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Structural decomposition of energy use in Brazil from 1970 to 1996 ☆

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ABSTRACT

This paper examines the sources of changes in energy use of the Brazilian economy of industries and households from 1970 to 1996, using structural decomposition analysis based on the logarithmic mean divisia index technique. Energy use can be decomposed into eight factors that explain changes in overall energy use over the entire time period, and within five sub-periods. The growth of energy use between 1970 and 1996 was mainly influenced by changes in affluence, population and intersectoral dependencies, while changes in direct energy intensity and per capita residential energy use had a retarding impact on energy use. The novel contributions of the paper are the alignment of a previously disparate data set, the use of supply-use tables for SDA, and the application of such an SDA to a developing country. Both contributions involve solving a range of methodological issues pertaining to handling of large data sets.

Contents

1. Introduction

Between 1970 and 2000, Brazil passed through significant structural changes. In this period, GDP grew by approximately 250% (from 145.9 billion U$2003 in 1970 to 507.2 billion U$2003 in 2000)[1], at an average rate of growth of 4.9% p.a. [2]. Population increased from 93 million to 170 million by 2.1% p.a., with declining growth rates over the period ([3], Fig. 1). The participation of primary sector (agriculture and mining) in GDP fell from 13.2% to 10.5%, whilst that of manufacturing (incl. construction) increased from 35.1% in 1970 to 45.5% in 1985 and fell to 31.5% in 2000. The service sector (excluding trade and transport) enjoyed a continuous growth from 27.9% to 44.4% of GDP [3]).

At the same time, Brazilian energy use patterns changed significantly (Table 1). Energy use almost tripled (from 2739 PJ in 1970 to 7408 PJ in 2000; [4]) at an annual average growth rate of 3.7%. Residential energy use stayed almost constant (from 1225 PJ in 1970 to 1643 PJ in 2000) whilst energy consumed in industry grew from 1515 PJ to 5767 PJ. This means that the share of households' energy use within the Brazilian total decreased from 44.7% in 1970 to 22.2% in 2000 and that the residential sector is responsible for only 9% of total change in energy use between 1970 and 2000).

☆ This paper is a résumé of the doctoral thesis of Wachsmann [1].

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[1] The Brazilian currency of 2003 is Real (R$). The exchange rate used is R$2003 1.00 = U$2003 0.345.

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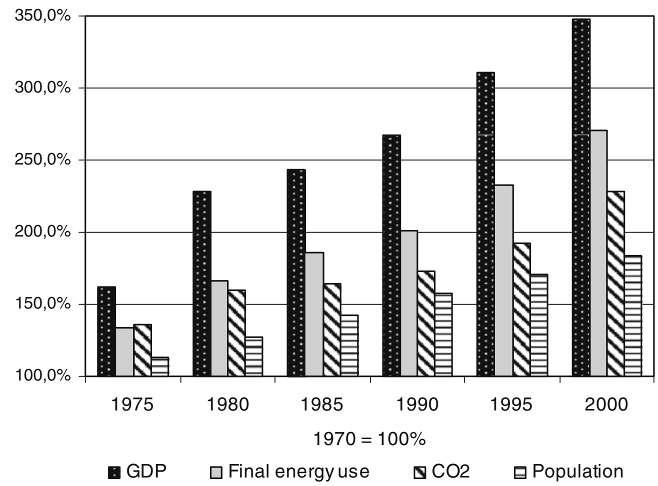

Fig. 1. Relative changes in GDP, final energy use, energy-related CO_2 emissions and population in Brazil between 1970 and 2000.

Table 1
Total, residential and intermediate sector's energy and corresponding growth rates

Year	Total energy use (PJ)	Residential energy use (PJ)	Industry energy use (PJ)	Growth rate of total energy use (%)	Growth rate of residential energy use (%)	Growth rate of industry energy use (%)
1970	2.739	1.224	1.514	–	–	–
1975	3.674	1.376	2.297	34.1	12.4	51.7
1980	4.564	1.290	3.274	24.2	−6.3	42.5
1985	5.105	1.196	3.909	11.9	−7.2	19.4
1990	5.507	1.299	4.207	7.9	8.6	7.6
1995	6.366	1.489	4.877	4.0	6.6	3.2
2000	7.408	1.642	5.765	10.6	2.6	13.1

Energy use always increased, with highest growth rates in the first two five-year periods (1970–1980). However, while industry was responsible for positive growth rates over the total period analysed, household energy use declined in the second and third period (between 1975 and 1985). By means of a structural decomposition analysis (SDA) we can quantify the drivers of these changes.

In contrast to other countries, exhaustion of primary resources is not an essential problem in Brazil, due to its huge potential of hydropower, biomass resources and, recently discovered, large oil and gas reserves. However, environmental degradation due to the construction of large hydroelectric plants and the subsequent resettlement of indigenous tribes, increasing CO_2 emissions due to a major participation of thermal plants as a consequence of a liberalised energy market, the preoccupation of energy supply security (after the rationing of electrical energy use in 2001), and the possible harmful impacts due to an extension of agricultural areas for bioenergy crop plantations (soya and sugar cane mainly) mean that the need for knowledge about driving forces of energy use has never been as important as today. Thus, the objective of this paper is determining and quantifying the driving factors of changes in energy use of the Brazilian economy between 1970 and 1996, the most recent years for which data is available, both within industry and households. Until now the majority of studies using SDA was applied to industrialized countries. This work is the first one applying SDA to Brazil, where changes in the economy, energy use patterns and population since 1970 occurred in a different way than in more developed countries. Other novelties of this study are the use of a supply-use tables (SUT) for SDA, and the assembly of a harmonised long-term (1970–1996) time series of SUT, disaggregating the Brazilian economy into 43 industries and 80 commodities.

