Published in *Advances in Energy Studies. Reconsidering the Importance of Energy*, S. Ulgiati, M.T. Brown, M. Giampietro, R.A. Herendeen, and K. Mayumi, Editors. SGE Publisher Padova, Italy, 2003, pp.45/61.

Societal Metabolism of Societies: The bifurcation between Spain and Ecuador

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Abstract: This paper presents an application of the Multiple-Scale Integrated Assessment of Societal Metabolism to the recent economic history of Ecuador and Spain. Understanding the relationship between the Gross Domestic Product (GDP) and the throughput of matter and energy over time in modern societies is crucial for understanding the sustainability predicament as it is linked to economic growth. When considering the dynamics of economic development, Spain was able to take a different path than Ecuador thanks to the different characteristics of its energy budget and other key variables. This and other changes are described using economic and biophysical variables (both extensive and intensive referring to different hierarchical levels). The representation of these parallel changes (on different levels and describable only using different variables) can be kept in coherence by adopting the frame provided by MSIASM.

Keywords: MSIASM, Societal Metabolism, Development, Energy, Ecuador, Spain.

1. INTRODUCTION

The paper aim is to present an alternative understanding on how economies evolve in time from less to more organisation by degrading low entropy energy. To do that, it shows the recent evolution of two different economies, one developing, Ecuador, and one developed, Spain, which, as it will be shown, are each an example of a different side of the bifurcation of economic development. A deeper analysis of both cases using MSIASM and other approaches can be found in Falconi (2001) and Ramos-Martin (2001).

Literature on economic development does not usually pay much attention to biophysical variables such as energy consumption (or conversion), which we think are very relevant for describing the evolution of societies and their technological development. Energy dissipation can therefore be used as a proxy variable for the environmental impact of economic activity.

Accounting for energy requires, thus, a methodology that links the several aspects involved. One relevant concept to be used here is that of 'societal metabolism' (Martinez-Alier 1987; Fischer-Kowalski 1997). We may consider the flows of matter and energy into the society, through the society and out of the society as described by the metaphor of metabolism. In fact, we owe this metaphor to Georgescu-Roegen (1971) who called it the 'metabolic flow'. Later, Daly (1991) introduced the concept of throughput, more usual nowadays. This metaphor stresses the fact that human societies use large amounts of materials and energy in a similar way to organisms. In this sense, the 'exosomatic metabolism' of societies or societal metabolism (Fischer-Kowalski, 1997) can be analysed, in which the consumption of exosomatic energy (e.g. for the working of tools and machinery) would be related to the internal organisation of that society. Organisation helps us to see economies as complex systems.

Economies are complex adaptive systems, that is, composed of large and increasing number of both components and of the relationships between them. Economies are also teleological systems (they have an aim, or end, the telos), and they are capable of incorporating the guessed consequences of their fulfilment into the present decisions and definitions of new tele; they are thus anticipatory. They also learn from mistakes and from present developments, and they react, by changing both the actions undertaken and the tele defined; they are thus self-reflexive. They also have the ability to adapt to new changing boundary conditions, but they may *consciously* alter the boundary conditions. This is why the economy, as a human system, can be understood as a complex, adaptive, *self-reflexive*, and *self-aware* system (see Kay and Regier, 2000, for more details).

When analysing their structure, economic systems are nested hierarchical systems. In the case of economic systems, we can distinguish several subsystems such as sectors within them, and every sector may be split into different industrial 'types' (sharing common features) and so on. The various levels of an economy exchange human activity and energy between them, reflecting the interconnected nature of those systems (the output of one sector enters other sector as input, and vice versa).

All the above characteristics of economies as complex systems make them difficult to comprehend. This is why we need a methodology that combines both economic and biophysical variables and information from different disciplines and from the different hierarchical levels of the system in a coherent way. The methodology we use is Multiple-Scale Integrated Assessment of Societal Metabolism (MSIASM) as described in Giampietro and Mayumi (2000a, 2000b). The use of integrated models to characterize changes in economies based on the use of different variables to generate parallel descriptions of the same facts at different level seems to be essential when dealing with the issue of sustainability. That is; when the effects of changes have to be assessed using different academic disciplines in parallel and in relation to events describable only on different levels. The generation of a 'mosaic effect' among the various pieces of information improves the robustness of the analysis and the possibility of getting new insights generating synergism in the parallel use of different disciplines.

Thus, the structure of the rest of the paper is as follows: Section 2 makes explicit the basic relations underlying MSIASM that are used here. Section 3 presents the case study for Spain, whereas Ecuador is dealt with in Section 4. Finally, the conclusion will highlight two kinds of arguments: one methodological, explaining which are the advantages of using MSIASM to analyze the exosomatic evolution of societies. The other, more practical, will give an explanation on the causes behind the two different development paths taken by Ecuador and Spain.

2. THE RELATIONS IN MSIASM

The parameters used are those presented and discussed in Giampietro and Mayumi (2000b) and applied by Falconi (2001) and Ramos-Martin (2001). In this analysis, economies are divided into two main sectors: the paid work sector (PW) and the household sector (HH). The paid work sector of the economy is the one that generates added value (or GDP), and the household sector of the economy is the one that consumes that value. Both of them, however, consume energy for their maintenance and development. The paid work sector can be divided into three major sub-sectors, the productive sector (PS), services and government (SG), and agriculture (AG).

$$PW = PS + SG + AG \qquad (1)$$

Energy intensity (EI) is total energy consumption, or total energy throughput (TET) divided by Gross Domestic Product and, in this study, it is measured in MJ/US90$.

$$EI = TET / GDP \qquad (2)$$

Some useful ratios that will be used later are defined as follows:
The exosomatic metabolic rate average of the society (EMR_{AS}) is the total exosomatic energy throughput (TET) divided by the total human time (THA) of the society which is population times 8760 hours. This ratio gives us the rate of energy use of the society in megajoules (MJ) per hour. The interpretation of that ratio is that this is an intensive variable that reflects the rhythm at which society dissipates energy for its maintenance and development per unit of human activity.

$$EMR_{AS} = TET / THA \qquad (3)$$

By analogy, we can derive the same kind of ratio in the case of the household sector and the paid work sector. That is,

$$EMR_{HH} = ET_{HH} / HA_{HH} \qquad (4)$$

Where ET_{HH} is the energy consumption in the household sector and HA_{HH} is the non-working human time in the society. In this study ET_{HH} is calculated as residential energy consumption plus 50% of transport energy consumption. An increase in EMR_{HH} reflects an increase in the standard of living (Pastore et al., 2000) and a higher capitalization and consumption in the HH sector.

By using the same procedure used in relation (3) and (4) we have:

$$EMR_{PW} = ET_{PW} / HA_{PW} \qquad (5)$$

Where ET_{PW} is the energy consumption in the sectors that generate added value, and HA_{PW} is the human working time (we use a flat value of 1,800 hours per year for employed people). EMR_{PW} can be taken as a proxy for investments in the PW sector. The same holds for EMR_{PS}, EMR_{SG}, and EMR_{AG}.

The last ratio used in this analysis is the economic labor productivity (ELP) that can be defined as GDP / HA_{PW} in dollars per hour. Again, we can also calculate ELP_{AG}, ELP_{PS}, and ELP_{SG}. By dividing a sectorial GDP (e.g. GDP_{AG}) by its relative amount of working time in hours (e.g. HA_{AG}).

