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Abstract

Economic growth since the industrial era has reduced poverty and increased societies' quality of life, but it also has implied negative environmental effects. There is an urgent need to correct this structural unbalance. The open issue is whether this correction implies sacrificing the perspective of economic growth or if it can be achieved by maintaining economic growth though changing its nature in a more environment oriented direction. In the following I argue that this second strategy is preferable and also more realistic, but it requires an appropriate combination of conditions and policies to be implemented. Environmental regulation, particularly through the use of appropriate price signals correcting negative environmental externalities, is necessary, but not sufficient to promote the required radical environment oriented innovations, particularly to build a low-carbon economy less and less dependent on fossil fuels. Environment oriented innovation policies are required, supported by a system of social norms and by a polycentric system of governance.

Keywords

Economic growth, green economy, sustainable development

JEL Codes

O44, Q54, Q55, Q56, Q57, Q58

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Challenges of economic growth to the environment in the industrial era.

The economic growth model experimented since the industrial era has provided a lot of benefits in terms of employment, increased levels and quality of life, reduced poverty; but it has been characterized by negative and increasingly worrying environmental effects. Correct this unbalance is increasingly recognized as urgent, which requires that the prevailing model of economic growth should be changed in a more environmentally sustainable direction. But this is not an easy task, as it is deeply constrained by an energy system based upon an increasingly extensive use of fossil fuels.

The fossil fuel based energy system is the crucial feature of what to the Nobel Prize winner Paul Crutzen (Crutzen, 2002) has christened as the Anthropocene, a new geological era in which the Earth system has entered since the latter part of the eighteenth century, and which is characterized by an unprecedented influence of human action on the rest of nature.

Pre-industrial human societies influenced the environment through hunting, gathering and, later on, through agriculture and handicraft manufacturing: labor was the primary energy source, augmented by animals, water power and wood (biomass). This kind of energy was available only in specific favorite locations; hence markets were predominantly local and trade was limited; self-sufficiency and local independence in food supplies played an important role; cities were small and distant (Scott Taylor and Moreno Cruz, 2012).

With the industrial revolution these constraints have been removed by the new sources of energy represented by fossil fuels, which offered access to carbon stored from millions of years of photosynthesis. Since then, energy transitions in the developing of the industrial era have been characterized by the passage first from biomass to coal, and then from coal to oil and natural gas. The widening and increasing use of fossil fuels has shaped the technological revolutions that characterized the world economy since the industrial era (Gordon, 2016).

During the Industrial Revolution (1750-1830) coal replaced wood as the main energy source. Steam engines and cotton spinning were invented. Communications improved through railroad and steamships.

A second technology revolution lasted more than one century and can be divided in two phases. In the first phase (from 1870 to 1914) oil and natural gas were added to coal, and partially replaced it, allowing radical

“general purpose” innovations such as electricity, internal combustion engines, chemical engineering and new technologies in communications (telephone, telegraph, radio).

These radical innovations set the roots for the technological transformations of the second phase (from the end of the First World War to the late 1960s), which was characterized by incremental innovations such as road means of transport (cars and trucks), durable consumption goods, new systems of communication and entertainment (motion pictures, TV). After the Second World War, these innovations allowed the economic growth model to be increasingly characterized as a model based on consumption expansion.

In the 1970s, the benefits of the second technological revolution started fading (with a “productivity slowdown” in US). Energy crises developed, characterized by subsequent increases in oil price. They fostered investments in energy savings, in nuclear energy and in renewable energy sources.

In this framework a new technology revolution developed, based upon information and communication technologies (ICTs), characterized by a growth in production of services and immaterial goods, such as information and knowledge, but continued to be founded on a material basis made up by a productive system whose energy supply coming from fossil fuels.

The periodical energy crises since the 1970s questioned the possibility of a permanent economic growth based on fossil fuels, due to their nature of limited and exhaustible resources. These risks still exist, but it is likely that they will show up only in a very distant future; in the short-medium run, many signs exist that the world is not running out of fossil fuels. A lot of reserves are becoming increasingly exploitable, particularly because of new unconventional sources, although at increasing costs.