Previous studies pertaining to Brazil were not successful in including the earlier years 1970 and 1975 (Machado and Schaeffer [5]), but these years are important because they span the import substitution policy implemented by the Brazilian Government. We included all data available, and an enormous effort was made to collect, re-classify and align them. Of course the resulting time series still has its limitations and, as such, results also have to be interpreted with care.

This paper is organised as follows: Section two introduces the methodology of SDA and its application to energy studies. The data sources are described in Section 3, the results are presented and discussed in Section 4. Section 5 concludes this study.

2. Methodology

In order to account for indirect final demand effects on energy use, a SDA was given preference over an index decomposition analysis (IDA).[2] The mathematical technique used is the additive logarithmic mean divisia index method (LMDI I) after Ang [7]. This method is exact (that is without leaving a residual[3]), non-parametric[4] and can handle a large number of explanatory factors without computational problems.[5] SDA is based on input–output theory [11], which looks at an economy as a table of inter-industry and final demand, representing the interdependencies of all sectors at a disaggregated level.

The basic input–output model describes the flows between *industries* of an economy. Consequently, the total output of an industry represents the sum of all outputs assigned to this industry, without distinguishing between primary and secondary products. Accounting for the fact that any one industry generally supplies different products, an alternative is to describe the intermediate industrial flows using a supply-use formulation that distinguishes explicitly between industries and commodities, and between intermediate production and final demand. In this formulation a supply matrix **V** describes the production of commodities j by industries i, while the use matrix **U** describes how the commodities j are in turn used by all industries i. Combined supply-use tables (SUT) are described in detail for example in UN [12], and will therefore not be explained further here.[6]

The structure of a standard static input–output model can be expressed as

$$\mathbf{x} = \mathbf{Ax} + \mathbf{y} = (\mathbf{I} - \mathbf{A})^{-1}\mathbf{y} = \mathbf{Ly} \quad (1)$$

where $\boldsymbol{x}$ is the vector ($n^{(i)\times 1}$) of gross production output by $n^{(i)}$ industry sectors, **A** is the matrix ($n^{(i)} \times n^{(i)}$) of technical coefficients ($a_{ij} = x_{ij}/x_j$) relating monetary flows from industry i to industry j to total output of industry j, **L** is the Leontief inverse matrix ($n \times n$) representing structural interdependencies and $\boldsymbol{y}$ the vector

[2] The main difference between IDA and SDA is the inability of the first to incorporate indirect effects of the final demand. Whereas, IDA uses aggregated data of the economy, SDA is based on information of input–output tables, which divide an economy into different industry sectors and commodities. Even though IDA requires less data, it yields less detailed results. For a more detailed comparison of IDA and SDA see [6].

[3] In contrast to exact methods, decomposition analysis based on the Laspeyres or the Paasche Indices are never exact (an exception exists for the number of explanatory factors $n = 2$ and the parameter $\alpha = 0.5$). They result in so-called residuals, an effect on variable y of simultaneous changes in the factors xi, also referred to as "joint" or "interaction" terms (Lenzen [8]).

[4] Ang and Choi [9] replaced the parametrical average used in the conventional divisia method with the logarithmic mean introduced by Törnquist [10]. A non-parametric method is desirable due to the objectiveness of the choice of parameter's value.

[5] For potential zero-value problems of other approaches, see [16].

[6] For further reading see Lenzen et al. [13].

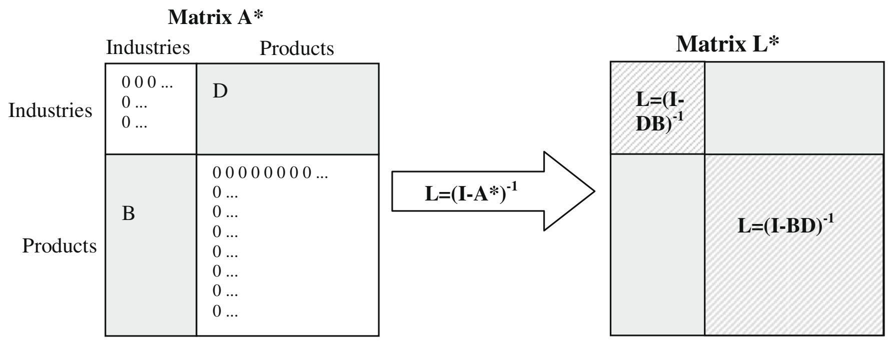

Fig. 2. Derivation of the Leontief matrix in a make-use framework.

($n^{(i)} \times 1$) of final demand from industries. In this work, **A** and **L** are used in their SUT forms $\mathbf{A}^*$ and $\mathbf{L}^*$, showing four-quadrants (Fig. 2).

Supply and use tables themselves are usually not square[7], however because of the arrangement of these in a combined SUT, the four-quadrant matrices $\mathbf{L}^*$ and $\mathbf{A}^*$ derived from this SUT are symmetrical. The matrix of technical coefficients **B** derived from the use matrix **U** is calculated as $b_{ij} = u_{ij}/x_j$. In this study we use the industry technology assumption, so that the technical coefficients matrix **D** (market-share matrix) is related to the supply matrix **V** by $d_{ij} = v_{ij}/x_j$. In contrast to conventional derivation of the Leontief matrix **L** (from a symmetric **A** matrix), we calculated $\mathbf{L}^*$ from a four-quadrant $\mathbf{A}^*$, where **B** and **C** are the matrixes of technical coefficients in a supply-use framework and all remaining values are zero (see Fig. 1).

