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Different trajectories of exosomatic energy metabolism for Brazil, Chile and Venezuela: using the MSIASM approach*

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Abstract: The article presents an application of the MSIASM accounting method for assessing economic development options for Brazil, Chile, and Venezuela by coupling economic data with energy use through different sectors and at different hierarchical levels. The paper shows the relevance of complementing a monetary reading of development with a biophysical one, and arrives to the main conclusion that the current development model shown by the three economies, based on almost solely increasing exports, is not sufficient for guaranteeing a long-term strategy of economic development that reaches all sectors and components of their economies, including the household sector.

Keywords: Development, Energy, Social Metabolism, MSIASM, Brazil, Chile, Venezuela

JEL Codes: O11, O13, O54, Q01, Q57, Q58

1. INTRODUCTION

Economic development goes hand in hand with an increase in the consumption of natural resources. Some analysts use material flows to describe such relationship [Eurostat 2001, Weisz et al., 2006], or exergy [Ayres et al., 2003]. Instead this paper will use a characterisation of the exosomatic energy metabolism based on expected benchmark values to describe possible constraints to economic development posed by available human time and energy.

The aim of the paper is to identify types of exosomatic energy metabolism of different societies to interpret its consequences for economic development. This is done with the application of the accounting methodology called *Multi-Scale Integrated Analysis*

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of Societal Metabolism (MSIASM) to the particular case of energy metabolism for the analysis of the economies of Brazil, Chile and Venezuela.

MSIASM establishes a representation of the performance of a system in terms of a set of attributes by using ‘parallel non equivalent descriptive domains’. The relationships among economic information regarding the generation and consumption of added value, demographical information regarding the availability of human time, and energy consumption data, were examined. This accounting methodology can be seen as a ‘discussion support tool’, since it allows both learning from trajectories of past development, and build robust scenarios of further development.

This is done in a number of steps summarized as follows:

(i) Choosing variables able to map the size of the system as perceived from within the system itself by means of fund variables such as “hours of human activity”.
(ii) Choosing variables able to map the size of the system as perceived by its context in terms of exchanged flows with the surrounding environment by means of flow variables. They describe the interaction of the system with its context. Examples are: “exosomatic energy”, “added value”, “other flows of key material inputs”.
(iii) Mapping the nested hierarchical structure of the system under analysis with both fund and flow variables and the ratio of the two (an intensive variable). The resulting family of intensive variables or coefficients can reflect a *biophysical* accounting (e.g. exosomatic energy flows per unit of human activity, MJ per hour) as well as a *monetary* accounting (flows of added value per unit of human activity, dollars per hour).

2. MSIASM BASICS

Multi-Scale Integrated Analysis of Social Metabolism (MSIASM) was introduced by Giampietro and Mayumi [2000a, 2000b] and finally formulated by Giampietro [2003]. The approach has been applied to Ecuador [Falconi, 2001], Spain [Ramos-Martin, 2001], China [Pastore et al., 1999; Ramos-Martin, 2005], Vietnam [Gomiero and Giampietro, 2001; Ramos-Martin and Giampietro, 2005], and Lao PDR [Grünbühel and Schandl, 2005]. One of the advantages of the approach is that it enables us to put different biophysical variables, i.e. energy and time, in relation to each other, analyzing the balance between limited resources each society exhibits. The focus is on energy and the available time constraints to further development, but one could consider different limiting factors depending on the system under analysis, such as available land (as for India or China) or water (as for Australia).

MSIASM uses four scale variables: total human activity (THA), total energy throughput (TET), human activity allocated to the productive sectors of the economy (i.e. agriculture, HA_{AG}; industry, HA_{PS}; and services, HA_{SG}) and energy throughput in these sectors (i.e. energy consumption in agriculture, ET_{AG}; industry, ET_{PS}; and services, ET_{SG}). These variables determine the size or scale of an economy in relation to the time that is actively spent and the energy that is available.