For example, when using the economic reading, we can define TET = EI * GDP (from relation 2), but from this integrated assessment, due to the fact that $HA = HA_{HH} + HA_{PW}$, and $TET = ET_{HH} + ET_{PW}$, we can define TET as follows,

$$TET = (HA_{HH} * EMR_{HH}) + (HA_{PW} * EMR_{PW}) \quad (6)$$

We can do the same for ET_{PW}. From relation (1) we know that PW = PS + SG + AG, so we can define ET_{PW} as follows,

$$ET_{PW} = (HA_{PS} * EMR_{PS}) + (HA_{SG} * EMR_{SG}) + (HA_{AG} * EMR_{AG}) \quad (7)$$

These examples show that it is possible to define the same variable (i.e. TET or ET_{PW}), using an economic reading (energy intensity and GDP) or using an integrated assessment (using exosomatic metabolic rates and human time allocation referring to the characteristics of lower hierarchical levels). This fact gives our analysis a wider scope and more robustness, and allows us to give different explanations to the same facts.

3. A CASE STUDY OF SPAIN

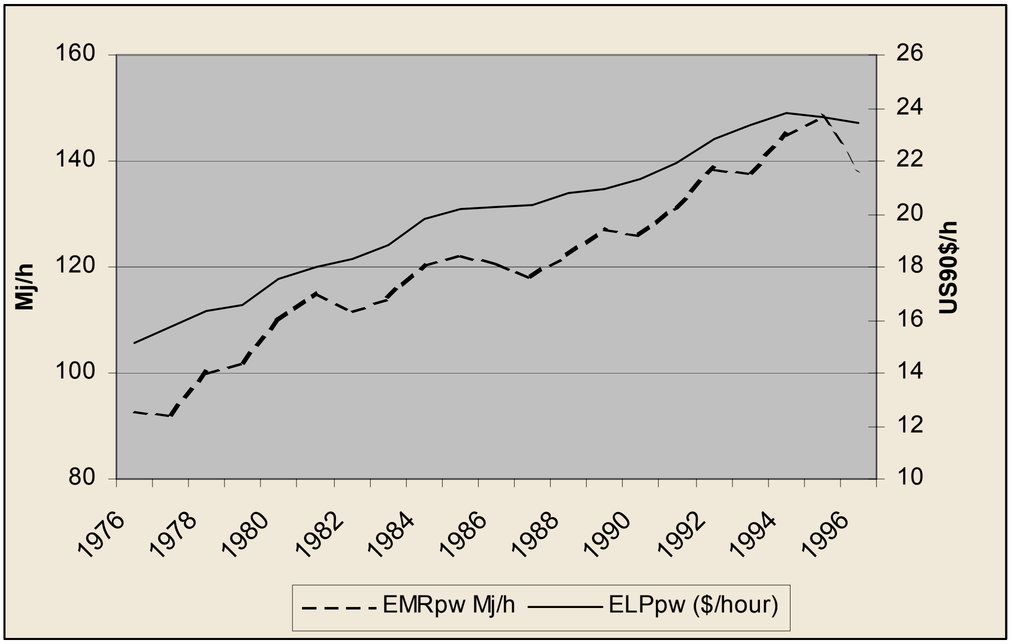
This section applies the relations presented above to the case of Spain. This allows us to see how Spain took the positive side of the bifurcation of economic development (in which surplus generated more surplus at a faster rate than population growth) and also why this happened.

3.1. Describing changes of ELP and EMR in the various sectors

One major hypothesis that can be used in integrated assessment is the correlation between the capitalization of productive sectors (assessed by their exosomatic energy consumption = fixed plus circulating) and their ability to produce GDP. Accepting this hypothesis implies that EMR_{pw} and ELP_{pw} are correlated (Cleveland et al. 1984; Hall et al. 1986). The good correlation obtained by Cleveland et al., in their historic analysis of US economy, is confirmed by the curves shown in Fig. 1 for Spain. When representing changes of EMR_{pw} and ELP_{pw} we find a similar shape or tendency in the considered period. That is, exosomatic energy consumption per unit of working time in the paid work sector follows the GDP trend. The same finding has been obtained in the historic analysis of Ecuador (Fig. 11).

If we accept the validity of this correlation during the considered time window, it follows that changes in the energy intensity of Spain are generated by: (1) differences in the speed at which the two parameters EMR and ELP adjust in relation to each other and (2) changes occurring outside the paid work sector. This second option points at the possibility that important changes, in Spain, are taking place in the household sector.

Figure 1: Exosomatic Metabolic Rate and Economic Labour Productivity in paid work sectors



Changes in the PW sector

The EMR_{pw} increased from 92.92 MJ/hour in 1976 to 138.13 MJ/hour in 1996), which is reflecting the accumulation of capital in the sectors of the economy producing added value. This change has been reflected in a relative increase in the economic productivity of labor (ELP_{pw}) (from 15.3 $/hour in 1976 to 23.4 in 1996). As a side effect, this allowed the relative decrease of the human time allocated in activities that generate added value. In fact, more exosomatic energy used per worker implies the existence of more exosomatic devices per worker (technology) linked to the ability to buy more oil to perform the given economic activity. The two things, *fixed investment* – the exosomatic devices needed to dissipate fossil energy in a useful way by workers – and *circulating investment* – fossil energy consumed – combined together can be considered as an indicator of a larger capitalization of the economic activity considered. That is, an increase in EMR leading to an increase in ELP is linked to more technology involved in production.

Changes in the HH sector

If the changes in the PW sector led to an increase of non-working time, how this was reflected in the level of capitalization of the household sector? In the example of the analysis of Ecuador, we show that a sharp increase in HA_{HH}, translated into a sharp reduction of EMR_{HH} since the increase in ET_{HH} could not keep the pace of growth of HA_{HH}.

Contrary to what happened in Ecuador in the last decades, the exosomatic metabolic rate of the household sector (EMR_{HH}) in Spain almost doubled. It went, from 1.67 MJ/hour in 1976 to 3.27 MJ/hour in 1996.

Combining the two

When combining changes in intensive variables (EMR_i) and extensive variables (HA_i) and when considering sectors dealing with both production and consumption, we obtain a different picture of changes of energy intensity in Spain from what obtained in the first analysis. Even tough industry is decreasing its energy intensity, the overall energy intensity of the economy is increasing, due to the behavior of the household sector, which is increasing energy consumption also in absolute terms, from 490 PJ in 1976 to 1,050 PJ in 1996 (1 PJ = 10^{15} J).

This fact is usually neglected by the studies on the environmental Kuznets curve (EKC) or energy intensity that focus only in the supply side of the economy (= on changes in the paid work sectors). However, the demand side, the household sector, can be a relevant factor explaining the development of energy intensity, and should be taken in account carefully. This result, so important for policy generation, cannot be found when using the traditional approach. That is, using an analysis based on human time allocation provides new insights to the Spanish anomaly energy intensity increase.

3.2. The crucial role of changes in HA among the various sectors

When representing the different exosomatic metabolic rates of the economy (Fig. 2) we obtain important information. That figure shows that $EMR_{PS} >> EMR_{SG} > EMR_{AG} > EMR_{HH}$. This sequence is very important since from that we can realize that when studying changes in the rate of consumption of exosomatic energy per capita in a country (EMR_{AS}), we have to look at the changes in the profile of human time allocation between these different sectors.