Examples of the negative environmental impact of the economic growth model based on fossil fuels are everywhere: in water quality degradation because of industrial pollutants discharged in freshwater and in groundwater resources; in worsened air quality because of the emissions from generation, distribution and use of electric energy; in damaged soil quality because of wastes and excessive pressure of the industrialized agriculture; in biodiversity losses because of the increasing specialization in the animals and plants used in the agro-food industry. These negative effects have been increasing since the beginning of the industrial era; they

accelerated with the higher intensity of economic growth after the end of the World War II.

The negative environmental effects of economic growth are increasingly global, with potential disastrous consequences on the whole mankind (Rockstroem et al. 2009, Wijkman and Rockstroem, 2012).

The globalization of the environmental impacts of economic growth has added to the complexity of the strategic approaches required to successfully dealing with them. Climate change is a typical example of a global environmental problem of increasing concern; and the reduction of carbon emissions needed to deal with climate change is a typical global public policy problem. Emission reduction is delayed by uncoordinated initiatives of national governments: as each country benefits from emissions' reduction by other countries, it is expected to avoid undertaking the implied reduction costs, trying to transfer them on other countries.

The complexity of the problems encountered in dealing with climate change is paradigmatic of the complexity of the problems that have to be addressed in implementing the required change in the economic growth model.

A critique to economic growth.

Many environmentalists and some economists claim that a contradiction exists between economic growth and the environmental quality: the reason being that persistent economic growth is inconsistent with the laws of conservation of matter and of thermodynamics.

Kenneth Boulding (1966) claimed that economists should radically change the way they approach the relation between the economy and the environment. What is forgotten in their approach, according to Boulding, is that the Earth is a closed system from the thermodynamic point of view: it is like a "spaceship" that does not exchange matter with the rest of the universe, but only receives from it a fixed supply of energy in the form of solar radiation to compensate the energy dispersion (entropy) in the matter and energy transformation processes. This implies that there are limits to the possibility of the environment to support the economy, and that economic activity cannot grow indefinitely.

On the basis of Boulding's arguments, Herman Daly (Daly, 1996) criticized the concept of economic growth claiming that the economic system should

aim at a “steady state” in which the flow of “throughput” (defined as the feasible flows of matter and energy from the first stage of production to the last stage of consumption) should be kept constant at the lowest level.

Daly’s argument deserves three types of observations. The first is that it holds at the level of the whole planet: economic growth cannot be growth of matter at that level; economic activity, considered at a global level, cannot make matter growing, it can only transform it. To be sustainable this transformation process must maximize recycling potential and minimize entropy (energy losses), as Daly suggests.

However, the world economy is widely heterogeneous: between one and two billions people still are still not able to satisfy basic material needs such as food, clean water, sanitation, electricity; these dramatic problems cannot be solved without growth in the availability of the material goods for poor people in so many areas of the planet. And this is the most important reason for the increasing demand for economic growth in developing countries.

The second type of observation concerns the possibility that economic growth can become increasingly less characterized as material growth, by increasing the share of immaterial goods and services.

Daly himself (Daly, 2008) recognizes this as a way that should be pushed as far as it can go; but he (rightly) warns that services and immaterial goods are always based upon material production.

For instance, a sector of the economy such as information technology, which is considered as having a very low material intensity, turns out to have a heavy physical base when a life-cycle approach is used, with a high amount of toxic wastes almost impossible to recycle and an increasing amount of polluting transport of goods exchanged through electronic commerce.

Another example is that of a typical service such as tourism, which has highly negative impacts on the environment not only in terms of congestion and tourist wastes, but also in terms of polluting transport of tourists increasingly travelling on long distance trips.

The third type of observation refers to the possibility of measuring economic growth in terms of growth of “economic value”, meaning quality of life improvements which do not have a material nature, such as better environmental quality.

The problem is that, often, these improvements are not revealed by market transactions; GDP, the typical index used in measuring economic growth, only relies on market transactions; hence, it turns out to be a very imperfect measure of economic well-being leading to a distorted measure of economic growth.