In the accounting for human time and its allocation to different activities we start with total human time, i.e. the population times 8,760 hours representing one year. From this budget (THA) we subtract the physiological overhead including all the time spent at the person level including time for sleeping, eating and personal care. In a second reduction we subtract a social overhead referring to those fractions of time, which can be best described as non active time including children in childcare and education, elderly after retirement and leisure time. While the physiological overhead on human time seems to be rather constant in the long run the social overhead allows for decisions such as how long children stay in education and from when on people enter retirement, or how much free time is conceded to individuals. After these reductions the amount of time, which appears in the economy/society as effective work time is determined. Work time serves for the reproduction of the household (cooking, cleaning, childcare) as well as all economically productive activities. The economically productive time, i.e. work time in agriculture, industry or services can be spent in subsistence (as is the case in traditional society's in the agricultural sector) or in formal employment. In our analysis we concentrate on the work time spent in agriculture, services and industry irrespective of whether the time is spent in subsistence or in the market (i.e. human activity in the productive sector, HA_{PW}).

The rest of available time, the non-working time, for which we use the sub index HH, would represent the pure dissipative component of the system, since is not directly related to production, but rather to consumption of the added value generated (i.e. human activity in non working activities, HA_{HH}).

Total energy throughput (TET) refers to the primary energy consumption in the economy/society including fossil fuels and wood fuel that are commercialised. Energy throughput in the sectors responsible for production (sub index PW) summarizes primary energy consumed in agriculture (AG), industry (PS), and services and government (SG), that is, the sectors generating economic added value.

Combining the extensive variables referring to these different compartments – e.g. THA and TET – results in a set of intensive variables associated with their Exosomatic Metabolic Rate (EMR), referring to the amount of total primary energy consumed per hour of active human time. The same equation can be established for each of the productive sectors of the economy (i.e. $ET_{AG}/HA_{AG} = EMR_{AG}$) representing the level of energy metabolized by that sector, which was used as a proxy variable for the level of capital accumulation of that particular sector (i.e. machinery and fuel consumption). EMR is measured in MJ/hour.

Changes in the scale (extensive) variables only indicate that a system is growing (and very rarely shrinking) whereas changes in the intensive variables, when compared over time, are indicating a qualitative change. For instance a rise in the energy available per human time, that is a higher EMR shows improvements either in the energy supply in households or the tertiary sector or in the capital accumulation of the economy (i.e. the successful replacement of machine power for human work in the productive sector considered).

This biophysical reading (mapping available energy against human time) is complemented by a monetary reading, i.e. mapping economic added value against human time. In this economic portrait the variables for primary energy consumption are replaced by overall GDP and GDP in the considered productive sector of the economy. Resulting intensive variables are economic added value per unit of active time (GDP/THA) or economic labour productivity in the different sectors (ELP_i).

Taken together, the biophysical and monetary reading should support a deeper understanding of the functioning of the economies in particular of the different use of resources compared to economic development in the three countries. The assessment is done for two points in time, namely for the years 1980 and 2000.

Before going to the results, one major hypothesis that is used in integrated assessment is the correlation between empowered productive sectors (assessed by their exosomatic energy consumption) and their ability to produce GDP, or economic labour productivity. Accepting this hypothesis implies that EMR_{PW} and ELP_{PW} are correlated, as was suggested by authors such as Cleveland et al. [1984] or Hall et al. [1986]. The high correlation found in the historic analysis of the US economy [Cleveland et al. 1984] was confirmed by Ramos-Martin [2001] for Spain and Falconi [2001] for Ecuador.

The logic of the process of development would be as follows: In order to have economic growth, the energy consumption in the productive sectors (ET_{PW}) has to grow faster than the time allocated to those activities (HA_{PW}), this will be reflected in an increase in the energy used per hour of work (EMR_{PW}), which is also reflecting a larger availability of investment for producing GDP. Clearly, the priority among the possible end uses of available surplus [= (1) increasing total population; (2) increasing the material standard of living; or (3) increasing the capital accumulated in the economy] will depend on demographic variables, political choices (e.g. the ability and the willingness of compressing increases in the consumption of the household sector to favour quicker investments in the productive sectors), and historical circumstances (e.g. existing level of capital accumulated of the various sectors).