This is shown in Fig. 3. In the upper part (A) we find that both HA_{HH} and HA_{PW} maintain approximately the same percentage of THA over the time window considered. In the lower part of Fig. 3 (B) we can see the evolution of the different HA_i as a percentage of HA_{PW}, a variable that we call X_i. The real value of EMR_{PW} and therefore its curve in time not only depends on the level of capitalization and technological efficiency of each one of the various sectors (the value taken by EMR_i) but also on the profile of distribution of "working time" over the three different sectors, PS, SG, and AG. The percentage of working time in PS and AG is decreasing, while the same percentage for SG is increasing (post-industrialization of the economy).

When combining this result with the relative value of the different EMR_i considered, we can conclude that the decrease in energy intensity in PS has been contrasted by: (1) an increase in EMR_{SG} linked to a growing size of the SG sector and (2) the increase in EMR_{HH}, occurring in a sector which is much larger than the others (Fig. 3 A). That is, to explain the overall increase in energy intensity of Spain we have to combine (using extensive and intensive variables) different changes in the characteristics of the various sectors.

Figure 2: Exosomatic Metabolic Rates of PS, SG, AG, and HH

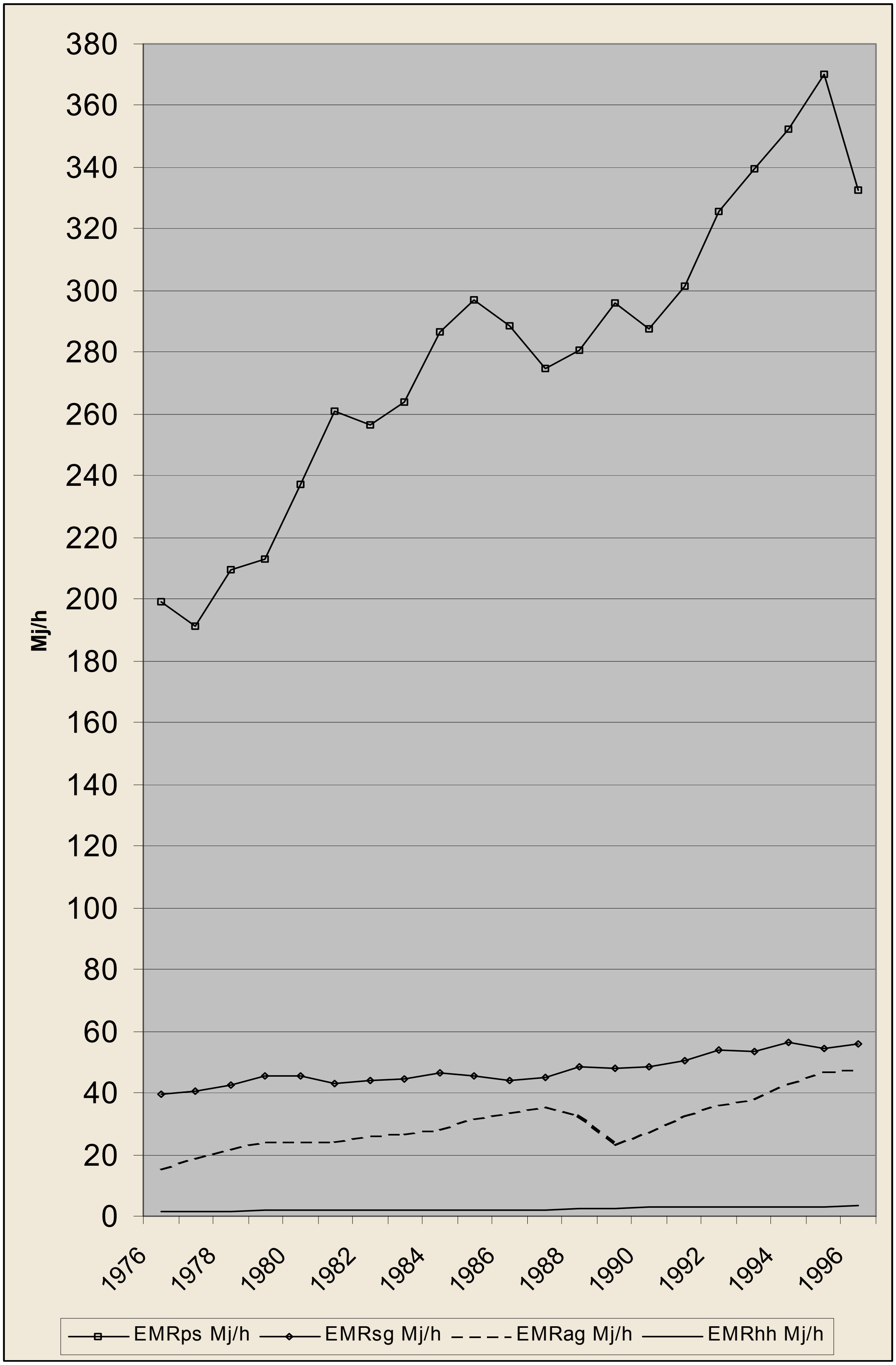
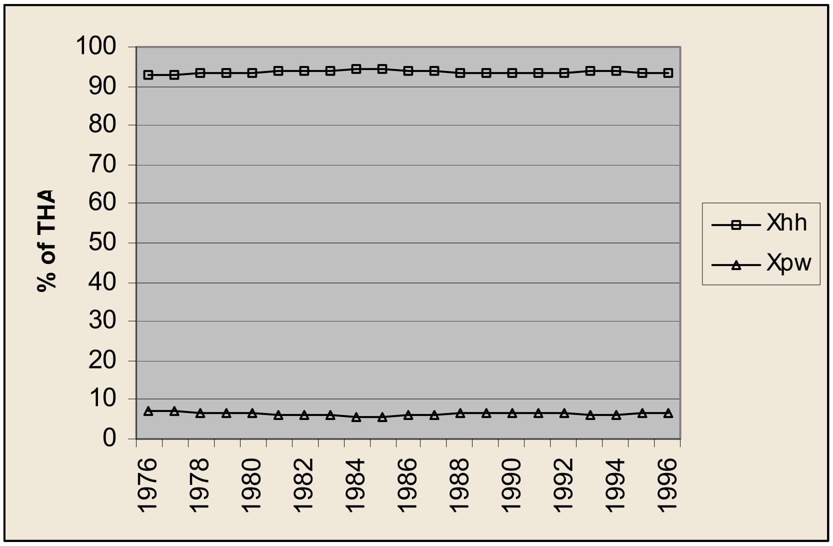
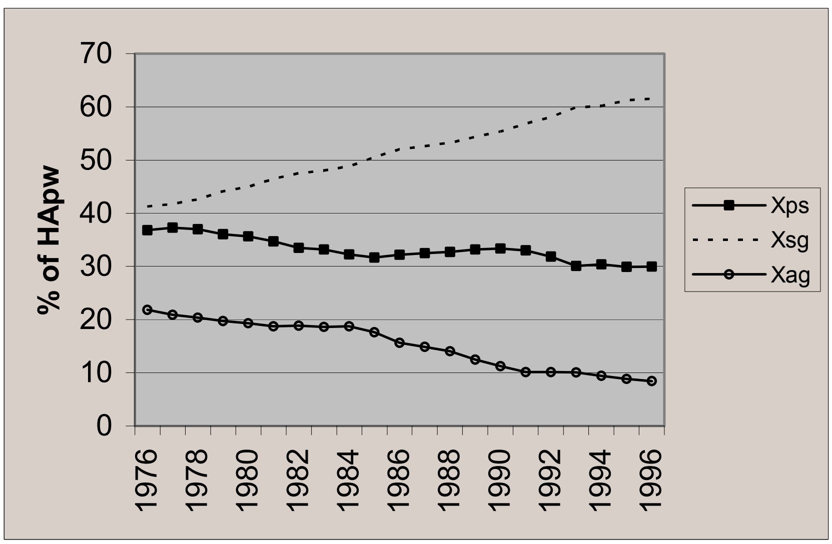


