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Technological Change and Environmental Sustainability: Limits of Techno-Optimism

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Technological change is often considered to be a means of achieving sustainable development, since it may increase eco-efficiency and substitute natural capital with man-made capital. However there are several hinders of introducing such innovations, furthermore the more efficient use of natural resources does not necessarily result in their decreased consumption at the macro level.

Present paper analyses the relation between technological change and environmental sustainability. It focuses on three main issues: first, eco-efficiency and substitution, second, uncertainty and reflexivity and eventually the rebound effect. In all the three fields we identify mechanisms that question the ability of technological change to induce a shift towards sustainability. In the existing structure – but not necessarily – technological change seems to be rather part of the problem than the solution in connection with sustainability.

Keywords: *technological change, sustainability, evolutionary economics, uncertainty, rebound effect*

1. Introduction

Technological change has been a core research topic in economics for decades now, however its exact relationship with natural environment and sustainability is a relatively young (and by no means central) issue. At the same time, the two major schools that examine the economy-environment relation (environmental economics and ecological economics), have accumulated abundant theoretical and practical knowledge in this field.

Beside scientific publications the issue is obviously present at political and public discussions as well. The political position concerning sustainability treats technological change unambiguously as part of the “solution”. More efficient use of natural resources or the reduction of the amount of waste appears in several documents as principal ways of the shift towards sustainability (Bruntland 1987, Stern 2006).

In scientific debates a wide range of approaches are articulated. At one end stands a view that considers technological change as the main opportunity for the shift towards sustainability. At the opposite end stands a viewpoint that regards it as the main cause of problems. In economics the “techno-optimist” approach is rather expressed by environmental economics, while “precaution” is propagated by ecological economics. It is important to declare that in certain aspects the border between the two schools is quite blurred. But in connection with the role they assign to technological change with respect to sustainability their approaches and conclusions are sharply distinct (Málovics–Bajmócy 2009).

In present paper we analyze the relation between technological change and environmental sustainability along three topics. In the first chapter we are dealing with the subject of eco-efficiency and substitution. The second chapter focuses on uncertainty and reflexivity, while in the third chapter we examine the rebound-effect and one of its special forms, namely the Jevons-paradox. At the end we draw our conclusion with respect to the relation of technological change and sustainability.

2. Eco-efficiency and substitution

The standard view of economics normally focuses on two basic aspects of technological change: the *increasing productivity* (change in the shape of the production function) and the *new ways of substitution* among factors of production (Mátyás 2003, Samuelson–Nordhaus 2000, Wentzel 2006). These characteristics of technological change provide possibilities in economizing with resources (also with natural resources).

The more efficient use of the factors of production (economizing) is a basic interest of enterprises, at least in case when they purchase them in the market[1] Technological innovations that enable economizing are stimulated by market forces. By increasing the productivity (eco-efficiency) of natural resources, the innovator will be able to reach a lower cost per piece compared to their competitors or will be able to provide more favourable solutions to the consumers (e.g. the significant reduction in the specific energy-consumption of lighting bulbs or the fall in the per kilometre fuel consumption of vehicles). But even in case of the significant improvement in eco-efficiency, the substitution of a given resource may become inevitable sooner or later.

One of the most heated dispute in connection with the role of technological change focuses right on the relation of natural and artificial (man-made) resources. If these types of resources were *substitutable*, than the concept of weak sustainability[2] would be acceptable. In other words it would be enough to sustain the sum of the value of the two types of capital, to create artificial capital in the value of the terminated natural capital (Harte 1995, Gutés 1996, Kerekes 2006).

[1] In present paper we can not deal with the pricing problem of natural resources in detail. However we must note that market prices do not necessarily indicate the scarcity of natural resources, or pricing may even be impossible (Gowdy 1997).

[2] According to the concept of weak sustainability natural and man-made capital are basically substitutable. In order to fulfil the criterion of sustainability the sum of the values of the two capital-types must remain constant. In other words, when the value of the natural capital decreases, it is enough to create man-made capital with the same value.

This substitution is direct if a new (more precise) device enables us to decrease the amount of waste (pollution), to utilize formerly un-utilizable resources or to recycle more efficiently (Solow 1997, Stiglitz 1997). A more important form is however the indirect substitution, when products that formerly were made from non-renewable resources are now produced from renewables with the help of processes with great capital-intensity (Solow 1997).

