative technology. Without any corrective tax, the model suggests the economy will take 205 years before switching to a backstop technology.

The presented work describes the need for imposing limitations on the production/ consumption of fossil fuels because of increased dependence on non-renewable energy sources that are scarce but on the other hand create pollution harmful for the environment, the climate, the society.

The first major section in the paper is called The *Nature of the Problem.* It gives an overview of three major topics related to the analysis of the depletion of natural resources, pollution and carbon taxation. These are the growing population, natural resources dependence and their availability and the pollution related to the extensive use. The conclusions drawn are given in the next few paragraphs.

The population has been growing in the poorer parts in the world. This is a trend that will continue in the future. The population has been able to feed itself due to the migration to unexploited territories, transformation of large areas into agricultural land and due to the advancement in the technologies. However, the growing population has decreased, in large, parts of the forest area in the world, has increased the environmental pollution and has led to loss of biodiversity.

When the world population stabilizes it will be mainly because of the offset between the decrease in the population in the wealthier countries and the addition to more people in the poorer regions. Because of the economic conditions in these regions the energy needs of these people are expected to be satisfied primarily from the least expensive energy sources such as coal. The availability of non-renewable energy sources (oil and natural gas) is another reason for the extensive use of fossil fuels such as coal.

With that said if the governments do not take any additional steps to the transition from fossil fuel dependence to other types of fuels and energy sources, the pollution rates will continue to grow. By taking a simple example shown on the figure below, the expectations of the market players could be observed.

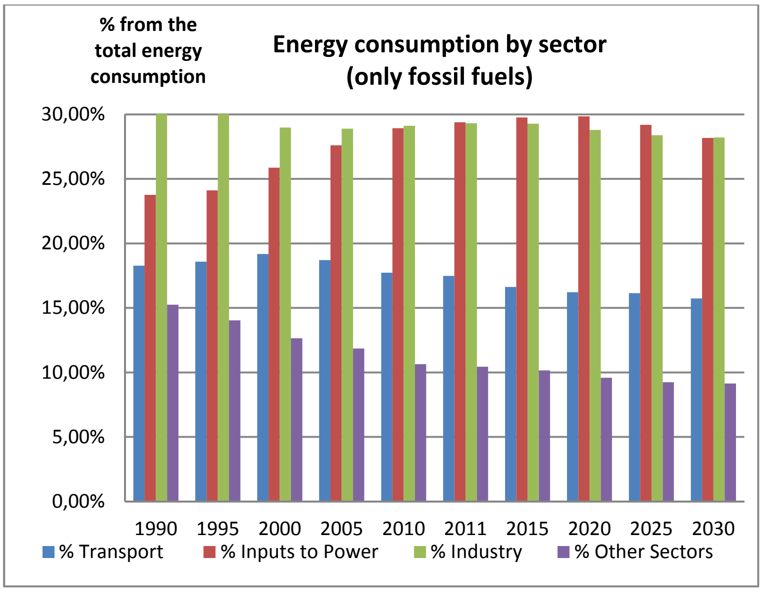

Figure 1 Energy consumption by sector (only fossil fuels) (BP Energy Outlook 2030, 2013)

The energy consumption of the fossil fuels by the industry does not include transition to cleaner fuel types. That requires the intervention of the governments and international cooperation.

The second part of the thesis includes analysis of a taxation scheme that a government could impose in order to correct for the scarcity of the fossil fuels and the pollution.

Both the scarcity and the air pollution determine the case as one that creates negative externalities. Generally speaking, they could be corrected by a tax or a quota. In this paper the focus is on taxes. As pollutants are divided in two main groups depending on the damage they do, the externalities are divided into two groups as well. The flow pollutants such as acid rain, smog, noise, etc. do their harm quickly and therefore corrective taxes for flow externalities have effect immediately. The static analysis and an example provided in the section *Environmental Taxation: Origin, Theory and Static Analysis* are relevant to the flow externalities. The stock externalities, on the other hand, have a damaging effect for longer period. Accumulation of carbon dioxide and the global warming are examples of such kind.

The pollution done by the good consumed/ produced is not only related to the good but it is also associated with a certain decay function that changes with time. The use of dynamic optimization problem is required and the static analysis is no longer valid. The analysis and the solution provided are based on optimal control theory.