Figure 3: Distribution of working time between sectors
A: HA_{pw} and HA_{hh} as a % of THA
B: HA_{ps}, HA_{sg}, and HA_{ag} as % of HA_{pw}





3.3. The dynamics associated to economic development

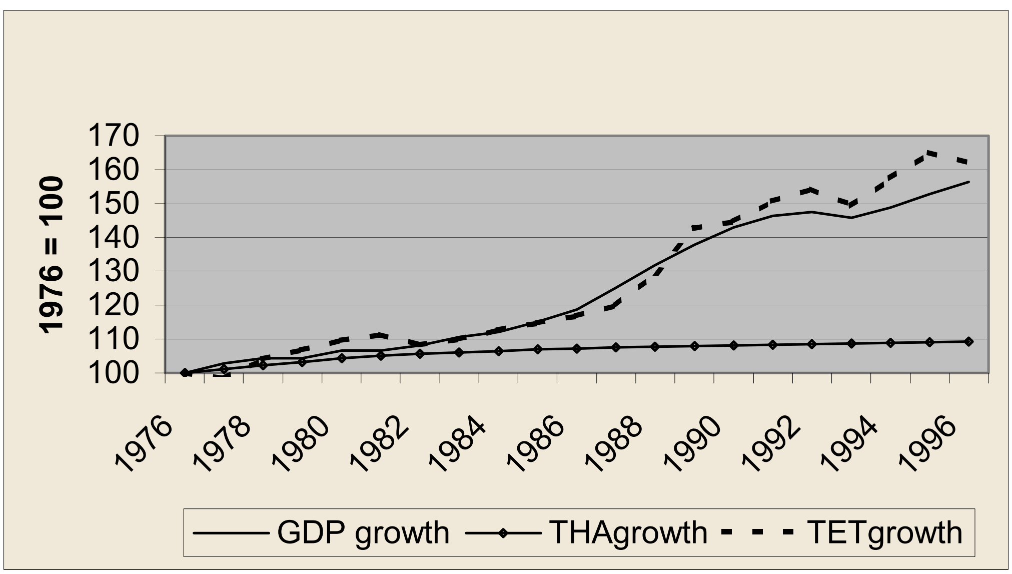
The relation between EMR_{PW} and ELP_{PW} would indicate that there is a quantitative link between GDP and energy consumption growth. However, the growth of total economic output can be explained by: (1) increase in population (dTHA/dt); (2) rise in the material standard of living ($dEMR_{HH}/dt$) or (3) increase in the capitalization of economic sectors included in PW ($dEMR_{PW}/dt$). Whenever, performance of the economy generates a surplus (an extra added value spare from what is used for its maintenance) this can be used for increase these 3 parameters.

What are the implications, then, of the link between EMR_{PW} and ELP_{PW}, shown in figure 1? In order to have economic growth ET_{PW} has to grow faster than HA_{PW}, this will be reflected in an increase in EMR_{PW}, which will be reflected into a larger availability of investment for producing GDP. Clearly the priority among the possible end uses of available surplus [= (1) increasing THA; (2) increasing EMR_{HH}; or (3) increasing EMR_{PW}] will depend on demographic variables, political choices (e.g. the ability and the willingness of compressing increases in the consumption of HH to favor quicker investments in PW), and historical circumstances (e.g. existing level of capitalization of the various sectors).

In opposition to what happened in Ecuador (see Section 4), the surplus generated by the economic development of Spain was enough to absorb both new population (due to internal demographic growth) and the exodus of workers from AG sector. In fact, in the last decades Spain has still been absorbing a large fraction of workers moving away from the agricultural sector. This process of economic development was speeded up by a compression of the increases in material standard of living (increases in EMR_{HH}) – under Franco regime there were no free-unions – which made possible to dedicate a larger fraction of this surplus to the capitalization of PW. Finally, the demographic stability of the country made possible to get into a positive spiral very quickly.

The evolution in time of GDP and TET and THA are shown in Fig. 4. Again the curves of GDP and TET are very similar (confirming the hypothesis that EMR_{PW} and ELP_{PW} are correlated). In contrast the evolution of THA is towards a stagnation rather than increase. This clearly indicates that the increase in the surplus was allocated in either increasing the capitalization of the economy (EMR_{PW}) or increasing the material standard of living (EMR_{HH}).

Figure 4: GDP, total human time and total energy consumption growth rates



The very low levels of EMR_{HH} (when compared with those of other developed countries) indicate that in the early stages of industrial development Spain experienced a certain compression of consumption. However, once EMR_{PS} reached values comparable to those of other developed countries (i.e. 300 MJ/h) and the political situation changed, the surplus was allocated mainly to boost the SG sector (increasing X_{SG}, by absorbing workers from agriculture and increasing at the same time EMR_{SG}) and to improve the material standard of living (by increasing EMR_{HH}). In particular, the capitalization of the Household sector is implying the sharp increase in EMR observed before.

When comparing the growth of EMR_{HH} and that of EMR_{PW} - as shown in Fig. 5 - we can actually see the lag-time reflecting the choices made in the process of economic development. Indeed, when Spain was still focusing on a fast capitalization of the economy EMR_{PW} was growing faster than EMR_{HH}. However, in the past 10 years, when the paid work sectors are slowing the growth rate, the increase in the material standard of living and the increase in transport were the major responsible for the increase in consumption of energy, resulting in the increase of energy intensity of Spain – Fig. 6.

Figure 5: Growth in Exosomatic Metabolic Rate (Household Sector and Productive Sectors) in Spain