But in case the natural capital can not be fully substituted, it constitutes an absolute external sustainability barrier, and a minimal level must be inevitably saved. According to our present knowledge nature provides such ecosystem services[3] to the economy that practically can be substituted neither by each-other, nor by man-made technology (UNDP et al 2000, Gustaffson 1998, Daily 1997, Gonczlik 2004)[4].

According to the standard economic arguments (on which environmentally economics builds to a great extent) technological change that enables substitution is basically generated by market mechanisms (the changes in the relative prices). The effects of relative prices on the direction and speed of technological change is analyzed in detail by the induced innovation theories (Ruttan 1997). Fundamentally they reach back to the hypothesis of Sir John Hicks put forth in 1932, in which he argued that "a change in the relative prices of factors of production is itself a spur to innovation, and to inventions of a particular kind – directed at economizing the use of a factor which has become relatively expensive" (Jaffe et al 2003, p. 470.).

Therefore market mechanisms, by signalling the scarcity of given resources, provide an incentive to economic actors to use other (potentially yet unknown) resources. This process and the ability to increase eco-efficiency lead to sustainable growth.

However *ecological economics* is rather sceptic about the abovementioned interpretation of technological change. On the one hand it criticizes induced innovation theories on the basis of the achievements of evolutionary economics, on the other hand it questions the presumptions of the weak sustainability concept.

Two main set of critical arguments towards induced innovation theories can be outlined. The first set of critics stand on the basis of positive feedbacks mechanisms linked to the use of technologies, which also infers the path-dependency of technological change. The use of a given technological solution provides additional advantages to both the producer and the consumer. On the top of

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[3] The most important types of ecosystem-services are: production services (e.g. food, resources, fodder), regulating services (e.g. climate, flood protection, pollination), cultural services (e.g. education, recreation, inspiration for art) and provisioning services (e.g. nutriment circulation) (MEA 2005).

[4] We must note that ecological economics does not necessarily propagate strong sustainability as an alternative for weak sustainability. This is because in the strong sustainability concept the criterion of sustainability is the constant value of natural capital, which presumes the existence of an objective valuing method. Ecological economics however questions that such a method could exist (Málovics–Bajmócy 2009).

this it generates negative externalities towards the other competing solutions. Thus the world of technological change can be characterized by positive feedbacks and dynamic increasing returns (David, 1985, Arthur 1989, 1990, Page 2006). Therefore technological change has such characteristics that totally “rewrite” the standard allocation problems of economics that presume constant or decreasing returns (Arthur 1989, 1990):

- *Non-predictable*: the long-run market shares of the technological solutions can not be predicted, uncertainty does not "averages away".
- *Non flexible*: a subsidy or tax adjustment to one of the technologies’ returns can not always influence future market choices.
- *Path-dependent* (non-ergodic): different sequences of choices lead to different market outcomes.
- *Not path-efficient*: such a situation may occur, when it is worth to choose one of the alternatives just because of the past decisions. In other words “lock-in” may occur, when a technological solution proves to be more valuable than all its alternatives just because enough people had already chosen it.

This means that when consumers or companies chose from different (e.g. polluting or less polluting) technological solutions, they do not solely consider the characters of the given solutions (and their own preferences), but also the effects of the earlier decisions. New technological solutions does not appear with a “clean slate”, they must compete the positive feedback mechanisms backing the existing solutions.

On the top of this several other factors may also strengthen positive feedbacks, such as institutional or infrastructural changes (Nelson 1995), and relational systems occurring parallel to (or in co-evolution with) the spread of the technologies (Witt 2003). The historically developed structures are not only able to select out the incompatible novelties, but are also able to shape the direction of the search process. A widely accepted opinion may occur with regard to the relevant problems and the desirable directions of research and development – a technological regime or paradigm (Dosi 1982, Kemp et al 1998).

Therefore *several barriers may hinder the spread of technological solutions with increased eco-efficiency or solutions that provide new ways of substitution*. The replacement of the existing (optionally less advantageous) solutions can be seriously hindered by the historically developed structures, systems.