But the solution is not to give up economic growth; rather it is to use a more appropriate measure than GDP, taking into account not only the private (expressed by the market) gains but also the social (and environmental) gains and losses of growing economic activity.

The challenge is to build a different measure of welfare including the environmental costs and benefits. (UN Commission for Europe, 2009; Stiglitz, Sen and Fitoussi, 2011). The difficulty lies in the fact that any new measure should be accepted by citizens, by institutions and by international accounting conventions; otherwise the GDP will continue to remain the dominating measure. Efforts in this direction are being made; but they have not yet arrived at a satisfactory result.

It is often suggested that changing the nature of economic growth in a more environment friendly direction requires a lower rate of economic growth. But this depends on whether an economy is currently growing at a very high rate of growth or is currently growing at a low rate of growth.

A too high rate of GDP growth for a too long period is likely to exert a pressure on the environment which will eventually become unsustainable. Hence, transforming the nature of the economic growth model is likely to require not only a transformation of the structure of the growth model, but also a transition to a lower long-run rate of growth.

A typical example is China. China has experienced a yearly average rate of growth of 10% in the period from 1995 to 2010. A recent report of the World Bank and the Development Research Center of the State Council of People's Republic of China (2012) confirms that the current economic growth model in China is excessively unbalanced not only in terms of a too high saving and investment share of GDP compared to consumption, but also in terms of an inadequate system of social security and of health protection, and in terms of environmental sustainability.

The report explicitly indicates that the objective of moving towards a more balanced and sustainable model of growth cannot be achieved without decreasing the rate of growth in the next two decades, to arrive at a yearly rate of growth of 5% in the period 2026-2030. In this case a "de-growth" perspective seems reasonable.

Much more problematic this receipt is in economies, such the mature western economies, whose long-run yearly rate of growth is much lower, so that further reducing it would create serious problems, particularly to the employment perspectives.

Conditions for a sustainable economic growth.

Maintaining economic growth and keeping it compatible with environment preservation requires imposing a set of qualifications on the structure of the economic growth model, which amount to deeply changing the economic growth model still prevailing today.

An economy can be defined as sustainable from an environmental point of view if the flow of polluting emissions related to the economic activity is balanced with the absorptive capacity of the environment.

In the long run this absorptive capacity can decline if the environmental quality is left to degrade; but it can also improve if enough care is devoted to avoiding the degradation of the environmental quality or to improve it.

In the case of most pollutants, the worsened situation of the environmental quality requires that the polluting emission flows decline over time until a point is reached where the “net emissions” are zero, which means they have balanced with a long run stabilized level of absorptive capacity of the environment.

In such a situation, which is the normal one in most economies of our time, sustainability of the economy requires that the absolute flow of polluting emissions should be falling over time.

If there is economic growth, meaning that the GDP is growing over time, the sustainability condition requires that emissions per unit of GDP must fall at a rate *higher* than the rate of positive growth of GDP (Brock and Taylor, 2005).

To understand the conditions at which this is possible, it is important to realize that the pressure of economic activity on the environment depends on the scale of the economic activity (scale effect), on how the economic structure changes (composition effect), and on the nature of technological development in each productive economic sector (technique effect).

If the effect of economic growth is simply to increase the size of economic activity, this alone will only have negative effects on the environmental quality because polluting emissions will be growing over time.

In order to have polluting emissions falling over time, a process of structural change is needed, aiming at compensating, or more than compensating, a pure scale effect.

This requires two things. First, appropriate changes are needed in the composition of investment and consumption. Consumption and investment in sectors which negatively affect the environment should be restricted, while environment-friendly consumption and investment should be expanded.

Second, the intrinsically ambiguous nature of technological progress should be acknowledged. Many people claim that technological progress in our time is intrinsically environment-friendly; but this is not necessarily true, as the historical experience confirms.

Technological progress increases labor productivity. This increases output per capita and hence contributes to the negative scale effect. Hence technological progress without qualification is not automatically in favor of the environment: a technological progress that simply increases labor productivity is a “bad” technological progress with respect to sustainable economic growth.

A technological progress is “good” with respect to sustainable economic growth when it produces a reduction of emission coefficients per unit of output in individual sectors. The net effect of technological progress will be positive for sustainable economic growth only if the “good” type of technological progress prevails over the “bad” type.