The model presented is simplified version of a model used in *Optimal Environmental Taxes: Effects of Pollution Decay and Consumer Awareness* by Sandal and Steinshamn (2008). The objective function in the model is to maximize accumulated welfare W based on the consumption of non-renewable energy sources/ extraction of fossil fuels that is also doing harm such as pollution. In addition, it is divided into two periods. The first one is from zero to sometime T. The second one is from T to infinity. T is the time when the fossil fuels are either completely depleted or the amount left is so small that it is more beneficial to switch to alternative technology such as the backstop. This model differs from the original one by the exclusion of the consumers' awareness from the utility function from the consumption of fossil fuels. That makes the utility dependent only on one variable instead of two. The individuals' happiness is measured only by the consumption of the good without the consumers being conscious about the harm done to the surrounding environment. However, the inclusion of the disutility function still reflects the damage coming from the extraction (consumption) of fossil fuels. To illustrate, a driver that is not conscious about the pollution emitted from his/ her car. The welfare is still decreased by the damage *D* because the car does harm with or without consumer's awareness.

Tested with present data the model gives the following results:

0% discounting		
x(0)	21.90	
x(T)	19.92	
a(T)	902.05	
T	28.01	
τ(a0)	0.72	Decrease in tax
τ(aT)	0.56	23%
U(x(a0))	147.81	
U(x(aT))	147.96	

Table 1 Key results

Figure 2 presents the pollution development when the taxation scheme is imposed. The tax is applied for up to 28 years when the pollution reaches 902.05 Gt GHG. This result is compared with a case when there is not any imposition of taxation scheme (figure 3). As it could be observed the pollution gets 46.9% higher before switching to an alternative technology at T=205 years.

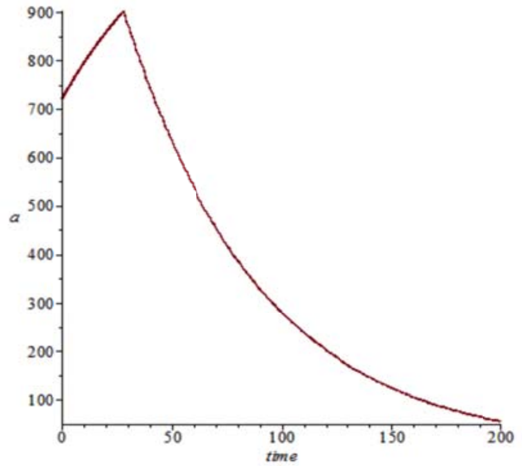

Figure 2 Plot of the aggregate pollution moving in time

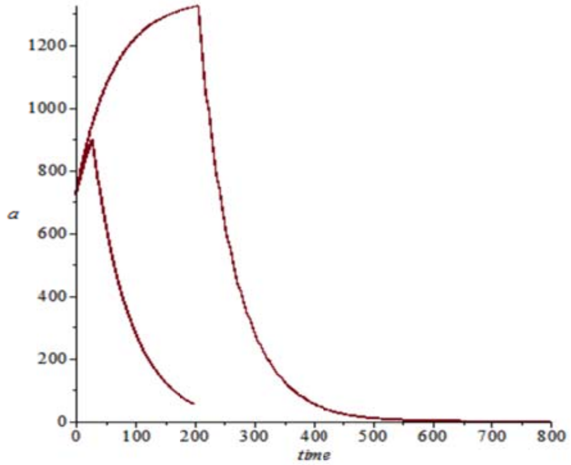

Figure 3 Plot of the aggregate pollution moving in time with/ without tax

Figure 4 presents how the tax changes over time. It is decreasing with time. By the end of the time period, when T is 28, the tax should be decreased by approximately 23%. As expected the utility increases by 0.1% since the tax is correcting for the damage done by the consumption of fossil fuels.

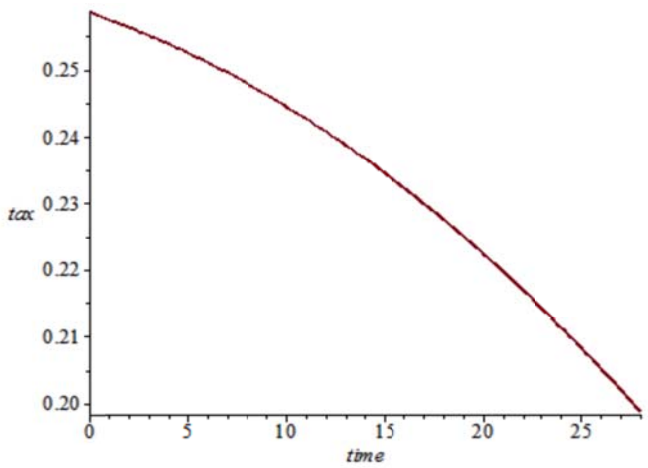

Figure 4 The path of the optimal tax over time

The decreasing tax is consistent with the findings in Sandal and Steinshamn (2008), where it is concluded that depending on the shape of the decay function the optimal tax path can be decreasing or increasing.