The result is an $\mathbf{L}^*$-matrix that provides four types of information: in the left upper field we obtain the matrix of total requirements in an industry-by-industry classification (the same results as $\mathbf{L} = \mathbf{I} - \mathbf{DB})^{-1}$; for further details see Miller and Blair [14]. In the right lower field there is the matrix of commodity-by-commodity total requirements $(\mathbf{L} = \mathbf{BD})^{-1}$). The two remaining fields can give additional information about total requirements from industries to supply products to final demand and vice-versa. The industry technology assumption was given preference over the commodity technology assumption for two reasons: (a) the Brazilian Institute of Geography and Statistics [2] calculates its technical coefficients based on this assumption on basis of a recommendation made by the 1968 System of National Accounts, being applicable to rectangular input–output tables as in our case, and (b) after Machado [15] this assumption is particularly adequate for the treatment of energy products, because, in general, the production of these goods and services is characterised by the peculiar processes in every industry. For example, inputs of the product 'electricity' vary corresponding to the generation industry, being in electric power stations or cogeneration units (i.e., in the paper, steel and food/beverages sectors).

Energy data was included in our input–output model using the intensity factor approach. Although the hybrid unit method should be the preferred method (i.e., after Miller and Blair [14]), in the Brazilian case the lack of detailed data for energy use in each industry accordingly to the input–output classification makes the application of hybrid units difficult. By applying the intensity factor approach, technological changes are decomposed into two effects: the input–output coefficients and an energy intensity effect.

We multiply both sides of Eq. (1) by the direct energy intensity matrix **N** ($f \times (n^{(i)} + n^{(c)})$), which describes energy use of f fuel types in physical units per unit of monetary output of each production sector. All energy use is by industry, hence $\mathbf{N} = 0$ for all $n^{(c)}$ commodity sectors. Final demand $\boldsymbol{y}^*$ has non-zero elements for $n^{(c)}$ commodities, but is extended with a zero vector of length $n^{(i)}$ to cover final demand by industry. We hence obtain the vector of total energy use ($f \times 1$) as

$$\mathbf{e}_{\mathrm{ind}} = \mathbf{Nx} = \mathbf{N}(\mathbf{I} - \mathbf{A}^*)^{-1}\mathbf{y}^* = \mathbf{NL}^*\mathbf{y}^* \ldots \tag{2}$$

In order to account for total energy use of the economy residential energy use has to be included so that

$$\mathbf{e} = \mathbf{e}_{\mathrm{ind}} + \mathbf{e}_{\mathrm{res}} = \mathbf{NL}^*\mathbf{y}^* + \mathbf{e}_{\mathrm{res}} \tag{3}$$

$\boldsymbol{e}_{\mathrm{res}}$ represents the energy directly consumed by households for cooking, lighting, private transportation etc. $\boldsymbol{e}_{\mathrm{ind}}$ counts for energy used in the intermediate sectors of the economy.

For further decomposition of energy use the vector of final demand $\boldsymbol{y}^*$ can be subdivided into four factors: final demand composition[8] **u** ($(n^{(i)} + n^{(c)}) \times d$), final demand destination $\boldsymbol{v}$ ($d \times 1$)), GDP/capita Y (1×1) and population P_{ind} (1×1). In addition, $\boldsymbol{e}_{\mathrm{res}}$ can be decomposed into residential energy use per capita per fuel $\boldsymbol{r}$ ($f \times 1$) and population P_{res} (1×1), resulting in

$$\mathbf{e} = \mathbf{NL}^*\mathbf{uv}YP_{\mathrm{ind}} + \mathbf{r}P_{\mathrm{res}} \tag{4}$$

The central idea of decomposition analysis is that changes in $\boldsymbol{e}$ are decomposed in changes of its determinants resulting in an exhaustive sum of contributions from all changes in energy use within a certain period.

$$\Delta e = (\Delta N + \Delta L + \Delta u + \Delta v + \Delta Y + \Delta P_{\mathrm{ind}}) + (\Delta r + \Delta P_{\mathrm{res}}) \tag{5}$$

where ΔN is the energy intensity effect, ΔL the input-mix effect (Leontief effect), Δu the product-mix effect, Δv the destination of final demand effect, ΔY the level of GDP/cap effect (affluence effect), ΔP_{ind} the population effect over changes in industrial energy use, Δr the residential energy use per capita effect and ΔP_{res} the population effect over changes in residential energy use.

In contrast to incomplete decomposition methods, Eq. (5) does not include a residual term. All calculations were carried out using an algorithm described in Wood and Lenzen [16]. The mathematical formulations is summarised in the Appendix A.

In order to avoid double counting of primary and secondary energy use, energy use is defined as final energy use minus losses (during transformation, distribution and storage), which is equal to domestic gross energy supply. Consequently, energy imports are considered within domestic energy use. On the other hand, imported goods and services are excluded from intermediate demand and recorded as primary inputs. Due to this, the matrix **A** does not reflect technological coefficients but domestic requirement coefficients. The reason for this is that: (1) the study deals with domestic energy requirements; and (2) detailed data on foreign energy use patterns are not available.

[7] $n^{(i)} \times n^{(c)}$ = 43 industries × 80 commodities in the Brazilian case.

[8] Five components: gross fixed capital expenditure, exports, changes in stocks, government final expenditure, and household final expenditure.