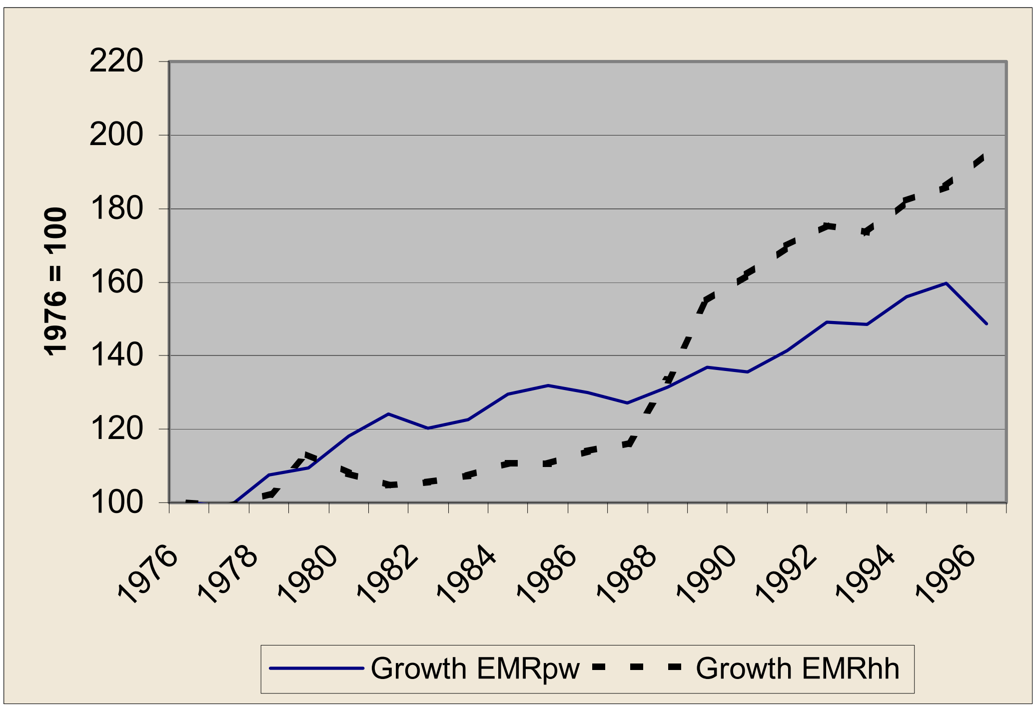
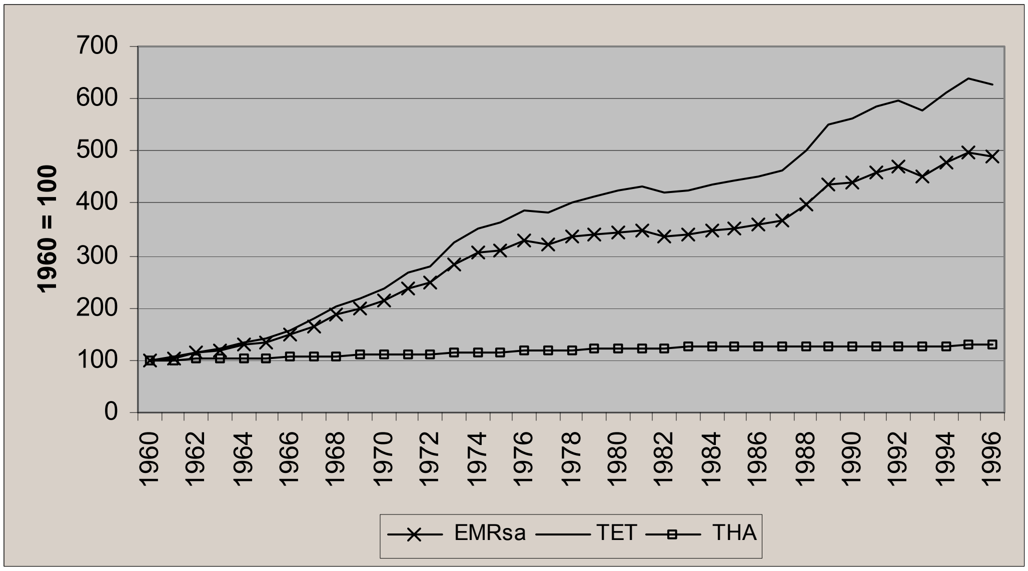


Figure 6: Population, Total Energy (TET), and Exosomatic Metabolic Rate (average of the society) for Spain.



4. A CASE STUDY OF ECUADOR

4.1. Overview

This section presents an application of the Multiple-Scale Integrated Assessment of Societal Metabolism to the recent economic history of Ecuador. Previous energetic analyses of the economic process (Cleveland *et al.,* 1984; Hall *et al.*, 1986; Gever *et al.*, 1991; Kaufmann, 1992) have indicated a clear link (theoretical and empirical) between the following: (1) the amount of exosomatic energy used in economic activities per hour of work (termed here the level of capitalization of the compartment in which human activity takes place, see Giampietro and Mayumi, 2000*a*); (2) the amount of added value generated by economic activities per each hour of work (called here Economic Labor Productivity - ELP). According to this hypothesis, if we graph changes of ELP and the amount of exosomatic energy used in economic activities per hour of work over the same compartment (e.g. within paid work, PW) during the same time window, we should find curves that look very similar. This is what Cleveland *et al.* (1984) found in a seminal paper published in *Science* when analyzing the USA and confirmed by successive studies of US economy. This section studies these theoretical and empirical implications for the Ecuadorian economy.

The text first presents a narrative of the most relevant phases in Ecuador's recent economic history: (1) a "single commodity" export oriented economy; (2) an import-substituting industrialization triggered by the oil-boom; (3) the current critical situation. Please note that the analysis has only been conducted through 1998 due to information access. Changes are described using economic variables and biophysical variables (both extensive and intensive referring to different hierarchical levels). These two parallel readings are combined at the end of the conclusions section.

4.2. Phases of recent economic history of Ecuador - narrative

Like many others less developed countries in Latin America, Ecuador had pursued an outward-oriented model of growth (Larrea, 1992: 98). This pattern prevailed from the second half of the nineteenth century to the mid-1960s when the nation began to pursue import-substituting industrialization. A moderate economic diversification and domestic market expansion took place in the following decades.

Three product-related periods can be distinguished in the historical evolution of the single-commodity export phase (Larrea, 1992). The first of these was the **cocoa period**, which can be divided into an upswing phase from about 1860 to 1920, a subsequent crisis until World War II, and then a period of senescence during which it becomes progressively less important. The second period dominated by a single export commodity was the **banana period**, which experienced a boom during 1948-1965, followed by a period of stagnation. The third commodity-driven period was linked to the exploitation of oil resources in the country. The **petroleum period** began with a boom phase from 1972 to 1982, followed in the 1980s by a crisis from which the country has partially recovered in the 1990s, though in the last five years the economic and social crisis has returned.

This section focuses on the changes that took place in the 1970s in relation to the oil boom. The country suddenly had a surplus of energy that was the trigger for the sudden economic growth in the 1970s. In order to take advantage of this opportunity, however, Ecuador had to face a huge demand for investments. We will discuss later on, using the framework of integrated assessment of societal metabolism, possible explanations and links between events described in this section. Remaining in a historic narrative, Ecuador experienced two important side-effects after the oil boom: (1) A debt crisis in 1982 linked to the decline of the import-substituting industrialization; and (2) a boost in population growth.

The combined result of these two side-effects was a period characterized by the recession and impoverishment in the 1980s. After that, at the beginning of the 1990s, the relatively favorable condition of the international financial system and the boom in exports (especially flowers, shrimp, and tropical fruits) generated an improvement in terms of stabilization and poverty. This period of relative prosperity ended, however, with a new depression occasioned by financial crisis y the political instability that characterized the last five years of the past century. In the year 2001, the economy grew 5.4% in real terms according to the Central Bank but per capita GDP was less than it was a decade earlier.

4.3. Examining these historical phases using an economic perspective

4.3.1 Country level – combining extensive and intensive variables

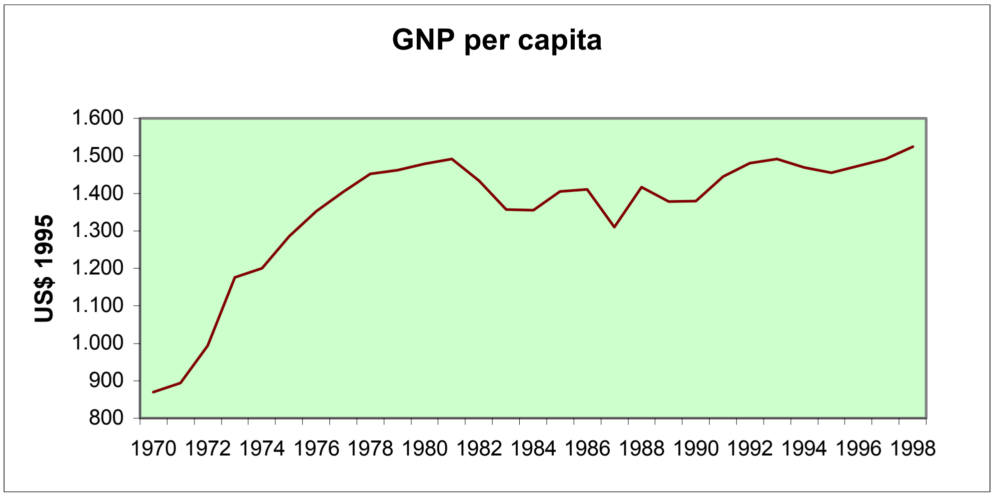
4.3.1.1 Changes in GDP per year

In 1970 the gross domestic product (GDP) at market prices (constant 1995 US$) of Ecuador was 5.2×10^9 and it was 19×10^9 (1995 US$) in 1998 (World Bank, 2000). The average growth rate of GDP between 1970 and 1998 was 3.9%. This increase reflects changes in an intensive variable, "economic output per person", and in an extensive variable, "population size".