Define E as the flow of polluting emissions, Y as the GDP level and P as the population level; we have

$$E = \frac{E}{Y} \cdot \frac{Y}{P} \cdot P = e \cdot y \cdot P$$

where $e = E/Y$ is the average coefficient of emissions per unit of GDP, $y = Y/P$ is the GDP per capita.

In terms of rates of growth we have

$$g_E = g_e + g_y + g_P$$

Where g_E is the rate of growth of emissions, g_e is the rate of change of the coefficient of emissions per unit of GDP, g_y is the rate of growth of GDP per capita and g_p is the rate of growth of the population.

The condition for a sustainable economic growth is

$$g_E = g_e + g_y + g_p < 0 \rightarrow -g_e > g_y + g_p$$

To reduce aggregate emissions the average coefficient of emissions per unit of GDP (e) must decline at a higher rate than the rate at which GDP (GDP per capita y and population P) grows.

Average coefficient of emissions per unit of GDP depends on the structure of production and the sectoral coefficients of emission per unit of output.

$$e = \sum_i \frac{E_i}{Y_i} \cdot \frac{Y_i}{Y} = \sum_i e_i \cdot s_i$$

where $e_i = E_i / Y_i$ is the coefficient of emissions per unit of output in sector I , and $s_i = Y_i / Y$ is the weight of value added of sector I over the GDP.

Clearly the average coefficient of polluting emissions per unit of GDP will decline most rapidly, the higher is the weight s_i of the sectors whose emission coefficient e_i will decline most rapidly.

The interaction between the various factors needed for a sustainable economic growth is so complex that there is no automatic guarantee that this target will be achieved.

The historical experience is that in the initial stages of development the scale effect dominates (as population and output per capita both grow), while there is a negative composition effect (because of the increasing weight of polluting industries) and a weak environmental regulation (as growth is preferred to environmental preservations). Hence economic growth and environmental quality are inversely related in the first stages of economic growth.

In mature economies, on the other hand, rates of growth usually do not persist as very high, which reduces the scale effect; the weight of less polluting sectors increases (services, immaterial productions), the technique effect starts acting in an environment oriented direction. With an increasing

income per capita, people's environmental awareness increases: this supports a more effective environmental regulation.

Thus in advanced economies a positive relation between growth and environmental quality is possible, although not always verified. The experience does provide limited and partial existence of what has been called Environmental Kuznets curve, implying an inverted U-shaped curve between environmental pollution and per capita income so that, when the GDP per capita increases, environmental degradation will first increase up to a turning point after which it will begin to fall.

While local air or water quality indicators seem to show a positive relation with income per capita above a certain threshold, no evidence of such a relation exists for global pollutants (CO₂) and for hazardous wastes and toxic chemicals.

Public policies for a sustainable economic growth: environmental regulation.

One of the most well-known results of economic analysis is that the market fails in taking into account, and correct, the negative environmental externalities.

Hence an economically oriented environmental regulation, making the prices to reflecting the environmental costs which the market is not able to reveal and to take account of, is a necessary pillar for building a sustainable economic growth.

As it is well known, the economic instruments of an economically oriented environmental regulation are environmental taxes and tradable emission permits.

An environmental tax gives polluters an incentive to undertake costly abatement activities or to choose more environment friendly *existing* technologies. The effect of environmental taxes in terms of increased prices of polluting goods is an indirect signal to consumers to switch to less polluting ones. This signal is transmitted to firms that are encouraged to shift to more environment oriented outputs and productive processes. Environmental taxes also provide revenues to the government, that can be used to support environment-oriented research and innovation.

The main problem with environmental taxes lies in the choice of the tax level. This should reflect the value of the environmental damage made by

additional pollution; but because this is not revealed by the market, artificial, and thus in a sense arbitrary, valuation methods are needed.

Incompleteness and asymmetry of information of the regulator increase the difficulties of choosing the appropriate level of an environmental tax. A reasonable second-best procedure would be to use some kind of “trial and error” learning process: if the tax level initially set by the regulator does not lead to a sufficient reduction in emissions, the tax should be increased; and vice versa (Helm, 2012). This instability, however, reduces the strength of the signal sent to polluters.