Table 2
Direct, indirect and total energy requirements of final demand of Brazilian economy in 1970 and 1996 (TJ)

Product	1970				1996			
Energy (TJ)	Direct	Indirect	Total	(%) of total	Direct	Indirect	Total	(%) of total
Primary products								
Agricultural products	82.815	29.269	112.083	4.1	139.069	125.938	265.007	4.0
Minerals	5.210	2.267	7.477	0.3	23.046	22.631	45.677	0.7
Oil, gas e coal	273	50	323	0.0	870	701	1.571	0.0
Manufacturing (total)	309.264	435.425	744.689	27.2	804.361	1.604.507	2.408.868	36.0
Non-metallic minerals	9.153	2.244	11.397	0.4	26.555	18.500	45.055	0.7
Iron and steel	10.220	8.297	18.518	0.7	109.917	102.068	211.985	3.2
Non-ferrous, other metal								
Non-ferrous metals	111	163	274	0.0	20.149	28.283	48.432	0.7
Other metallurgies	5.133	17.988	23.121	0.8	12.441	48.264	60.705	0.9
Paper and pulp	6.588	4.594	11.182	0.4	44.298	39.708	84.006	1.3
Chemistry and refinery								
Chemical elements	3.839	893	4.732	0.2	103.883	34.455	138.338	2.1
Petroleum refinery	20.675	8.465	29.140	1.1	45.445	75.047	120.492	1.8
Other chemical products	5.223	4.849	10.073	0.4	10.911	17.577	28.488	0.4
Food and beverages								
Café	1.855	11.756	13.611	0.5	7.312	35.143	42.455	0.6
Vegetable products	37.431	47.546	84.977	3.1	65.822	117.731	183.553	2.7
Meat	11.897	53.833	65.730	2.4	22.001	118.443	140.445	2.1
Milk	4.610	20.767	25.377	0.9	14.261	50.827	65.088	1.0
Sugar	5.673	19.172	24.844	0.9	7.069	24.813	31.882	0.5
Vegetable oils	22.056	21.714	43.770	1.6	10.747	51.049	61.796	0.9
Other food products	125.003	46.090	171.093	6.2	227.442	149.464	376.906	5.6
Textiles and clothes								
Textiles	17.033	31.838	48.871	1.8	10.894	26.392	37.286	0.6
Clothes	861	12.574	13.436	0.5	3.097	48.740	51.837	0.8
Other products of manufacture								
Machines and tractors	1.484	22.578	24.062	0.9	9.033	88.525	97.558	1.5
Electrical material	681	6.801	7.482	0.3	4.463	66.826	71.289	1.1
Electronic equipment	258	4.296	4.554	0.2	3.454	62.580	66.034	1.0
Automobiles, trucks	1.521	30.022	31.543	1.2	6.225	162.760	168.986	2.5
Other vehicles, pieces	655	7.851	8.506	0.3	3.769	60.748	64.517	1.0
Wood and furniture	8.638	14.067	22.704	0.8	19.129	49.008	68.136	1.0
Rubber	817	2.864	3.681	0.1	841	4.963	5.804	0.1
Pharmaceuticals, cosmetics	1.542	16.007	17.549	0.6	6.268	61.956	68.224	1.0
Plastic products	377	2.268	2.645	0.1	929	8.155	9.084	0.1
Leather products	727	6.410	7.136	0.3	2.876	25.864	28.739	0.4
Others	5.204	9.475	14.679	0.5	5.130	26.618	31.748	0.5
Public services (electr., gas)	35.143	3.352	38.495	1.4	135.570	59.338	194.908	2.9
Construction	20.825	218.844	239.669	8.7	24.629	496.761	521.389	7.8
Trade	11.160	53.625	64.785	2.4	31.643	203.730	235.373	3.5
Transportation	177.497	19.294	196.791	7.2	468.792	111.907	580.699	8.7
Other services (total)	24.296	50.934	75.230	2.7	189.827	603.899	793.726	11.8
Communication	88	719	808	0.0	1.894	10.883	12.778	0.2
Financial institutions	0	0	0	0.0	2.672	17.032	19.704	0.3
Services for families	5.939	9.840	15.779	0.6	67.576	248.938	316.514	4.7
Services for enterprises	0	0	0	0.0	1.897	9.789	11.687	0.2
Rent	0	0	0	0.0	15.274	44.087	59.361	0.9
Government services	17.457	39.021	56.478	2.1	98.213	267.642	365.855	5.5
Private services	812	1.354	2.166	0.1	2.300	5.527	7.827	0.1
Total of productive sectors	666.483	813.059	1.479.542	54.0	1.817.806	3.229.411	5.047.217	75.3
Subsidies	0	0	34.990	1.3	0	0	51.248	0.8
Households	0	0	1.224.619	44.7	0	0	1.600.988	23.9
Total of economy	666.483	813.059	2.739.151	100	1.817.806	3.229.411	6.699.454	100

3. Data sources

Two types of data are required for the realisation of a SDA of changes of energy use: (a) input–output tables (IO) recording the monetary transactions between the sectors of the Brazilian economy (interrelationship within production sectors and between them and final demand), and (b) physical data on energy use.

