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Title: Non-linearity in energy metabolism of Spain: "Attractor Points" for the Development of Energy Intensity.

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Abstract: the relationship between the GDP and the throughput of matter and energy over time has been explained basically by the intensity of use hypothesis, that defines it as an inverted-U shaped curve, leading to the concept of dematerialization. The evidence has shown that Spain is increasing the energy intensity over time (using more energy to generate an unit of GDP), but does this tendency is a continuous one as implied by the inverted-U shaped curve or environmental Kuznets curve? Or rather is it 'punctuated' showing some 'attractor points'?

Keywords: Spain, dematerialization, EKC, punctuated equilibrium, energy intensity, attractor points, societal metabolism.

1. INTRODUCTION

It is known that economic activity induce some repercussions upon the environment. In economics we use to measure the level of economic activity by means of the GDP. Without judging the convenience of GDP as a measure of wealth, one way of trying to measure the environmental impact induced by wealth generation is by using the evolution of some inputs for the economy such as energy. Thus, we can understand the economic process as the elaboration of goods and services through the transformation of energy and matter. Daly [1991: 36] has called this transformation the throughput (the entropic physical flow of matter-energy from nature's sources, through the human economy and back to nature's sinks) or the 'metabolic flow' of Georgescu-Roegen. Once this point is clarified, we made a first simplification in our analysis when we consider the level of throughput as an indicator of environmental impact. Nevertheless, due to the lack of data available upon pollution, it is usual, in the different studies on throughput, to take only into account data of energy and resources use.

Based on calculations of these intensive variables (throughput indicator/GDP) some studies showing the dematerialization of some developed economies have been published (see Ramos-Martín [2000] for a critique of the use of intensive variables when analysing the throughput of the economy with the example of the Spanish economy). However, most of these studies assume the continuous relationship between the evolution of GDP and throughput, either growing tendency (in the early development stages) or decreasing (for the main developed countries). But the evidence of the German case [De Bruyn 1999] shows that sometimes the relationship is not continuous, but shows some 'jumps'. This kind of behaviour is the one we will test here for the Spanish economy. That is, I will try to show non-linearity in energy metabolism of Spain, by analysing the process of becoming energy intensive. In order to do that, I apply here the methodology used before by De Bruyn [1999], a phase diagram. In this diagram, the intensity of energy use of the year t and that of the year t-1 are

represented. In that way we can check the validity of the continuous relationship, or to check the possibility of having consecutive phases of dematerialization and rematerialization around certain ‘attractor points’, the so-called ‘punctuated equilibrium’ [Eldridge & Gould 1972; Gowdy 1994].
The structure of the rest of the paper is as follows: the second section will present briefly the present theoretical explanations around the issue of dematerialization, as well as the evolution of energy intensity of Spain. The third section will deal with the ‘evolutionary’ perspective, showing the phase diagram for Spain as well as some basic explanations, and the last section will give some policy recommendations.

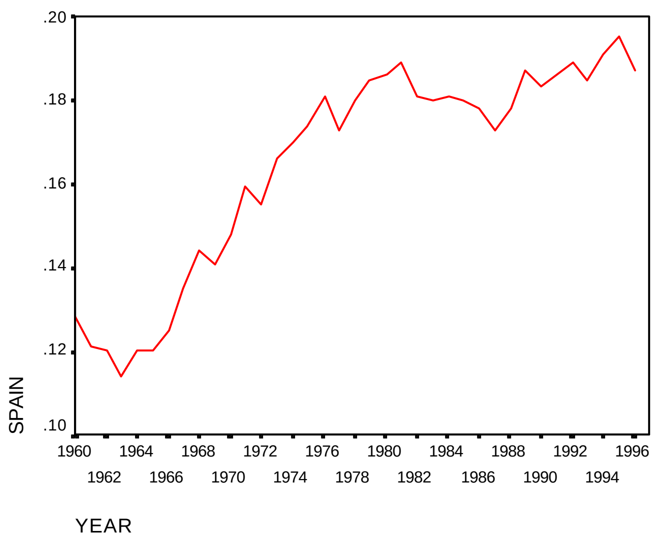
2. DEMATERIALIZATION AND ENERGY INTENSITY IN SPAIN