Further problems with environmental taxes arise in the case of global environmental problems such as climate change. In this case the environmental tax is more specifically a carbon tax. In order to avoid the negative effects of a tax race between different nations, a carbon tax should be set through coordination among governments; the experience reveals how difficult it is to achieve such an agreement.

If the decisions to fix a carbon tax is left to national governments, it is very important to be aware that carbon consumption, not only carbon production, should be taxed, which means taxing not only the carbon content of domestic production, but also the carbon content of imports.

Carbon border taxes are objected by those claiming that they are protectionists; quite the contrary, not having these taxes would distort trade that would be based upon private, not social, comparative costs; it would favor “carbon leakage” by subsidizing foreign firms exporting polluting goods (Helm, 2012; Nordhaus, 2013).

Environmental taxes are often resisted by the public opinion because they usually imply higher prices of the good whose productive processes or whose consumption are polluting. It is often the case that the demand for these types of goods is inelastic (think to gasoline and electricity prices) which makes environmental taxes a regressive type of taxes, impacting relatively more on the poor segments of the society, with the consequence of requiring some kind of redistributive compensatory policy.

Policy makers may try to convince the public opinion to assume a more favorable attitude towards environmental taxes by promising to use at least part of the tax revenue to compensate those who are more severely hit by the essentially regressive nature of this kind of indirect taxation.

Another way to support environmental taxes is to promise that they will substitute for other types of taxes that negatively affect income and

employment (for examples taxes) providing the same revenue. In these “environmental fiscal reforms” two dividends could be obtained: the first is reducing pollution and the second promoting employment.

A third proposal would be to use the tax revenue such as environment-oriented research and innovation.

The selection of one of these strategies or their combination is a typically political decision involving different vested interests in the society and therefore lengthy debates. This decisional complexity is one of the reasons that make difficult the implementation of environmental taxation

The other instrument to arrive at a pollution price are tradable pollution permits (Tietenberg and Lewis, 2009). This method, known as “cap and trade”, is suggested particularly when an aggregate emission standard is required to avoid overcoming some dangerous pollution threshold.

Using standards may also have the advantage of being introduced more quickly than taxes as they only require administrative decisions while taxes should be approved by law.

If the permit market works properly, it will allocate emission abatement among polluting sources so as to meet the aggregate standard in a cost-effective way by minimizing the aggregate abatement cost; the reason being that sources with too high abatement costs will prefer to buy emission permits, while source with low abatement costs will prefer to abate emissions and sell permits.

In order for a “cap and trade” system to work well, it should be organized as a competitive market with the minimum of information asymmetries: hence appropriate rules of the game should be set and the environmental regulator should monitor that these rules are followed. This may imply high organization costs, at least initially; once the market has learnt how to function properly, it is likely that the current costs will turn out to be lower than those related to imperfect and asymmetric information in the case of environmental taxes. But the high initial organizational fixed costs often discourage regulatory authorities from establishing these markets.

The problems of implementing a “cap and trade” system increases when the “cap” has an international dimension, as it happens with CO₂ emissions in the case of the climate change issue. An example is the European Union Emission Trading System (EUETS), which covers CO₂ emissions from all the larger sources in the power and heat sector, oil refineries, and other big material producers.

Since the beginning the allowances have been distributed for free according to the so-called “grandfathering” principle. Only in the future the permits will be auctioned before the trading among the firms takes place.

Due to the decentralized system of capping emissions, based upon proposals from individual European countries only coordinated at EU level, and to the economic crisis that reduced the demand for carbon permits, since 2009 the EUETS has experienced a growing surplus of allowances.

At the start of 2013, the surplus was almost two billion allowances, doubling the level in early 2012. This has significantly weakened the carbon price signal: the price of permits, that had reached almost 30€ per ton. before the global crisis in 2008, collapsed to less than 4€.

The European Union has approved some proposals for reforming the European carbon market, but the European experience reveals the main drawbacks of the carbon permit system.