Input–output tables are published by the Brazilian Institute of Geography and Statistics (IBGE) since 1970, between 1970 and 1990 in 5-year steps and from 1990 to 1996 annually. As the last input–output tables were published in 1996 this analysis is restricted to the time period from 1970 to 1996. After 1985, Brazilian input–output are expressed in a constant sector/product classification and a constant level of disaggregation: 43 activities, 80 commodities and five final demand categories. In the three former years (1970–1980) the classification was more detailed, but due to a further disaggregation of the later years' data being impossible, all tables were adjusted to the recent classification.[9] For consistency, supply and use matrixes of all years should be valuated

[9] Some authors (i.e., Guilhoto [17]) have attempted macroeconomic analyses on Brazilian input–output time series, some of them energy-related (i.e. Machado [15]), but no study has covered the entire period from 1970 to 1996 at a disaggregated level as in this paper. This is the first study to re-classify all existing Brazilian input–output tables in order to make further studies based on long-term detailed input–output tables possible.

in the same prices at the same concept of price valuation (United Nations [12]). Trade and transport margins and taxes may vary for a given product, so that the consumer price could be different for the same good/service. Although structural decomposition analysis in consumer prices is possible, basic prices are a better proxy for energy studies in the intensity approach. Thus, all input–output tables are valued at basic prices. In the Brazilian case, the deflation of the input–output values to a common base year is more difficult than in stable developed nations. In the late 1980s and the early 1990 Brazil passed through periods of very high inflation rates (i.e., 81% in March of 1990). In order to combat high inflation, the Brazilian currency was changed six times between 1970 and 1996, so that most of the input–output tables are expressed in different currencies. Because of high inflation rates and frequent currency changes (usually in the middle of the year) the calculation of a price index for each commodity group is rather difficult. In this study we circumvent this problem by assuming a homogeneous inflation rate across all commodities converting all input–output tables into R$2003.

Energy data are published annually by the Ministry of Mines and Energy (MME [4]). The Brazilian energy flow matrix comprise 10 sectors of transformation (from primary to secondary energy sources), 20 sectors of final use and reports 24 types of energy sources in physical units (9 primary and 15 secondary fuel types). Because the classification of energy consuming sectors in the energy flow matrix is more aggregated than in the input–output tables, some sectors had to be disaggregated into sub-sectors. In disaggregating the energy flow tables into the input–output classification, we assume that industries grouped together pay the same energy price.

4. Results and discussion

The participation of direct household energy use in total Brazilian energy use fell from 44.7% in 1970 to 23.9% in 1996, so that changes in household energy use contributed only 10% to changes in total energy use. As mentioned above, industry sectors are the main contributors for the growth of energy use from 1970 to 1996. Table 2 shows the evolution of energy requirements of Brazilian final demand between 1970 and 1996. We can observe that the portion of total direct energy requirements declined from 45% in 1970 to 36% in 1996. Increasing indirect energy requirements mean that productive processes have turned more complex, with longer production chains (with more embodied energy over all production stages from mining over manufacturing to distribution), and an increase of mechanisation level of Brazilian industry

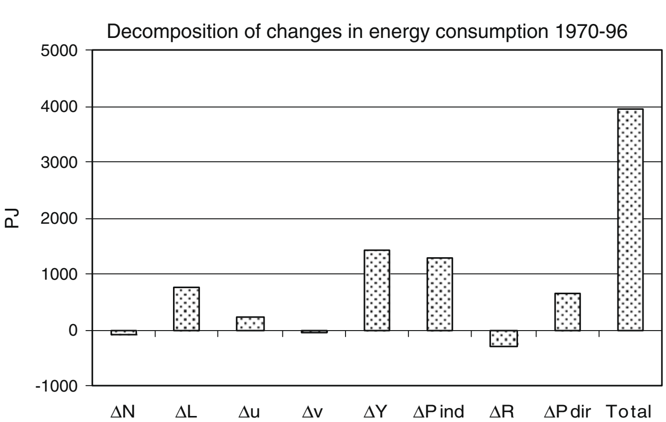

Fig. 3. Contribution of eight effects to changes in energy use between 1970 and 1996 in Brazil [PJ].

(with more equipments and machines that count for a high amount of embodied energy). As an example, indirect energy requirements of agricultural products represented 26% of total energy requirements in 1970 and 78% in 1996. This trend could be observed for other products too, mainly for primary products and minerals, oil and natural gas, coal, as for manufactured products as refinery products, which direct energy requirements share declined from 71% in 1970 to 38% in 1996. Generally, basic products as agricultural products, minerals, and steel, as well as pulp and paper, chemical and refinery products require a higher share of direct energy due to the fact that inputs are usually primary materials, which did not pass through a long production chain before. Naturally, transport and utilities (mainly generation and distribution of electric power) are accounting for high direct energy requirements, too. On the other hand, construction materials, trade and other services are characterised by a high share of indirect energy requirements.

4.1. Decomposition of changes in energy use of aggregated economy from 1970 to 1996

Fig. 3 shows the contribution of all eight explanatory factors to changes in energy use of the Brazilian economy between 1970 and 1996. Together, the affluence effect ΔY and the population effect ΔP ($\Delta P_{\text{ind}} + \Delta P_{\text{res}}$) are responsible for 85.1% of energy use growth within this period. This increase in energy use is completed by the Leontief effect ΔL and the product-mix effect Δu that contributed with 19.2% and 6.1%, respectively. On the other hand, the intensity effect ΔN (−2.2%), the destination effect Δv (−1.1%) and the effect of changes in household energy use per capita Δr (−7.2%) caused a decrease of Brazilian energy use in the total period.

In these 26 years accelerating effects have shown a significant prevalence over retarding effects, so that Δe increased by almost 4000 PJ. These results are conform to studies for other countries such as for the case of Denmark (Wier [18]), India (Mukhopadhyay and Chakraborty [19]) and China (Lin and Polenske [20]). Wood [21] shows in a recent study that ΔY, ΔP and ΔL are also the most important factors of an increased energy use in Australia from 1969–1997.[10]

Nevertheless, results for the whole period give only a general idea about what happened in the analysed time period but do not show the changes due to influences of short-term events such as the oil price shocks in 1973 and 1979, the counter shock in 1986, political measures of the Brazilian Government in order to combat inflation and to open the economy for the international market, etc. In order to obtain a better reflection of these events, we divided the period of 26 years into sub-periods of five-years. Thus, in the following section we show the results of SDA for all five sub-periods.