Summarising, the economy was divided into two main subsystems: Paid-work sector (PW) responsible for generating added value, and Household sector (HH) responsible for consuming added value. The paid-work sector can be split into Industry, mining and energy (PS), Services and Government (SG), and Agriculture (AG), and our main variables are therefore:

THA: Total human available time in the society in one year, that is population time 8760 hours.
HA_i: Time allocated to activity i.
TET: Total energy throughput of the society, or the amount of exosomatic energy the society consumes in one year.
ET_i: Energy consumption by activity i.
EMR_i: Exosomatic metabolic rate of activity i, which measures the amount of energy consumed per hour of available time allocated to that activity, and is used as a proxy for the level of capital accumulation of that sector.
ELP_i: Economic labour productivity, which states the amount of added value generated by one hour of working time in activity i.
$(ELP/EMR)_i$: which measures the energy efficiency of productive activities, that is how much added value is generated by one unit of energy spent in activity i.

3. PRESENTATION OF RESULTS

Using the accounting method described above, section 3 presents the results for the three countries analysed at three hierarchical levels, that of the national economy, that of consumption vs. production, and that of the singular economic sectors. First, however, some key characteristics about Brazil, Chile and Venezuela need to be considered in order to better interpret the results later.

Basic characteristics of the selected three countries

The three countries for which we are going to present results have certain common characteristics that we would like to stress. For a full description of the recent history of these economies see Bulmer-Thomas [1995] or Franko [1999]. Economic development is constrained by their integration into international markets. Older industrialised economies like the UK or most of western Europe developed by investing economic surplus from agriculture to fund a process of rapid industrialisation. This has not been the case for Brazil, Chile and Venezuela. The three economies are dependant on exporting commodities and natural resources, from agricultural products, from copper to oil. This means their economies are playing a particular role in the era of globalisation. The role is that of cheap suppliers of raw materials to the industrialised world. As shown by Eisenmenger et al. [forthcoming] in 2002 the share of the value of primary exports over total exports was 44% in Brazil, 80% in Chile and 89% in Venezuela. This has translated in the fact that in the period of 20 years under analysis economic growth has been disappointing in all countries but Chile, in contrast to what standard trade theory would imply.

The three countries have a large fraction of their population living in cities, they are mostly urban economies, where the tertiary sector (including government) is oversized. Finally, regarding their relation with other countries, they all are more specialised in capital-intensive primary exports than in labour-intensive goods.

Main results at three hierarchical levels

Table 1 shows data derived from the use of the MSIASM accounting approach for the three countries at three different hierarchical levels. *Level n* represents the unit of analysis, in this case the nation; *level n-1* shows the disaggregation of human time into working and non-working time, that is, between production and consumption of added value; *level n-2* explains the composition of working time, by representing the different economic sectors, Agriculture (AG), Industry (PS), and Services and Government (SG). In all cases, we represent the extensive variables that are defining the scale of the system: human time (HA_i), the use of resources, in our case energy (ET_i), and the economic output (GDP_i). We also show the relative intensive variables that result from the combination of the others, such as the energy requirement per hour of working time (EMR_i), and the productivity of labour (ELP_i). We have added the energy efficiency per sector measured as the relation between the added value generated and the energy consumption in a sector (ELP/EMR), measured in dollars per Mega Joule.

3.2.1. At level n or the nation

The first result we find when looking at the national level for the three economies is that the differences in size between the economies are reflected in both GDP and energy consumption. It is interesting to notice that in the three countries energy consumption (TET) grows faster than GDP in the period of analysis. By no means at all these countries are reducing their energy intensity. This is reflected in an increase in EMR_{SA} (MJ of energy consumption per unit of human time). However, only Chile is able to increase that variable at a 2.9% per year. Later we will see whether the increase in the energy metabolised translates into higher level of standard of living or goes to increases in the capitalisation of production.