The first is that a lot of carbon-emitting sources are not covered by a permit system: the EUETS does not cover small emitters such as those in transport, housing, agriculture and waste. The opportunities provided by information technologies may contribute to widen the number of polluting sources that could be involved in the future permit trade.

The second drawback is that permits remain a short term extremely variable instrument, strongly dependent on the business cycle fluctuations, as the European case clearly shows.

Finally, while environmental taxes by definition provide a revenue to the government, this is not the case when tradable permits are initially allocated for free (grandfathering), as it has been the case of the European experience at least until now. Only when permits are auctioned, the sale of the permits provides revenues to the government, as it happens with environmental taxes.

Some claim that environmental regulation should prefer using subsidies to pollution abatement activities rather than environmental taxes or cap-and-trade systems, arguing that subsidies would be better accepted by polluters, thus reducing the short-run trade-offs between environmental regulation and economic growth. Moreover, there are political economy pressures to prefer subsidies to abatement costs as instruments of environmental policy, as it is always better to receive something than to pay something.

But using subsidies to emission abatement activities as an alternative to environmental taxes or tradable permits is not the appropriate policy choice. A subsidy must be ultimately financed and this would eventually require some form of taxation, that is likely to derive from distorting types of taxes discouraging employment and investments.

Environmental taxes and emission permits on the contrary are efficient as they help reducing negative externalities; on the other hand, subsidies to pollution abatement and to environment-oriented innovations are efficient if they are financed through government revenues from environmental taxes or auctioned permits.

A difficulty in using government revenues from environmental taxes or auctioned permits to support green innovations comes from the available alternative of using them to compensate those that are more heavily hit by the higher prices of polluting goods, who are normally the poorer segments of society.

A case where the combination of pricing environmental externalities and using subsidies works well is energy efficiency. Energy efficiency is stimulated by a higher energy price, if the current costs of the energy improvements are lower than the present value of the benefits from future lower energy use.

Energy saving private companies should emerge in the market to favor this process; but they very often aren't, most likely because the perception of present higher costs for energy improvement is stronger than that of the future energy savings. In this case government subsidies to support energy saving investments may be helpful (Helm, 2012).

Another case in which subsidies can work in combination with pricing negative environmental externalities is when subsidies provide financial support to remove entry barriers for new existing green technologies. An example is provided by "feed-in tariffs" to favor the adoption of renewable energy sources. Producers of renewable energy are given a subsidy paid with the revenue of higher prices of traditional fossil fuel energy sources.

However, feed-in tariffs often encourage imports of the equipment embodying the new technologies (for instance, renewable energy PV panels), thus discouraging endogenous innovation in the field. Moreover, the European experience shows that the amount of subsidies to existing renewables has in some cases been excessive, implying a too high price for

traditional energy with negative short-run effects on production and employment.

Finally, from the point of view of environmental regulation, what is necessary and urgent, although often not recognized, is a restructuring of subsidies by phasing out existing subsidies to activities with harmful effects on the environment, such as subsidies to carbon intensive energy use or to the use of chemical fertilizers.

Public policies for sustainable economic growth: environment oriented innovation policies.

A successful environmental regulation is a necessary but not sufficient condition for a sustainable economic growth; it should be complemented with an appropriate environment oriented innovation policy.

An important role in promoting this policy is played by government's demand. The public sector is one of the largest consumers; hence environment-oriented public expenditure and public procurement can provide great help to widen the markets for environment friendly products and services.

Policies to promote environment oriented innovations are necessary because the market does not encourage this type of innovation. In general, innovations provide social benefits larger than private benefits to research activity (being a source of positive externalities) because new technologies, once available, become public knowledge and produce positive spillovers in terms of further innovations. This gap between social and private benefits is particularly relevant for new environment oriented technologies not only because of their positive environmental spillovers but also because of the higher market risk.

As shown by Acemoglu, Aghion, Bursztyn and Hemous (2012) the current average productivity of existing machines is likely to reflect past innovations that have accumulated mainly in the “dirty” (or “brown”) sectors of the economy over a longer time period. The higher average productivity, also a result of a wider market, in “brown” sectors encourages the market to favor further innovation in those sectors. This increases market uncertainty for “clean” (or “green”) innovations and therefore the risk of investing in them.