Intensive variable: Economic output per person

The gross national product (GNP) per person was 870 (constant 1995 US$) in 1970, and 1,524 (constant 1995 US$) in 1998 (see Figure 7). Per capita real GNP has risen at an average rate of 1.2% a year between 1970 and 1998.

FIGURE 7



Source: World Bank/IBRD (2000).

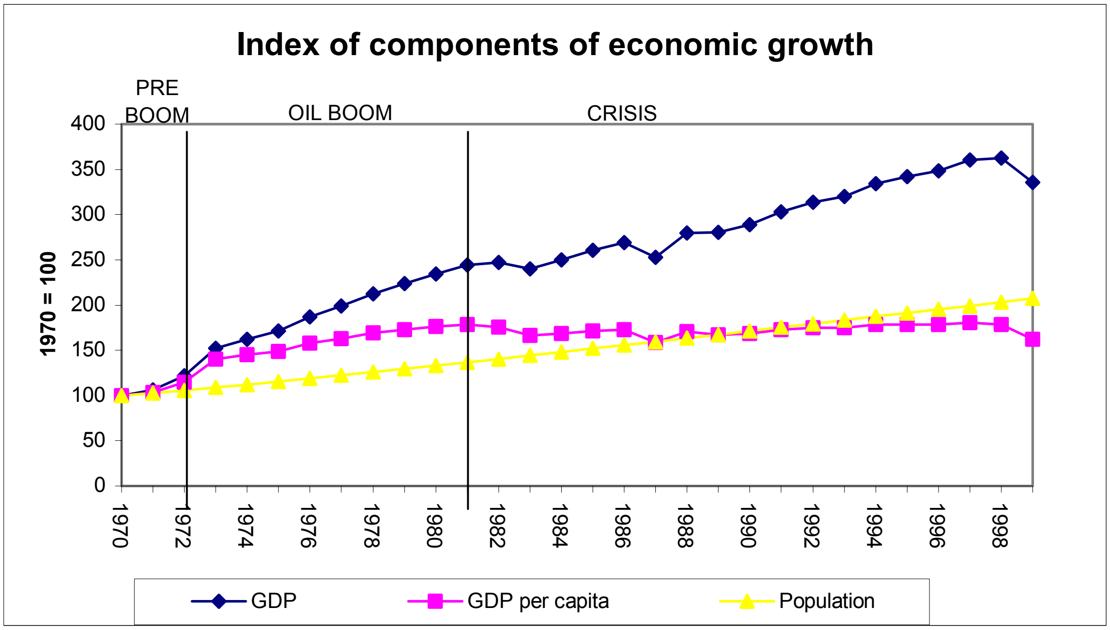
Extensive variable: Population (THA)

The Ecuadorian population doubled between 1970 and 1998, from 6 million inhabitants to 12.2 million inhabitants, with a growth rate of 2.6% a year. Now, Ecuador has a population of approximately 13.1 million people.

Combining the effect of intensive and extensive variables

Between 1970 and 1998, the rate of growth of population (2.6% per year) has been more than the double the rate of growth of economic output per person (1.2% per year). The phases described in the narrative are indicated in Figure 2. They are: (1) the pre-oil boom, before 1972; (2) the oil-related boom, between 1972 and 1981; and (3) the crisis following the oil-boom, after 1982.

FIGURE 8



Source: Calculated on basis of Banco Central of Ecuador data.

4.3.1.2 Changes in Economic Labor Productivity per year (ELP_{AS})

The Economic Labor Productivity – defined as average value for a society (ELP_{AS}) - is the value of a country's final output of good and services in a year, assessed in terms of overall added value, divided by the work hours delivered by its Economically Active Population (EAP). ELP_{AS} assesses the average productivity of a country's workers reflecting the availability of capital, technology, natural resources, and "know how".

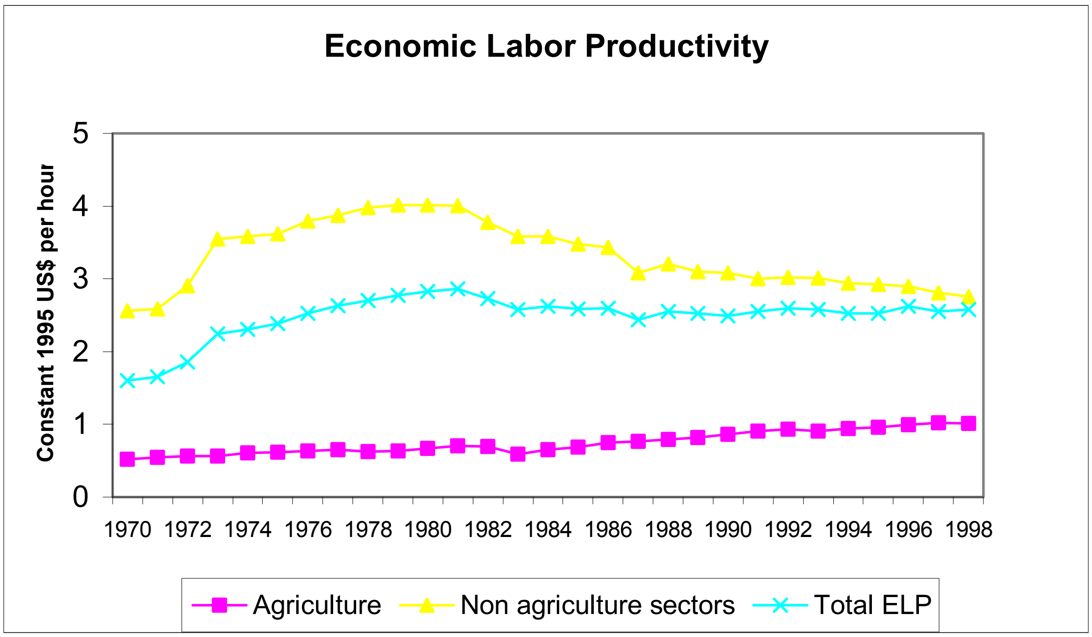
To calculate values of $ELP_{AS,}$ one must have data on GDP (presented in the previous section) and labor supply. Labor supply is proportional to (1) the size of the Economically Active Population (EAP= able-bodied people of working age); (2) unemployment; and (3) yearly workload of the labor force.