Table 1: Main MSIASM variables for Brazil, Chile and Venezuela (1980-2000)

	Brazil			Chile			Venezuela		
	1980	2000	annual growth rate	1980	2000	annual growth rate	1980	2000	annual growth rate
TET PJ	4.685	7.772	2,4%	405	1.013	4,5%	1.492	2.373	2,2%
THA Gh	1.065	1.493	1,6%	98	133	1,5%	132	212	2,3%
EMR_{SA} MJ/h	4,40	5,21	0,8%	4,14	7,60	2,9%	11,29	11,21	0,0%
GDP Mio 90$	361.546	567.040	2,2%	23.934	55.149	4,1%	45.319	58.172	1,2%
ELP $/h	3,96	3,74	-0,3%	3,33	4,65	1,6%	4,84	2,99	-2,3%
ELP/EMR_{PW} $/MJ	0,11	0,02	-6,9%	0,09	0,39	7,2%	0,04	0,15	6,9%

	Brazil			Chile			Venezuela		
	1980	2000	annual growth rate	1980	2000	annual growth rate	1980	2000	annual growth rate
ET_{PW} PJ	3.261	5.879	2,8%	265	692	4,7%	1.203	1.975	2,4%
ET_{HH} PJ	1.424	1.893	1,4%	139	321	4,1%	290	398	1,5%
HA_{PW} Gh	91	152	2,4%	7	12	2,4%	9	19	3,5%
HA_{HH} Gh	974	1.341	1,5%	90	121	1,4%	123	192	2,2%
EMR_{PW} MJ/h	35,70	38,78	0,4%	36,96	58,34	2,2%	128,47	101,53	-1,1%
EMR_{HH} MJ/h	1,46	1,41	-0,2%	1,54	2,64	2,6%	2,36	2,07	-0,6%
(ET_{HH}/TET)	0,30	0,24	-1,0%	0,34	0,32	-0,4%	0,19	0,17	-0,7%

	Brazil			Chile			Venezuela		
	1980	2000	annual growth rate	1980	2000	annual growth rate	1980	2000	annual growth rate
ET_{AG} PJ	241	306	1,2%	3	8	4,1%	1	7	10,7%
ET_{PS} PJ	2.355	4.209	2,8%	208	533	4,6%	978	1.636	2,5%
ET_{SG} PJ	665	1.363	3,5%	54	151	5,0%	224	332	1,9%
HA_{AG} Gh	27	31	0,7%	1	2	1,8%	1	2	1,7%
HA_{PS} Gh	23	30	1,4%	2	3	2,4%	3	4	2,5%
HA_{SG} Gh	42	90	3,7%	4	7	2,6%	5	13	4,4%
GDP_{AG}	22.752	39.236	2,6%	1.249	3.576	5,1%	2.147	2.919	1,5%
GDP_{IND}	132.758	153.877	0,7%	8.030	18.240	4,0%	19.178	28.966	2,0%
GDP_{SG}	182.868	338.432	3,0%	13.027	29.439	4,0%	19.283	23.532	1,0%
EMR_{AG} MJ/h	9,01	9,82	0,4%	2,94	4,67	2,2%	0,56	3,35	8,9%
EMR_{PS} Mj/h	104,42	139,08	1,4%	122,28	192,13	2,2%	377,57	376,90	0,0%
EMR_{SG} Mj/h	15,81	15,12	-0,2%	12,50	20,45	2,4%	41,78	25,31	-2,4%
ELP_{AG} $/h	0,85	1,26	1,9%	1,07	2,09	3,2%	1,53	1,47	-0,2%
ELP_{PS} $/h	5,89	5,08	-0,7%	4,72	6,57	1,6%	7,41	6,67	-0,5%
ELP_{SG} $/h	4,35	3,76	-0,7%	3,02	3,99	1,3%	3,59	1,79	-3,3%
X_{AG}	0,29	0,21	-1,7%	0,16	0,14	-0,6%	0,15	0,10	-1,8%
X_{PS}	0,25	0,20	-1,0%	0,24	0,23	-0,1%	0,28	0,22	-1,0%
X_{SG}	0,46	0,59	1,2%	0,60	0,62	0,2%	0,57	0,67	0,8%
ELP/EMR_{AG} $/MJ	0,09	0,13	1,5%	0,36	0,45	1,0%	2,75	0,44	-8,4%
ELP/EMR_{PS} $/MJ	0,06	0,04	-2,0%	0,04	0,03	-0,6%	0,02	0,02	-0,5%
ELP/EMR_{SG} $/MJ	0,27	0,25	-0,5%	0,24	0,20	-1,0%	0,09	0,07	-0,9%

Note: Energy data was obtained from Internacional Energy Agency Data Services (download December 9, 2004). Employment data was obtained from the Internacional Labour Office Statistics online (LABORSTA, http://laborsta.ilo.org/). GDP figures in constant 1990 USD (UN Statistics Division 2004). Population from UN Statistics Division 2004.