The literature, both theoretical and empirical, confirms that environmental regulation and environment oriented innovation policy work best together (Rodrik, 2013).

Environmental regulation can provide an appropriate incentive to the adoption of *existing* environment friendly technologies and *incremental* innovations in this area. But these types of innovations are not enough for achieving a sustainable economic growth.

A sustainable economic growth requires *radical* innovations that shift the technological regime towards a “good” model of environment friendly innovation.

Moreover, it will be necessary to displace existing production structures and infrastructures (such as in energy and transport market) which imply relevant costs. All this requires an active government intervention both direct in promoting research and through appropriate subsidies, involving financial resources additional to those deriving from the government revenue of environmental taxes and/ or auctioned emission permits.

Governments should give priority to research and development investments, an area where the expected social return is potentially higher than the private one. Government agencies should not only support research towards radical environment-oriented innovation in private firms; a direct involvement of government agencies is required in research activities and in establishing a productive relation with firms.

This relation should not only involve large firms, but also innovative small firms (often emerging as start-up), and it should promote competition in innovation between large and small firms.

The recent experience in producing innovative general purpose technologies, such as information technologies or nanotechnologies, confirm that an active role of the government agencies in selecting areas or even projects in which to invest in research is necessary (Mazzucato, 2013).

Government agencies should also be active in linking university research to firms interested in environment oriented innovation, and in connecting innovative start-up firms to venture capitalists. It is crucially important that government agencies involve credible researchers working in universities and other research institutions; which is unlikely if an inadequate investment in such knowledge infrastructure has not been decided in advance.

Government agencies should be very careful in encouraging an efficient allocation of the funds made available to firms for research and development investments, by promoting competition in selecting the firms to be financed and the private partners to join public-private research ventures.

Funding should not be granted additional funds without some constraint that progress in research is achieved for the funding to continue, although taking into account that this progress may require a longer horizon to be clearly revealed particularly in an area with so much uncertainty as the “green” innovation one.

Once new green technologies are made available from successful research, governments should give priority in helping their deployment and commercialization to those still far from commercial viability in order to help them achieving a technological maturity supported by a stable market (Mazzucato, 2013).

Environment oriented innovation policies, as any other type of innovation policy, are often criticized because of government’s lack of information and the risk of decision makers being captured by vested interests.

Governments pretend knowing what is needed to achieve public goals and being able to select the economic agents and the right incentives to make them undertaking appropriate investment; which is often not the case.

These are risks to be taken into account. Government agencies should be aware of the risk of “picking losers”, i.e. picking up specific technologies that will not succeed once confronted with the challenge of the market.

However, given the strong theoretical arguments in favor of an environment oriented innovation policy, the problem is not whether the government should have such a policy, but how it should be appropriately designed (Rodrik, 2013, H. Schmitz et al., 2013).

The risk of distorted information and of capture can be reduced by appropriate and transparent networks of interaction and communication between public and private sectors (Rodrik, 2013; Mazzucato, 2013).

A crucial pillar of an environment oriented innovation policy concern the required transition to a low-carbon economy based on renewable energy sources to deal with the challenge of climate change.

The last decade saw a huge step forward in innovations aimed at widening the use of renewable energy sources, particularly wind and solar power,

allowing to deal with the problems still existing, such as those related to intermittency.

The cost of using renewable energy sources has declined to reach a parity with traditional fossil fuels.

Major technological opportunities come from the possibility of applying the new information and data technologies to markets and systems for energy and transport.

However the technological progress to permanently decarbonize the economy will only partly be supported by private demand, even if the required cultural change in the demand structure for consumption takes place. The prevailing demand for building a low carbon economy will come from the government or will be supported by the government.

This will happen through carbon prices, through the removal of subsidies to fossil fuels, through the adoption of public procurement rules in favor of low-carbon products and services, through the support of R&D, through education, training and public information. New investments of big size will be necessary to find out new technologies and make them deployable.

The role of society in sustainable economic growth: the need of a polycentric approach.