4.2. Decomposition of changes in energy use in five sub-periods (1970–1995)

Fig. 4 shows the contribution of all effects to changes in Brazilian energy use and the development of these changes (sum over all effects) in the five sub-periods between 1970 and 1995. It can be observed that within the 25 years energy use increased in each sub-period because of the superiority of accelerating effects to changes in energy use (Δe).

As mentioned above, changes in residential energy use were moderate throughout the entire period, with two declines in the

[10] Wood [21] and Wier [18] deal with changes in terms of greenhouse gas emissions and not energy use. Nevertheless, the results are comparable, because these emissions are exclusively related to energy use.

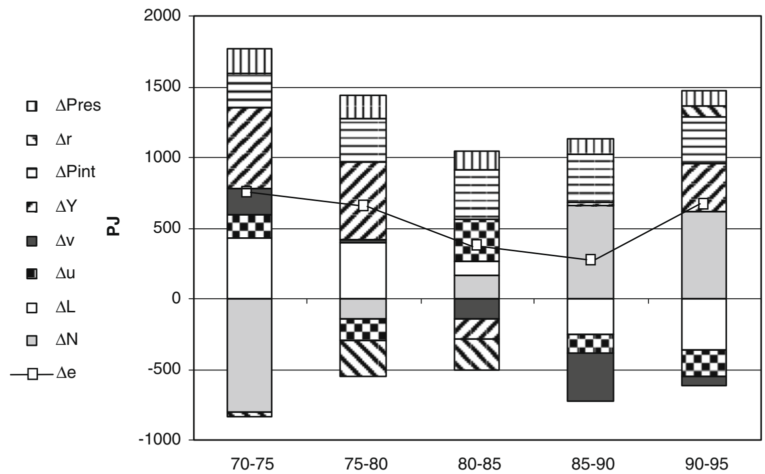

Fig. 4. Contribution of all effects to changes in Brazilian energy use Δe from 1970 to 1995.

second and third periods, because of a population effect ΔP_{res} prevailing over a per capita residential energy use effect Δr. The "retarding" influence of Δr on Δe does not necessarily mean that households diminished their energy use. In addition to a reduction in the use of gasoline in consequence of the oil price shocks in the second period, in Brazilian households occurred a substitution of inefficient energy sources as firewood by more efficient sources such as LPG (i.e., one toe of LPG can substitute 7–10 toe of firewood due to the higher efficiency of gas fired stoves; see MME [4]). These two facts are the main reasons for the decline in per capita energy use of Brazilian households in the first four periods. The population effect of residential energy use ΔP_{res} was always accelerating, but showed a retarding trend due to declining rates of population growth.

In contrast to the SDA results for the total period (1970–1996), where the intensity effect ΔN (changes in Δe due to changes in direct energy intensity of economic activities) was responsible for a decline of Δe, the division in sub-periods tells a different story. Now ΔN contributed retarding only in the first two periods, while in the last three periods it tended to be accelerating and became the most accelerating effect from 1985 to 1995. This evolution is opposite to the trend of ΔN in developed countries[11], but does not mean that sectors of the Brazilian economy became less efficient in its energy use over the time. Rosa and Tolmasquim [22] and Machado and Schaeffer [23] show evidence that the deterioration of prices of industrial commodities, the long-term fall in agricultural commodities' prices and governmental interventions in prices (such for energy as for basic materials by state-owned companies, mainly steel and petrochemicals) lead to a decline of value-added in several sectors. For instance, Brazil has witnessed a downward trend in steel prices, and a shift towards the production of lower value-added steel products. The product group that mainly contributes to this trend is "products of manufacturing", where price devaluation occurred for the most part (see Fig. 5).

The Leontief effect ΔL (changes in Δe due to changes in intersectoral dependences) showed an opposite trend to ΔN, positive in the first three periods and retarding afterwards. Usually ΔL can be explained by two effects: (a) inputs to the production of a certain product are substituted by less energy-intensive inputs, and (b) the very products are inputs into less energy-intensive activities. However, as the majority of sectors recorded an accelerating trend for ΔN, ΔL cannot be explained just by intersectoral changes in favour of less energy-intensive sectors. Thus, in the Brazilian case, this fact is a result of a substitution of non-energy inputs by energy inputs, so that the energy embodied in non-energy inputs was higher than the energy directly used by sectors. This observation can be verified in some examples: In the service sectors, each time more energy inputs were necessary to supply services to final demand (mainly electricity for lighting, cooling and freezing) while the proportion of non-energy inputs (in the past mainly metallurgical products, machines and equipments) declined. Another example is the construction sector, where over the time the proportion of energy inputs as electricity, fuel oil and natural gas increased and the proportion of non-energy inputs as steel and wood (both with high contents of embodied energy) decreased. Fig. 4 shows these described trends.

Changes in lifestyles, consumption patterns and income of households, the variation of export product-mix, etc influence Δu, so that this product-mix effect should be exposed to a lot of changes. However, changes in the relative proportion of goods and services in final demand (product-mix, Δu) showed during the entire period no significant contribution to Δe. Nevertheless, several products were responsible for an important contribution within Δu. For instance, from 1980 to 1985 an increased export of chemical/refinery products and steel products increased the total energy use by 4% and 2.5%, respectively (see Fig. 5).