The Ecuadorian labor force has increased from 1,9 million adults in 1970 to 4,6 million in 1998 (World Bank, 2000), an average growth rate of 3.2% a year during this period. The unemployment rate was 11.5% of total EAP in 1998 and 6.1% in 1990. Data on unemployment is not available between 1970 and 1986, so a flat rate of 5% for those years is used. The "work load per year" has been calculated using a flat value of 1,800 hours/year per worker for all economic sectors.

The resulting changes in ELP_{AS} can be described as follows: In 1970 ELP_{AS} was 1.6 (constant 1995) US$/hour, rising in 1980 to 2.8 (constant 1995) US$/hour, then lowering in 1998 to 2.6 (constant 1995) US$/hour. That is, Ecuador experienced an annual average growth rate of ELP_{AS} (assessed in constant 1995 US$), which is positive over the whole period 1970 and 1998 (+ 0.9%). This positive trend reflects, however, the robust economic expansion of the 1970`s. When analyzed over the last 18 years, ELP_{AS} shows a negative trend reflecting the economic crisis.

Figure 9 shows that ELP sector growth has been negative in non-agricultural sectors and positive in the agricultural sector between 1970 and 1998. Agriculture productivity increased at 2.4% per year between 1970 and 1998. However, this can be easily explained by its very low initial value. Actually, ELP of agriculture remained well below the values of ELP reached by the other economic sectors– around one constant 1995 US$ per hour in 1998. As expected, the ELP of the industrial sector is the highest. As will be discussed later on, however, this is the sector that also requires the highest level of capitalization per worker.

FIGURE 9



Source: Calculated on the basis of World Bank/IBRD (2000) information.

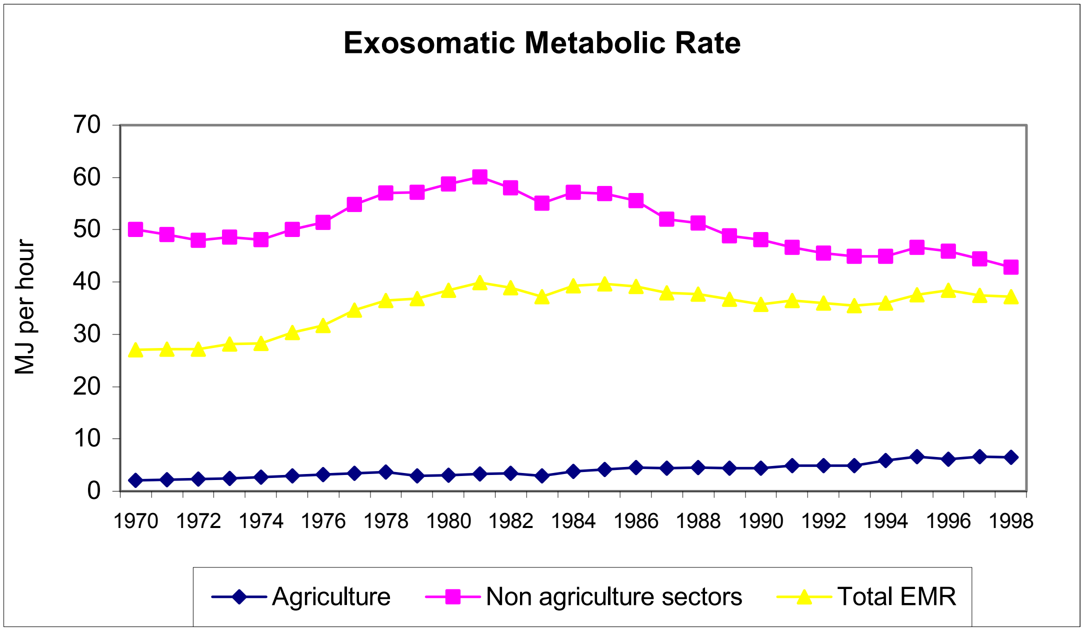
4.4. Examining the historical phases using a biophysical perspective

4.4.1 Intensive variable at country level: Exosomatic Metabolic Rate by sector

The Exosomatic Metabolic Rate of Paid Work (EMR_{PW}) has increased from 27 MJ hr^{-1} in 1970 to 37 MJ hr^{-1} in 1998. Exosomatic Metabolic Rate (EMR) is the energy of a country's final consumption in a year, referring to the activities included in a given sector, divided by the hours of human activity spent, in the same year, in the same sector. When dealing with Paid Work the exosomatic final consumption of this sector must be divided by the labor force, discounting unemployment. To arrive at an assessment per hour we also assume a flat value of 1,800 hours/year per worker.

Ecuador had a positive annual average growth rate of EMR_{PW} over the whole period 1970 and 1998 (+ 1%). Again, this trend reflects the robust economic expansion of the 1970's. Between 1970 and 1998, however, EMR grew positively in agriculture and negatively in non-agricultural sectors (see **Figure 10**).

FIGURE 10



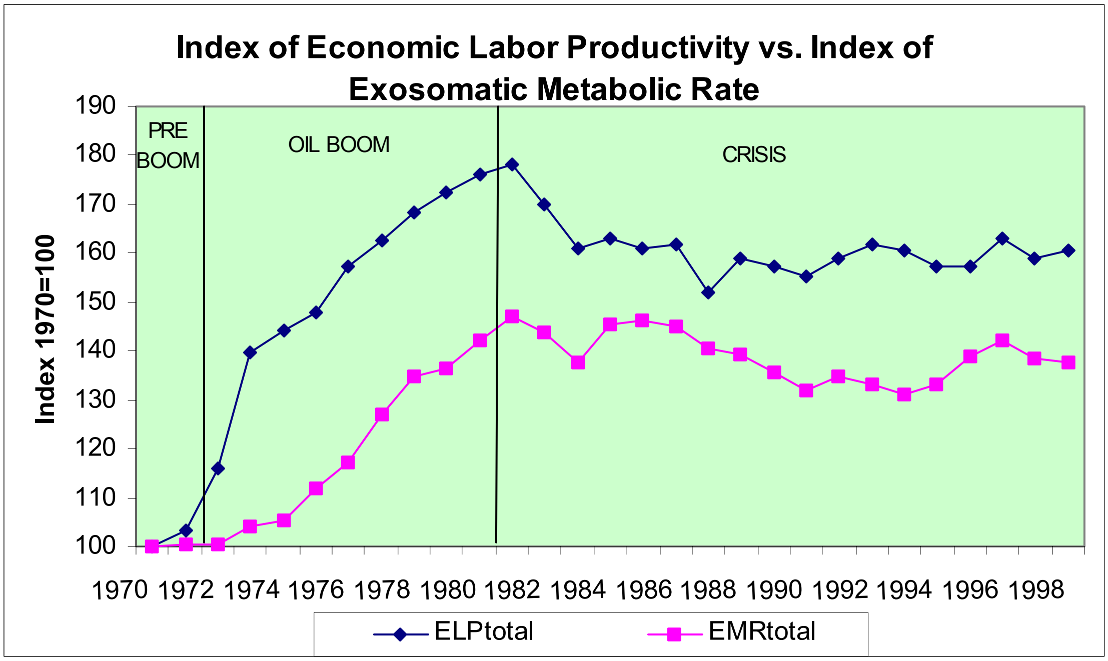
Source: Calculated on the basis of OLADE-SIEE (1999) and World Bank/IBRD (2000) information.

4.5. Examining the historic phases using an integrated description

5.5.1 At the country level - The link between capitalization of Paid Work and Economic Labor Productivity: The negative spiral leading to the crisis

The relation between the index of ELP_{AS} (1970=100) and the index of EMR_{PW} for Ecuador over the considered period is shown in **Figure 11**. The figures confirm the link suggested by previous authors. The curves of ELP and EMR for the Paid Work (PW) sector of Ecuador look very similar. Ramos-Martin (2001) in his historic analysis of Spain obtains the same result.