No step forward towards a sustainable economic growth can be made without having the participants to the society convinced that increasing wealth should not necessarily be identified with increasing production and consumption of material goods.

Public policies are a necessary condition for a sustainable economic growth, but they are not sufficient: they will not be effective unless accompanied by a change in the social norms of behavior, able to shift the consumption model and the structure of final demand in an environment friendly direction. These social norms cannot be imposed through a top-down paternalistic approach; they should be the result of a bottom-up cultural change, freely accepted by the large majority of the persons in a society.

It is sometimes claimed that this change of behavior should imply the adoption of a model of frugality in consumption. This statement can be accepted, provided that it is recognized that the issue at stake concerns mainly the need of changing the quality and the nature of the consumption

model. This is not easy in times of economic crisis, when the feeling prevails that the quick needed recovery is easier if guided by an expansion of the existing consumption model.

But the challenge is precisely that of seeing the crisis in its meaning of “opportunity” to change the lifestyle and productive models: dealing with this challenge requires awareness of the risks embodied in reduced resilience and increased fragility deriving from an unbalanced relation between the economic system and the wider ecological system of which the economy is a part; and it requires consistent behaviors. Education is crucial to obtain some significant result in this area.

In this perspective of cultural and behavioral change, an increasingly important role can be performed by local communities in governing environmental resources as “common-pool” resources, whose sustainability is at risk because of non-exclusivity and rivalry in their use allowed by open access.

Economic analysis has oversimplified the possible modes of dealing with open access, by only considering property rights as assigned to the State or to some private person or company.

Privatization of a resource means, where possible, to divide it in parts and to assign the property of each part to one owner who could exploit it to maximize profit; or it may mean that the whole resource is assigned to one owner who could maximize profits by leasing the different parts to individual users who should pay a rent as right of access and withdrawal. With respect to sustainability, the reason for privatization is that the private owner should reduce the use of the resource in order to increase profits.

The problems when transforming an environmental common-pool resource in a private good derive not only from difficulties due to the physical characteristics of the resource (as it is the case with atmosphere), but also from the likely market failures. Private management leads to monopoly when the resource is not technically divisible; there is no incentive to take into account the positive externalities from preserving the resource stock or the negative externalities from destroying it; on the other hand there is an incentive to take advantage of asymmetric information.

Assignment of property and management of the resource to the State, requires that the government agency has the information necessary to establish the correct penalty (for instance a tax) to discourage the excessive resource use, and the ability of monitoring and enforcing the chosen policy, and of resisting to the inevitable attempts of capture from private interests.

Elinor Ostrom (1990, 2002, 2010) has shown that there are many cases in which neither the State nor the market are successful in granting a productive use and the long term sustainability of environmental common-pool resources; on the contrary, a community of users was found able to voluntarily arrive to an enforceable and stable agreement for a sustainable management of the resource.

But Ostrom has showed that this requires some conditions: ability to define technological solutions for a sustainable resource use; willingness to share the benefits from such a sustainable management; reciprocal trust; absence of too relevant differences in the size and power of the community members; homogeneity of community members; not too large size of the community.

These conditions can more easily be found in local communities. Examples are found in the use of traditional knowledge of local communities in developing countries for a sustainable management of agriculture, grazing areas, forests and biodiversity preservation; or in local experiments in energy distributed systems using renewables sources, in waste collection and treatment, and in traffic organization.

But local communities cannot act in isolation. The increasing complexity of obtaining a sustainable management of a common pool environmental resource requires a corresponding complexity in the levels of hierarchical organization (a “polycentric” system, according to Ostrom), giving to each level well defined and not overlapping tasks. Governments, at different levels, and public policies are not excluded in a polycentric governance system; but the public sector should not be seen as a top-down hierarchical level without giving space to communities’ action. Networks among successful experiments can be very helpful to move in the right direction also the higher levels (national, and even international) in a polycentric system of sustainable governance.

To conclude, the secret for the success of a sustainable economic growth is the appropriate combination of a change in the cultural values towards environment-friendly lifestyles and production models, and of a set of public policies embodied in a polycentric system of governance; they reciprocally reinforce in a synergic way.

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