Another interesting result is that the productivity of labour (ELP) only increases in Chile, and decreases in both Brazil and Venezuela. Accepting the hypothesis mentioned before of the relationship between energy consumption and physical capital stock, and therefore productivity, this result already indicates that these two countries seem to have failed in directing energy to production. As we will see later this poses some doubts on future development options, and is maybe reflecting a case that has been named *Dutch disease*[‡]. In fact, Brazil gets less efficient in the consumption of energy. In 1980 it made 11 USD cents out of one MJ of energy, and this figure went down to just 2 USD cent in 2000. So, Brazil consumes more energy (TET), but uses it more inefficiently (ELP/EMR_{PW}) reflected in a lower labour productivity (ELP). It does not increase material standard of living (EMR_{SA}).

3.2.2. At level n-1

When scaling down to see the performance of the two sectors of production (PW) and consumption (HH) we see first that energy use for production (ET_{PW}) grows more than for consumption (ET_{HH}) in Brazil and Venezuela, while the reverse is the case for Chile. This means that the growth in overall consumption of energy we saw before has been mainly directed towards increasing the amount of physical capital found in these economies, rather than in boosting the material standard of living of households. In fact only Chile increases the amount of energy consumed by households (although still low if compared with developed countries), while in Brazil and Venezuela it decreases at a yearly rate of 0.2% and 0.6% respectively.

Another interesting result is that working population (HA_{PW}) is increasing at high yearly rates in the three countries, advancing the need for future capital to be invested in providing them with capital (such as machinery) per worker. Despite the increase in energy allocated to production, due to the rapid growth of working population in Brazil and Venezuela, the amount of energy controlled per hour of work (EMR_{PW}), which we use as a proxy for the level of capital accumulation, grows a mere 0.4% per year in Brazil, and alarmingly decreases at 1.1% per year in the case of Venezuela. Since, as discussed earlier, this variable is closely linked to labour productivity, one can expect low rates of labour productivity in the near future.

This result is also indicative of the kind of economic activity these countries are based on. Since energy used by consumption activities is growing less than energy used for production, the share is reducing over time, meaning more energy is used to support production. This makes it relevant to analyse how the different sectors use energy.

3.2.3. At level n-2

‡ The term Dutch disease was coined by The Economist (November 28, 1977, pp.82-83) to explain the relationship between the exploitation of natural resources and the decline in the manufacture sector. It implies that an increase in revenues from natural resources will de-industrialise a nation's economy by raising the exchange rate, which makes the manufacturing sector less competitive.

Finally, when going down to the level of economic sectors it was possible to observe considerable differences between the three countries. First of all, one may note that only Chile shows a balance in the growth of energy consumption for the three sectors. Brazil is increasing consumption in services more rapidly, as Venezuela does for agriculture. However, the increase in energy is not enough to compensate for the increase in working population in a particular sector (HA_i), this is why EMR is only growing in manufacturing in Brazil, and in agriculture in Venezuela. That is, these two countries are boosting two sectors that are mainly driven by exports, either of light manufacturing or agricultural products, while Chile is spreading growth through all sectors, therefore gaining in economic resilience. In this sense, the decrease in labour productivity in Brazil and Venezuela can be explained not only by the low increase in energy consumption, but because they are still absorbing large amounts of working population coming from agriculture in the services sector.

As a result, in both Brazil and Venezuela the rate of capital accumulation (the relative increase of ET_{PS} versus HA_{PS}) in the manufacturing sector is not keeping the pace with the increase in work force (the increase in HA_{PS} generated by the combined effect of population growth and movements across age classes of youngsters into the work force). As a result EMR_{PS} is decreasing and this is the reason why labour productivity (ELP_{PS}) is decreasing and will continue to decrease in the near future, unless the existing trend, of the internal profile of energy and human time use, changes. These two economies are producing mainly for export, and this is not reflected in increases in the material standard of living of their population, in contrast to Chile.