As for Δv, changes in the destination of final demand (reflecting changes in the relative contribution of final demand components in GDP) did not exert a high influence on Δe. The most accelerating contribution can be observed in the first period when the relative proportion of gross fixed capital expenditures (GFCE) in final demand increased. The two most important products in this final demand category are construction materials and machines, accounting for almost 76% of GFCE and for an increase of 8% in energy use from 1970 to 1975 within Δv (see Fig. 4). Another example for an accelerating contribution to Δe within Δv could be observed in the forth period (1985–1990), when the relative participation in GDP of the final demand component 'Public Administration' increased. In 1988, when the first civil government after the 1964–1985 military regime consolidated the universalisation of social wellbeing of the Brazilian population in the Constitution of 1988, the demand for public health and education grew. Both final demand services count for a high content of embodied energy so that these items contributed with 2% to an increase in

[11] Mielnik and Goldemberg [24] show that the energy intensity paths of industrialised and developing countries in the period from 1971 to 1992 are converging to a common pattern of energy use with decreasing energy intensity for the first group of countries and increasing for the second.

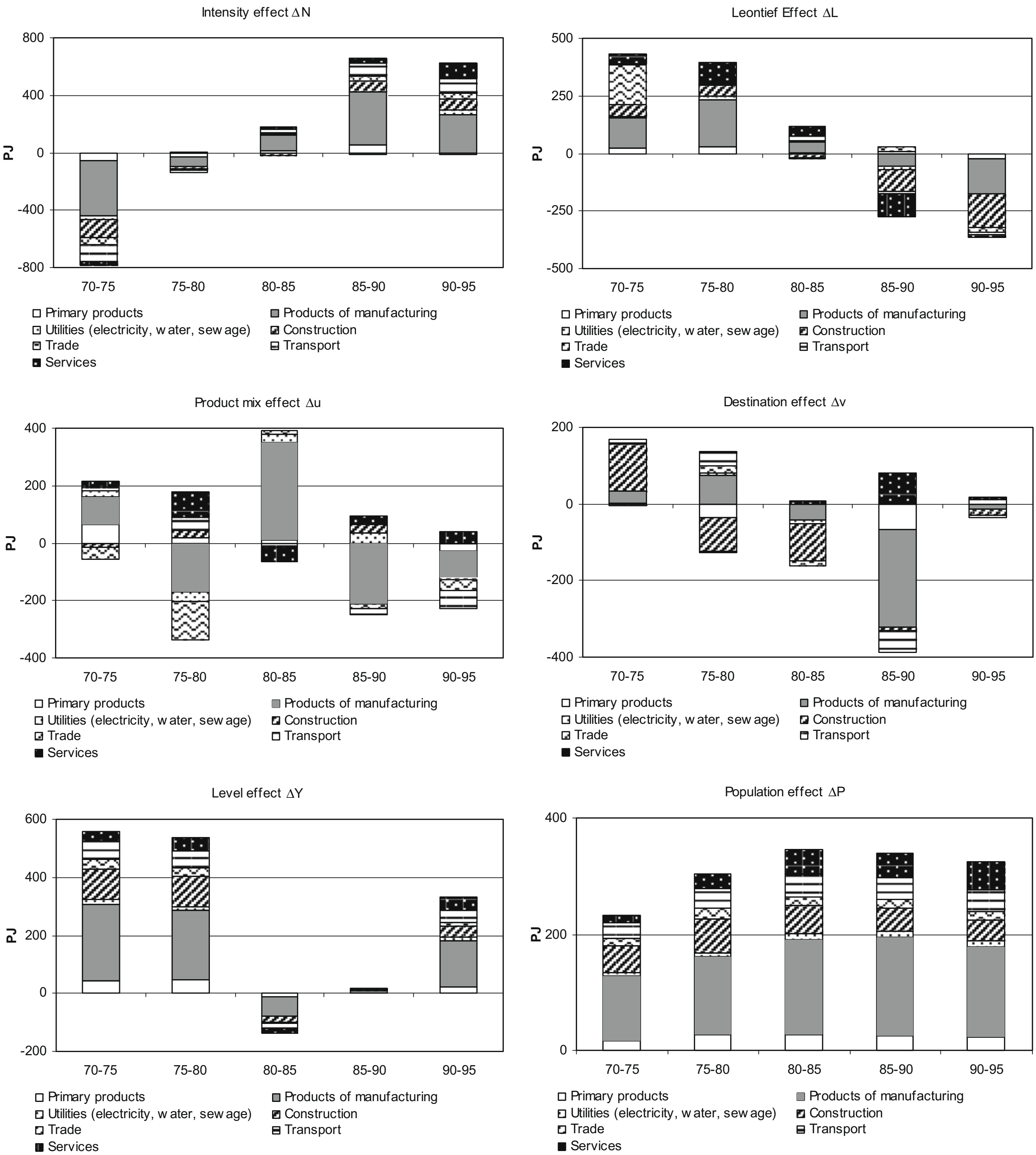

Fig. 5. Contribution of each product group within the factors of SDA to changes in energy use of industry sectors between 1970 and 1995 in Brazil [PJ].

total energy use from 1985 to 1990. Nevertheless, this impact was compensated by a retarding contribution of primary goods and products of manufacturing to Δe due to losses in exports in the same period (see Fig. 5).

Except for the third period, changes in the level of economic activity ΔY – measured in GDP per capita – always contributed to an increase of total energy use. We can see that the evolution of ΔY and Δe proceeded in similar ways, even if Δe shows a slower trend compared to ΔY. This evolution can be explained by a possible installation of less energy-efficient plants in consequence of an unexpected rise of activity level and by an idle capacity that did not permit Δe to adjust immediately.