The other set of critical arguments towards induces innovation theories question the implicit presumption under which economic actors would always be able to predict their needs, and enforce the emergence of the new solutions with optimal productivity characters. According to the evolutionary interpretation of technological change the global objective function, the definite set of choices, maximizing behaviour and rational decision making are indefensible presumptions (Nelson–Winter 1982, Dosi–Nelson 1994).

Uncertainty is an inherent element of the process of technological change. It is not solely a problem of information gathering but an integral part of the process (Hronszky 2005). This is a clear consequence of the abovementioned positive feedback mechanisms, but also well underpinned by the theories that analyse the process of innovations in depth (Marinova–Phillimore 2003, Fagerberg 2005).

3. Uncertainty and reflexivity

Uncertainty does not only appear in connection with the direction of technological change but also regarding the social and environmental effects of innovations. The systemic nature of the biosphere and the high number of factors influencing certain technological situations (Ropolyi 2004) make it even theoretically impossible to predict the potential effects of the new solutions. In addition, new solutions may alter the circumstances in which they emerged, and thus their own potential effects as well (*reflexivity*). A significant part of today's new technological solutions aim to remedy the (often unforeseen) problems caused by the former solutions (Beck 2003).

Therefore, we have a good reason to assume that new technological solutions will have such (e.g. environmental) *effects that cannot be estimated in advance*. In addition, the time for the potentially necessary adaptation becomes even shorter because of the accelerating innovation activity.

The handling of these effects becomes even more problematic if we consider the fact that many of the effects of new technologies cannot be perceived "in the usual way" (i.e. with our senses). These risks of modernization – as Beck (2003) denominated them – are based on casual interpretations and come into being through the scientific knowledge on them. Thus their recognition (even the acknowledgment of their existence) and the search for solutions are to a high extent influenced by social processes and institutions.

The shift in the discipline of technology assessment – a method for the research of the future effects of new technologies – illustrates well the aforementioned characteristics of technological change. The hard (expert) methods which were originally peculiar to the area systematically reached their limits, therefore the focus shifted towards the involvement of the widest possible range of stakeholders, and thus the consideration of the plurality of possible aspects and interpretations (Schot 2001, Hronszky 2002). In addition, the emphasis increasingly shifted from valuation to influencing (even in the early phases of development), since the possibilities of alteration – owing to the positive feedback mechanisms – may be seriously limited later.

4. The rebound effect

We considered the *rebound-effect* to be the third significant area regarding the relations of technological change and sustainability. This notion refers to the phenomenon that the increase in the productivity of a given natural resource does not result in the decrease of the absolute use of the given resource to such an extent that could be expected on the basis of the eco-efficiency gain. Moreover, in many cases productivity-increase goes hand in hand with the even more intense use of the given resource (this latter case is the so called *Jevons-paradox*).

The growth in fuel efficiency in the case of cars for example went hand in hand with the growth in the number of cars and kilometres driven (Kemp et al 1998, York 2006). A growth in household size and electric household appliances, and also higher room temperature were observed parallel to the introduction of energy efficient solutions into households (Hanssen 1999).

Fouquet and Pearson (2006) report the parallel growth of lighting-efficacy and the absolute energy need for lighting in the United Kingdom in very a long (several hundred years) time-scale. During this period lighting-efficacy has been multiplied by more than 700 times, still, energy use connected to lighting has been multiplied by 6600 (Table 1). Due to the relative cheapness of lighting an increased number of people could afford it, and new utilization methods (e.g. outdoor lighting) could emerge, which eventually resulted a sharp increase in the total energy consumption.

Table 1. Changes in the price, efficiency and consumption of domestic lighting from 1800 to 2000

Year	Price of lighting fuel (%)	Lighting efficacy	Price of light per lumen (%)	Consumption (lumen-hours per capita)	Real GDP per capita
1800	100	1	100,00	1	1
1850	40	4	26,80	4	1
1900	26	7	4,20	86	3
1950	40	331	0,15	1544	4
2000	18	714	0,03	6641	15

Source: Fouquet–Pearson (2006) and Herring–Roy (2007, p. 197.)

Rebound-effect can not only emerge regarding the use of the resource at stake. The growth in the eco-efficiency of a given resource may be the source of effects emerging at higher levels of aggregation. Thus, we may distinguish different rebound-effect types, such as (Herring-Roy 2007):

- direct,
- indirect, and
- economy-wide rebound effects.