Malenbaum [1978] presented the hypothesis of the intensity of use, in which income is the factor that explains the consumption of materials. That is, during the process of economic development countries would increase consumption of energy and materials following the growth in income until one defined level of income is reached. Beyond that level, we would see a delinking between the economic growth and the consumption of materials. This is the so-called inverted-U shaped curve or environmental Kuznets curve (EKC). According to this hypothesis developed countries would be dematerializing, whilst developing ones would be materializing. Traditionally [Mielnik & Goldemberg 1999: 307; Opschoor 1997] the delinking can be explained by three factors:

i) Structural change in the economy, shifting form high energy intensity sectors to lower intensity ones,
ii) Improvement in energy efficiency, and
iii) Changes in consumption patterns

One problem with the EKC (for a comprehensive critique, see Giampietro & Mayumi [2000]) is that, if it works, it is only beyond certain high levels of income and consumption of energy and materials. That is, it implies only a week dematerialization (per unit of GDP) but not a strong or absolute dematerialization (decrease in the metabolism of the system). Anyway, there are some studies that show that some countries are facing dematerialization phases [Jänicke et al. 1989]. But, is it continuous? De Bruyn and Opschoor [1997] show that some countries have dematerialization but followed by phases of rematerialization, neglecting, then, the hypothesis of the inverted-U shaped curve.
It is the turn of analysing the case of Spain. We will take only into account (to simplify) the relationship between GDP and the used, or commercial, energy as a proxy of an intensive indicator of throughput, Total Primary Energy Supply divided by GDP (toe/1000 US90$ GDP). This is what we do in figure 1.

Figure 1: Energy intensity for Spain (toe/1000 US90$)



Two results can be drawn from figure 1. First, the Spanish economy is increasing the energy intensity over time. Second, this tendency is not continuous. Thus, we can see how energy intensity increased very quickly from 1963 to 1981, to show, beyond that year, values around 0.18 toe/1000 US90$, with light ups and downs until 1996. We can say, then, that Spain does not follow the hypothesis of the inverted-U shaped curve. Some people could, however, argue that Spain has not yet reached the inflection point, that is, is still not rich enough. I do not think this is so, especially because, as it is shown by Unruh & Moomaw [1998: 225], the majority of the developed countries show the peak year for energy intensity in the 1970s. They also show values of GDP per capita in the range of 8884 US$ (Austria), and 15425 US$ (USA) with most of them around 11000 US$ for the same peak year. But Spain, far from being a fuel-based economy like the USA or Canada, still shows a growing tendency with 13774 US$ in 1996.
Anyway, even if it is true that Spain has not reached the peak year, this argument does not explain why the evolution of energy intensity is not continuous, but with ups and downs. This is what we explain in the next section.

3 THE EVOLUTIONARY PERSPECTIVE

We can see human society (and its subsystems) as a complex adaptive system [Giampietro 1997: 83], as well as a hierarchic system, operating at different space-time scales (probably technological change and changes in individual preferences occur with different rhythms). Then, we should include in our analysis not only variables reflecting efficiency (such as energy intensity), but also some others from the point of view of the evolution of the systems. This is very important since the studies that show dematerialization (based on past developments of the variables) are often used to recommend policies for the future. But the question is whether past developments of dematerialization can be extrapolated into the future or not. As stated half a century ago by Schumpeter [1949: 58] “it is not possible to explain *economic* change by previous *economic* conditions alone” (emphasis in the original).
One factor, which supports the position against this extrapolation, is that efficiency implies a faster processing of information and knowledge, leading, then, to a faster potential depletion of resources. This is the so-called Jevons paradox [Jevons 1990], that is, efficiency of one process only implies improvements in intensive variables, but this only leads to effective savings in resources if systems do not evolve over time. This is not the case for human systems, so in response to efficiency we can expect increases in the level of activity. This fact might explain the ups and downs of energy intensity for Spain. That is, when the result of the efficiency improvement is over, we can see, again, a process of increase in energy intensity. The conclusion is that we can be more energy efficient but still consume more energy!
Because of these characteristics, it is difficult to describe the behaviour of these systems with the traditional linear techniques. Thus, we have to use non-linear dynamic technique that allow us to observe the patterns of temporal behaviour and the intermittent changes in the variables.
For example, Gowdy [1994] applies to the economy the vision, originated in palaeontology [Eldridge & Gould 1972], of the evolution as a ‘punctuated equilibrium’. This is the new name for something that has been studied before by Schumpeter, who saw development as “spontaneous and discontinuous changes in the channels of the flow, disturbance of equilibrium, which forever alters and displaces the equilibrium state previously existing” [Schumpeter 1949: 64]. That is, economic systems might have stable phases followed by radical changes in the technological paradigm and in the industrial structure. This explains why during the stable phases the values of the variables concentrate around certain ‘attractor point’. The evolution would be, then, going from one attractor point to the next, or, in words

of Schumpeter [1949: 66], “carrying out new combinations”, meaning structural and institutional changes.