FIGURE 11



Source: Calculated on the basis of OLADE-SIEE (1999) and World Bank/IBRD (2000) information.

What are the implications of the link between EMR_{PW} and ELP_{PW}? In a country such as Ecuador this implies that in order to have economic growth the value taken by the parameter ET_{PW} (exosomatic energy throughput of Paid Work) has to grow faster than the value taken by the parameter HA_{PW} (human allocation of Paid Work).

Put in another way, the condition for economic growth can be expressed as:

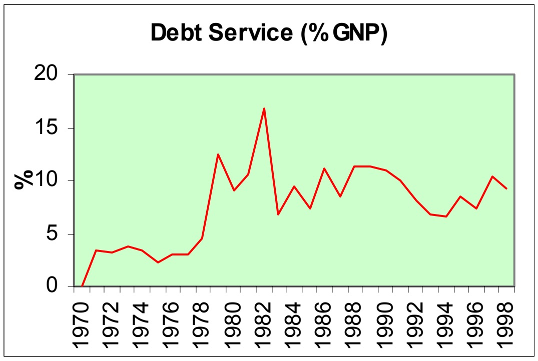
$$d(\boldsymbol{ET}_{PW})/dt > d(\boldsymbol{HA}_{PW})/dt \qquad (1)$$

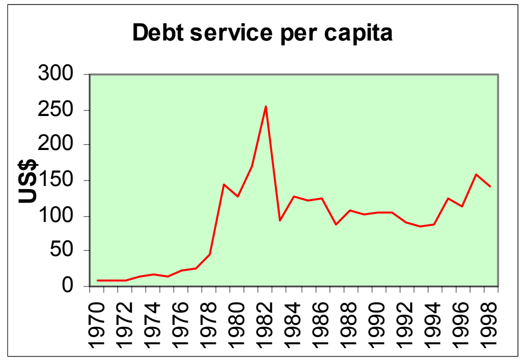
However, in the case of Ecuador, two facts have prevented the realization of this condition:

A. The burden of debt service since the 80s

The debt crisis exploded in 1982 when the Ecuadorian economy suffered a series of adverse shocks, worsened by periods of declining world oil prices. This was particularly damaging due to the heavy dependence on oil exportation by the economy. Ecuador still has, today, one of the largest per capita external debt levels in Latin America. At the end of 2001 its public debt stood at $11.2 billion (62 percent of GDP), according to Central Bank of Ecuador (2002). **Figures 12 and 13** show two self-explanatory indicators: (a) debt service (as % of GDP) and (b) debt service per capita.

FIGURES 12 AND 13





Source: World Bank/IBRD (2000).

The cost of "buying capital" in the 70s to take advantage of the opportunity given by oil (to be able to increase the levels of EMR) translated into the existence of a large debt in the 1980s. This in turn prevented (and it is still preventing) Ecuador from using its disposable added value to further capitalize its economic sectors. The flow of disposable added value is used for servicing the debt rather than for keeping high $d(ET_{PW})/dt$. In effect, the sectors providing well paid jobs, which are the ones requiring also the highest level of capitalization, are the most affected by the crunch.

The debt crisis of 1982 implied a fall in government resources available for spending, and the fall in oil prices in the international market had a similar effect. This implied that demand dropped, real wages declined as a result of devaluation of the currency, and as a result of all this, production and energy consumption fell.

Of course, it was not only the debt service that caused lower growth and energy consumption. There were other exogenous shocks such as the fall in oil prices that also reduced Ecuador's income and therefore caused a lowering in effective demand, and therefore of production and employment and energy consumption.

B. The baby boom of the 1970s resulted in an expanded work force in the mid-1980s.

Rapid population growth allowed by the oil-boom in the 70s implied a growth in $d(HA_{PW})/dt$ in the 1980s, which would have required the creation of an adequate number of job opportunities. As noted earlier, this would have required a massive capitalization of ET_{PW}. However, due to the shortage of capital to expand job opportunities in the PS sector and the location of the households that experienced the largest demographic growth (largely residents of rural areas), it was unavoidable that the vast majority of this new work force entered into the agricultural sector. However, the agriculture sector had the lowest economic labor productivity of any economic sector. The already difficult process of urbanization (requiring the fast building of infrastructures for which capital is not available) does not indicate an easy way out of present situation, at least in the short term.

5. CONCLUSIONS

In this paper we presented an example of application of a Multiple-Scale Integrated Assessment of Societal Metabolism to the analysis of recent economic history of Ecuador and Spain. Societal metabolism analysis was used to integrate economic analyses with a biophysical view of the economic process. This was done with the goal of providing a complementary tool of analysis to be used in addition to other analytical tools already available (historical analysis, social analysis, institutional analysis, economic analysis, etc.).

The major advantage of this integrated method of analysis is not in the provision of totally "new" or "original" explanations for events. Rather it creates the possibility of integrating the various insights provided by different disciplines, discovering contradictions among them, or on the contrary, agreements.

The principal conclusion of this article is the confirmation of a very close relationship between the productivity of work and the Exosomatic Metabolic Rate per hour using data from Ecuador and Spain. The relationship between these two curves does not imply that these countries have experienced the same course of development, a fact that was confirmed by the societal metabolism. In fact, each nation's arrival at this similar development trajectory has been totally different.

For example, when comparing the Spanish trajectory of development with that presented for Ecuador, it can be said that in the case of Spain, low population growth and low debt service allowed getting into a positive spiral. Available surplus was first invested to increase EMR_{PW} ($dET_{PW} > dHA_{PW}$). This fact led to an increase in ELP_{PW} that allowed the increase in the surplus (due to the temporary holding of EMR_{HH}). When a sufficient level of capitalization was reached in the PS sector (EMR_{PS} = 300 MJ/h) the surplus was allocated to expand the SG sector (by absorbing the workers in AG with a reasonable amount of investment – since $EMR_{SG} < EMR_{PS}$) and to increase EMR_{HH}. It has to be stressed that the dramatic difference in demographic trend between Spain and Ecuador is crucial to explain the different side of the bifurcation taken by Spain in its trajectory of development.

In the case of Ecuador there has been a marked difference in its social and economic development when compared with developed countries. In Ecuador, the principal reason of the decapitalization of households and of society in general was the exit of economic capital through problems related to its structural development such as poverty, inequality and unjust international relationships that are observable in problems such as foreign debt. In effect, in the case of foreign debt, when foreign debt is compared to the large macroeconomic aggregates, it exceeded all of the normally acceptable financial parameters in that there was a negative flow of financial resources out of the country, shown in the trajectory of the curves.

According to these points, the crisis experienced by Ecuador following the oil boom can be seen as generated by two factors: (1) the necessity of a fast capitalization of the economy of the country (both in the productive sectors and in building infrastructures) in that decade; (2) the side effect on demographic trends allowed by better economic conditions or, better said, by a widespread expectation for better economic conditions. As a consequence of this fact, the servicing of the debt, among other factors like exogenous shocks as the fall in oil prices, reduced the speed at which the country could capitalize its economic sector (dET_{PW}/dt), at the very same moment in which the rate of dHA_{PW}/dt was peaking. As result of this, the rate of growth of HA_{PW} was higher than the rate of growth of ET_{PW}.

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