In case of *direct rebound effect* the demand for the products and services of enhanced eco-efficiency grows as a result of the decline in the relative price of the used factors. This may enhance the total use of resources. First, we may buy more from a certain product (e.g. when the price of fuel/kilometre falls we have the chance to drive more), and second, the product or service may become accessible for new consumers (e.g. the spreading of air-conditioning).

Indirect rebound effect refers to the phenomena when we spend our savings arising from efficiency increase on other resource-intensive products or services (e.g. luxury goods). Households may spend their savings coming from more efficient heating on overseas holidays. The save in resource use coming from more efficient heating is thus lost because of the growing fuel use of airplanes.

Similar processes may take place on the producer-side as well. For example an energy-efficiency increase in steel production reduces the relative price of steel. This may reduce the price of cars which enhances their demand. This process expectedly enhances fuel use.

Economy-wide effect refers to the process that technological development and changes in consumer preferences allow new (formerly not known) ways of factor use. Increasing eco-efficiency may significantly contribute to such new utilization forms, since economic actors in their investment decisions prefer technologies that are based on the relatively cheap factors. For example, the use of electricity became common in many areas where no non-renewable resources were used earlier (e.g. watches, escalators, air conditioning etc.).

Articles on rebound-effect agree that users “take back” a certain part of savings coming from eco-efficiency increase (Alcott 2005, York 2006, Sorell 2009). But the literature is not at all unified regarding the extent of the rebound-effect and the casual relationship between efficiency increase and growing total resource use.

It is practical to measure the *extent of the rebound-effect* as a percentage of the expected resource-saving (due to efficiency-increase). This extent is at almost every occasions above zero, but according to some authors only exceeds one hundred (and thus causes an increase in total resource use) in special cases. It is quite hard to conclude this debate, since on the one hand empirical cases supporting the Jevons-paradox usually focus on energy intensive technologies with a wide range of utilization opportunities (Sorell 2009), and on the other hand empirical investigations are necessarily limited to a specific period, economic sector or country (or group of countries) (Alcott 2005).

Still, numerous aforementioned examples and other empirical data (Polimeni–Polimeni 2006) show that it is not at all rare that growth in resource-efficiency and absolute resource use go hand in hand. Still, it is quite difficult to prove any causality since the growth in absolute resource use may derive from a lot of other factors and the methodology of the empirical analyses dealing with the Jevons-paradox is not conclusive in this respect (Alcott 2005, Sorell 2009).

What can be stated however is that saving opportunities deriving from enhanced eco-efficiency can never be fully realized. The increase in the absolute use of a given resource (and even more likely in the economy-wide absolute resource use) can especially be expected in case of resources with wide utilization opportunities and the strong path-dependency of the related technologies. Thus we can suppose that enhancing eco-efficiency is in itself not enough to generate a shift toward sustainability, moreover, it may even have an opposite effect.

5. Summary and conclusions

We reviewed the relationship between technological change and sustainability in our paper. We analyzed three topics: eco-efficiency and substitution, uncertainty and the reflexivity of technological change and the rebound-effect. In all three fields we explored mechanisms that question the ability of technological change to generate a shift towards sustainability.

Market mechanisms have a limited ability to enforce the occurrence of solutions with increased eco-efficiency or substitutes for the scarce resources. The main reasons for this are the positive feedback mechanisms that are linked to technological change. Furthermore, it is sensible to presume that the substitution of ecosystem services with man-made capital can not be simply solved in each case.

On the top of this *new technological solutions almost necessarily infer new, until that time unknown problems* (new environmental problems among others). Therefore technologies that were originally created to remedy environmental problems generate the new problems partially themselves. This is caused by the inevitable uncertainty that characterises technological situations.

The third range of problems are in connection with the macroeconomic (rebound) effects induced by enhanced eco-efficiency. A number of mechanisms exist in the economy that *transfers the savings gained from the increased efficiency towards a higher level of resource use*. These processes lead to the increased use of the resource in several cases. This is ultimately due to the new utilization opportunities provided by technological change, the path-dependence of change and the maximizing behaviour of the economic agents.

Therefore within the existing structure we can not expect that technological change (more eco-efficient or waste reducing and –treating solutions) would result in a shift towards sustainability. Within present circumstances – but not necessarily – technological change is rather part of the problem than the solution with regard to sustainability.

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