Interpretation of results: future development options

Economic development over time is not only constrained or framed by internal conditions such as resource endowment (natural resources, labour force, knowledge), but it is also affected by external constraints upon national economies such as the different role an economy is playing at the world level, either because of historical lock-in (i.e. enclave and extractive economies), or because national strategies of development must be conducted under international economic, and political settings (i.e. World Trade Organisation, IMF or World Bank dictates).

South America is integrated into world markets as a provider of raw materials, especially minerals and fossil fuels. Extraction of raw materials for exports thus characterizes those countries and results in high levels of material extraction and a negative physical trade balance [Eisenmenger et al., forthcoming]. Since raw materials only gain low and fluctuating prices on world markets, profits from specialization on raw material exports in return do not provide high economic gains. The specific role of South America countries in the world economy results in a high specialization and concentration on a very small number of economic activities and a high dependence on world markets.

One critical issue is that of how to incorporate new labour force in the economy without lowering the energy metabolized by each worker. This can only be done by increasing the total energy used by the economy. This result is more obvious in Chile where we could see labour force shifting from agriculture (with less consumption of energy per hour) to industry (with higher and increasing consumption of energy per hour of work). Actually, authors dealing with the deterioration of the terms of trade, such as Sapsford and Balasubramanyam [1994], see diversification as a way out to this trap of specialisation. But that requires capital accumulation, i.e. increases in the energy metabolism reflected in an increase of the amount of energy controlled per hour of work.

On the other hand, the large fractions of population that are still fixed to the agricultural sector in the region, are likely to be released sooner or later, putting more pressure on these economies to raise their level of energy consumption. The problem, again, is that both the amount of energy metabolized in agriculture or services per hour of labour (EMR) is much lower than the EMR in the industry sector, and so is the productivity of labour. To make things more difficult, the large amounts of energy in industry (which in our analysis includes energy and mining sectors) are not coupled with high economic return. Therefore the necessary move from agriculture to industry will imply a huge increase in energy demand by these countries.

4. DISCUSSION AND CONCLUSION

In conclusion, according to the data presented in this paper is that a strategy of economic development based on exporting natural resources and cheap labour cannot be maintained if the goal is further economic development spreading to the household level. There is the need of overcoming the pace of growth of the work force (associated with population) by investing more energy in capital accumulation for production that eventually may bring countries upward in the ladder of added value generation.

Relying mainly on incomes from the export of natural resources is not an appropriate economic strategy since, apart of de-capitalising the economy, these are activities that require large amounts of capital and energy per worker and do not generate large amounts of jobs. This implies that an internal demand finds it more difficult to pick up. Moreover, countries relying on the exploitation of natural resources may face the so-called Dutch disease which implies an overvaluation of the local currency, a loss of competitiveness, and therefore a decline in the secondary sector that translates in both trade deficit and no incentives for new activities, and investment in manufactures.

But it seems to us that a strategy like the one of Chile, based on a more balance use of energy between economic sectors and between production and consumption would have higher yields in terms of medium and long term development for those nations. This requires directing more energy to consumption (EMR_{HH}), which will boost internal demand, and also increasing EMR_{PW} to increase labour productivity which will yield two benefits: increasing competitiveness and enhancing the ability to cope with internal demand. This is not calling for autarkic solutions like those of the past, but rather to change the way these economies are integrating in global markets by diversifying the range of products they can offer. Climbing up the ladder of activities generating more added value and offering processed products may revert the current trend of growing inefficiency in the use of energy. It is a bad sign that the three economies were making in 2000 less dollars out of a MJ of energy than they were doing in 1980, and this reflects a major shortcoming of the present development strategy based on just increasing exports, and not considering internal demand.

From a methodological point of view, it should be highlighted that, even though substantive findings are difficult to obtain, we can structure information to improve the quality of the narratives used to describe economic development, by integrating some elements of energy analysis like the MSIASM approach used here. This will allow not only examine spatial and historical regularities or similarities between countries as was done here, but also look at the emergent properties the system under analysis may show.

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