One way of analysing this discontinuity is by means of a phase diagram. This methodology has been used in the case of CO_2 emissions [Unruh & Moomaw 1998], and in the case of energy intensity [De Bruyn 1999].

In figure 2 we can find the phase diagram for energy intensity for Spain. In the Y-axis the energy intensity in the year t is represented, and in the X-axis, the same variable in year t-1. Then we join all the point by using a line. If the increase in energy intensity observed in figure 1 would be due to gradual changes in intensity of use (as it is said by the hypothesis of the intensity of use), then the phase diagram in figure 2 should show a more or less straight positive line, implying greater intensities over time. However, if it would be due to a punctuated equilibrium, the phase diagram would show different attractor points where the energy intensity will be stable. In the case of Spain we can see clearly two different attractor points, one between 1960-1966, and the second between 1976-1996 with the values around 0.18 toe/1000 US90$. Between the two points we can see a transition period characterised by re-energisation. It seems, then, that Spain also follows the behaviour in phases described by De Bruyn [1999] in the case of energy intensity.

Figure 2: Phase diagram for Spain

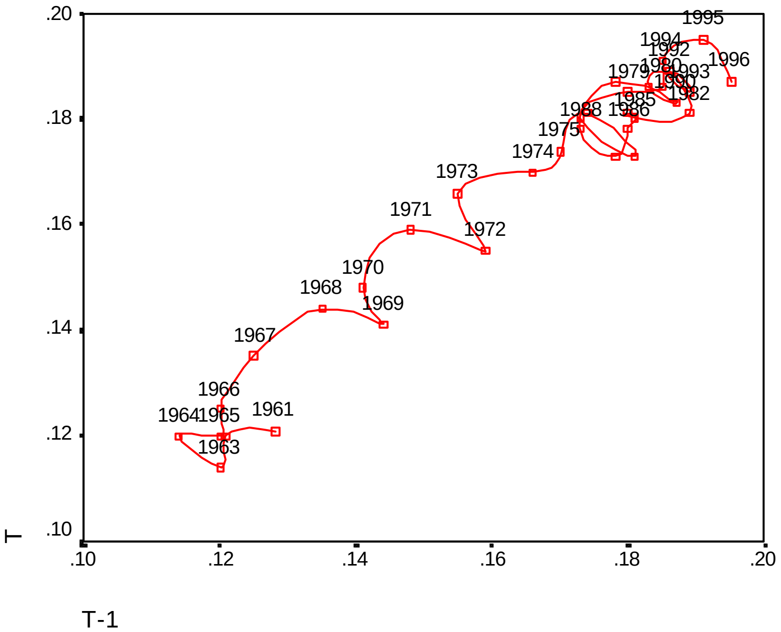
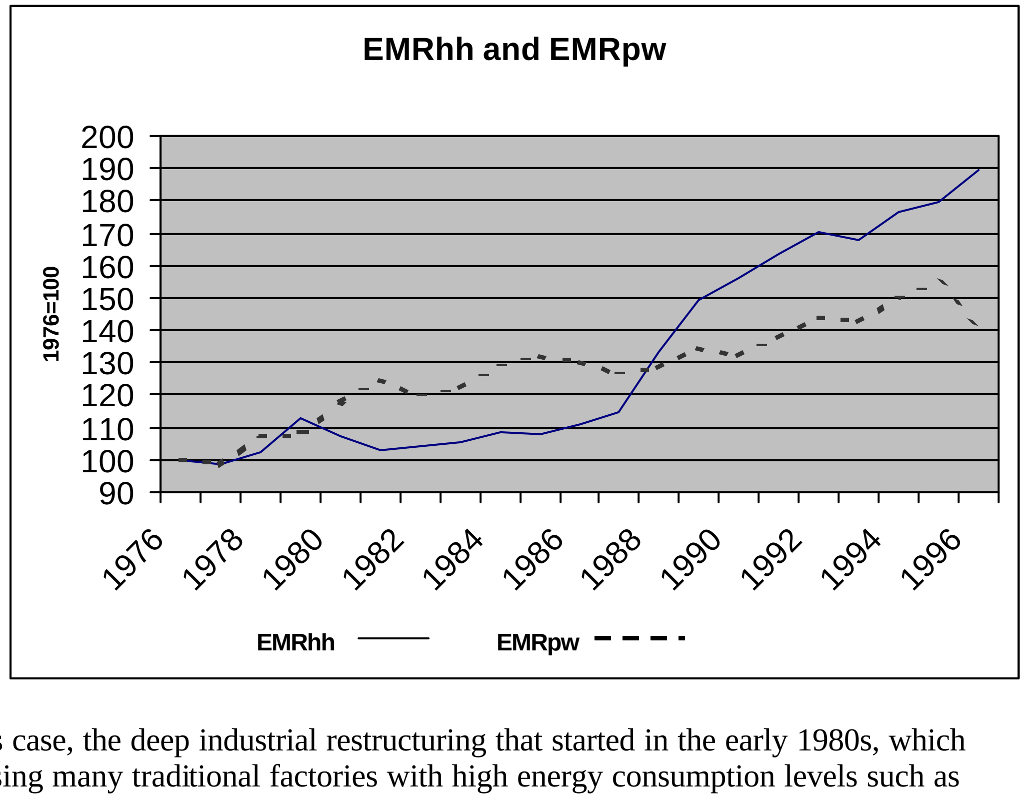


Figure 2 shows that there are phases of stability (the two attractor points) in which energy intensity goes parallel to GDP Growth, while during the transition phase the intensity increases.

Thus, in the Spanish case, it can be said that the energy intensity tendency is to grow over time. In this case, the structural and/or institutional changes do not contribute to reduce energy intensity but to stagnate it around the attractor points. This is the way in which we have to understand the different evolution of the sectors of the Spanish economy. Indeed, the Spanish economy is shifting activity from the industrial sector to the service sector, and the industrial sector is reducing its energy intensity. Then, if Spain would follow the tendency of other developed countries, we could see the energy intensity of the overall economy reducing. But this is not the case, since the service sector is growing its energy intensity [Ramos-Martín

2000]. There are, as well, two more factors that explain why energy intensity is increasing. One is the fact that Spain has not yet shifted all the energy intensive production to developing countries, as other developed countries have done. The other is more relevant. It is the fact that both the process of accumulation of capital shown by the increase in the exosomatic metabolic rate of the productive sectors (energy used in the productive sectors divided by human time allocated there [Giampietro & Mayumi 2000]), and the increase in the productivity per hour in the Spanish economy (GDP/Total human time), have allowed the decrease in the human time allocated in activities that generate added value. That is, the leisure time has increased. Moreover, the exosomatic metabolic rate for the household sector (energy consumed in the household sector divided by human time not working, EMRhh), has also grown, explaining that, even though industry is decreasing energy intensity, the overall economy is increasing it. This is the message we get from figure 3, where we can find the growth of both the exosomatic metabolic rates for the household sector and for the productive sectors (agriculture, manufacturing, services, and the government, EMRpw). Indeed, when Spain was capitalising the economy, we could see that EMRpw grew faster than EMRhh, but in the past few years, when the productive sectors are consuming less, the increase in the material standard of living is the responsible for the higher consumption of energy, explaining the evolution of the energy intensity. This fact is usually neglected by the studies on the EKC or energy intensity that focus only in the supply side of the economy, the productive sectors. But as we can see, the demand side, the household sector, is getting more important in explaining the developments of energy intensity, and should be analysed.

Figure 3: Growth in Exosomatic Metabolic Rate (Household Sector and Productive Sectors) in Spain

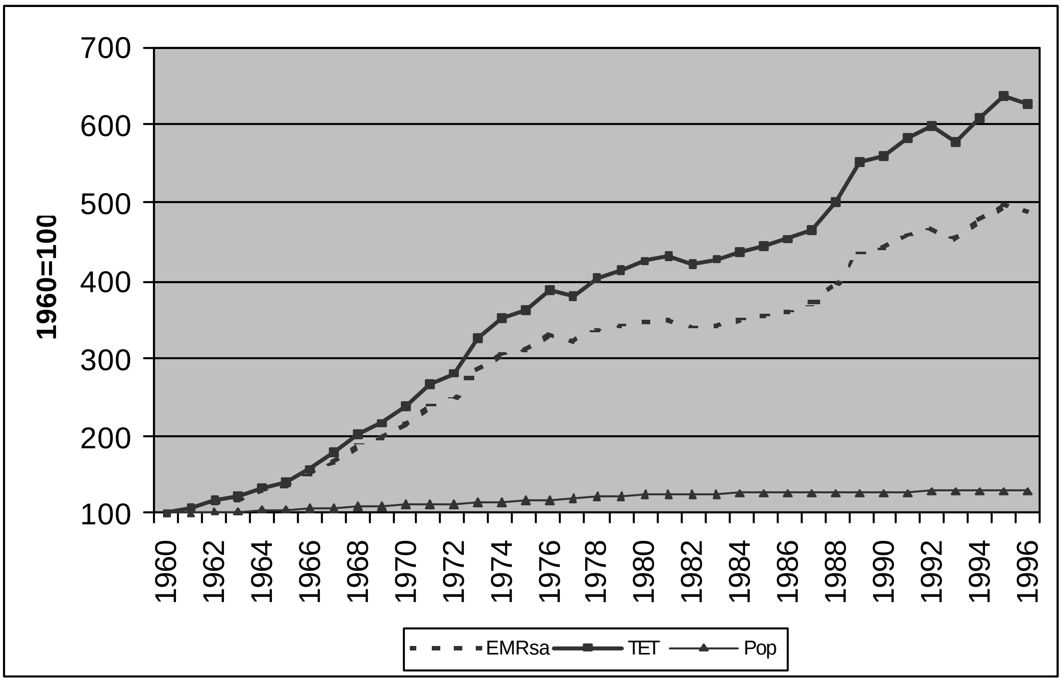


Thus, in this case, the deep industrial restructuring that started in the early 1980s, which implied closing many traditional factories with high energy consumption levels such as shipyards and steelworks, has only implied the stabilisation of the values around 0.18 toe/1000 US90$. We can foresee that when the effect of the structural change disappear, we might see a new increase in intensity. This fact can only be stopped with a new structural change that reverts the tendency. Could it be the 'new economy' of knowledge and information? Maybe this can be the solution for individual economies (actually means externalising production to other countries), but from an environmental perspective, this is not the solution for the whole globe. Maybe we have to look more seriously to the demand side, and try to redefine material standards of living and energy and materials consumption.

4. POLICY RECOMMENDATIONS

We have to admit the importance of using intensive variables in our analysis, such as energy intensity (they are relevant, for example, to choose between processes). But this analysis is not sufficient to show whether the evolution is continuous or not. Moreover, it is also not relevant since an environmental point of view, because if we are interested in the metabolism of the society we have to look at the extensive variables. For example, in figure 4 we can see population, total energy (TET), and the exosomatic metabolic rate growth (commercial energy divided by human time, EMRsa) in average for the society. Notice that the overall curve of TET is the result of changes in an intensive variable (the curve of EMRsa) and an extensive variable (the curve of Pop). It is when looking at these kind of variables that we have an overview of the throughput of the economy, and then, of the possible environmental impact. For example, in figure 4 we see that the increase in TET is due to the increase of the Exosomatic Metabolic Rate (that might be seen as a measure of standard of living) rather than to the increase of population. Anyway, if the development for energy intensity is continuous, it can be due to gradual changes in the economic system (such as an improvement in productivity). If it is not continuous, it might be due to deep structural changes.

Figure 4: Population, Total Energy (TET), and Exosomatic Metabolic Rate (average of the society) for Spain.



When observing the data for the Spanish economy it is clear that energy intensity is growing. But we cannot say if the evolution is due to either the fact that Spain has not reached the "peak" in wealth, or has not faced the necessary structural changes.
Anyway, something that is also clear is that the change in the variable is not continuous.
The policy implications of these results are twofold. First, if the hypothesis of the intensity of use does not hold, as we have shown here for Spain and De Bruyn & Opschoor [1997] have shown for other OECD countries, then we should not just wait for economic development to

bring less energy intensity and to solve our environmental problems. Second, structural and institutional change have to be sought in order to avoid both the rematerialization phases and the repetition of the same mistakes (or trends) by developing countries.
Thus, the attitude of governments should be to strength this change to revert the tendency of the energy intensity as well as to reduce, later on, the metabolism of the system (absolute dematerialization, TET in figure 4) at least until the throughput of the economy is compatible with some environmental thresholds. In fact, the later is the relevant since an strictly environmental point of view.
Anyway, it seems that developed economies show this evolution, that we can understand as a punctuated equilibrium. The next step is to find out why the economy changes from one attractor point to the next.

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