As expected, the population effect ΔP_{ind} over the energy use of industrial sectors was accelerating in each period, because the rate of population growth in Brazil was always accelerating in the past. Because of its continuos accelerating contribution to Δe, ΔP_{ind} became the second-most important effect over the total period (1970–1996).

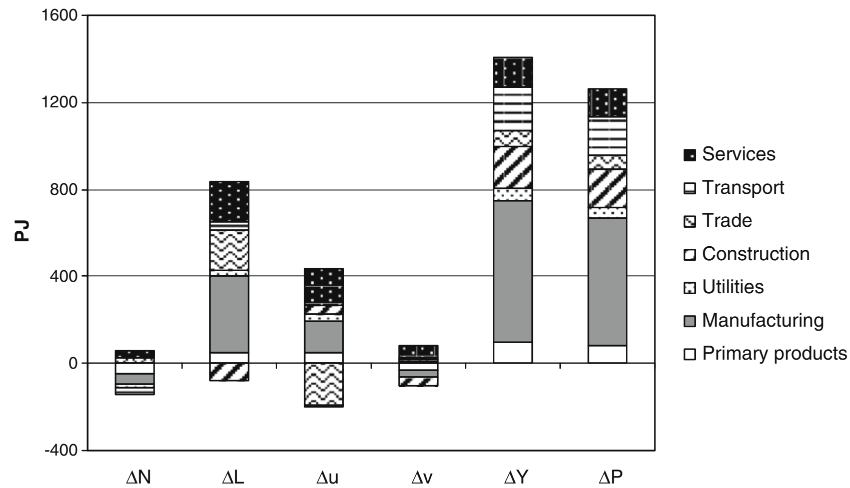

Fig. 6. Contribution of each product group within the six effects over changes in energy use of intermediate sectors between 1970 and 1996 in Brazil [PJ].

In addition to the results of each factor's impact on Δe, it is interesting to show how product groups participated in each effect and influenced changes in energy use of industrial sectors. Fig. 6 shows the participation of seven aggregated products groups in the decomposed factors of Δe_{ind} for the total period 1970–1996. The product group of manufactured products represented the major contribution in all factors except Δv, mainly in ΔY, ΔP_{ind} and ΔL. Accompanying the development of the Brazilian economy within these 26 years, construction and transport – both important for an improvement of infrastructure – were responsible for a high accelerating impact over Δe_{ind} in ΔY and ΔP_{ind}. It is remarkable that services contributed to all factors accelerating over time, reflecting the transformation of the economy to a more service-oriented one. Trade has a retarding effect on Δe_{ind} in Δu, which is reflected in Brazil's industrialisation which caused trade to lose in importance in the economic landscape. Primary products and utilities do not represent any important contribution to changes in intermediate energy use.

The results of the SDA show that changes in energy use in Brazil from 1970 to 1996 were mainly influenced by changes in affluence, the number of people and intersectoral dependencies, rather than changes in direct energy intensity in the final demand product-mix and in the final demand destination. This trend is similar to studies for other countries. As mentioned above, for the entire period the results of this study (magnitude and sign of each factor) are similar to those obtained by Wood [21] for the Australian case. However, the results of the two studies differ in some parts when the entire period is divided in sub-periods, mainly regarding to ΔN and ΔL. The most recent previous decomposition analysis of energy use in Brazil is the study by Machado and Schaeffer [23], which uses an index decomposition and arrives at the driving forces of changes in energy use with a similar magnitude to the ones determined in this work. However, as their work does not present results at a more disaggregated level, a more detailed comparison of the results is not possible.

Considering the results of our study, factors of major accelerating contributions (ΔY and ΔP) are not suitable to bring about a reduction in energy use of the Brazilian economy. Economic development is also both important and desirable in the Brazilian context, mainly to achieve a better income distribution, which influences directly and indirectly the total energy use (for more information see Cohen et al. [25].

According to estimations of the IBGE [2], population growth will occur at lower annual rates in the future (from 2.86% in 1970 to 0.71% in 2030). Consequently, its accelerating contribution to changes in energy use will continue albeit at lower rates, so that this factor will not be easy to deal with in the medium term. Therefore, ΔY and ΔP represent more a context in which policies should be introduced. These measures should be applied to product groups associated with major energy requirements, and with high final demand in monetary terms (as in the case of public administration and construction materials), with high direct energy intensities (steel and iron, chemical products, non-metallic minerals, utilities and transport) or with high indirect energy intensities (other metallurgical products, pulp and paper, refinery products, other chemical products).

The decomposition of direct household energy use shows a tendency to an accelerating contribution of residential energy use per capita over the last years, a trend that will probably continue in the future due to higher incomes, continuing urbanisation and more electrified households. The substitution of inefficient energy sources will continue, but with less visible effects into the future as in the past.

The opposite evolution of the intensity effect ΔN and the Leontief effect ΔL points out a substitution of non-energy inputs by energy inputs, a fact that indicates that non-energy inputs can account for higher energy embodiment than energy directly used by industrial sectors. As a result, a reduction in energy use in production does not necessarily mean a reduction in total energy use if the energy input is substituted by a non-energy input with a higher embodied energy content. Interesting enough, an opposite evolution could be observed in Australia where ΔN presents a retarding and ΔL an accelerating contribution to Δe. For the Australian case, Wood [21] stressed that credits given to industries that reduce their direct energy use may be unfounded, as the substituted non-energy inputs could have a higher embodied energy.

Although the product-mix effect Δu of the aggregated economy does not represent a significant contribution, after a disaggregation in product groups this factor can show itself important for certain goods and services. Public policy measures influencing consumption habits of the population, as well as government decisions about the participation of Brazil in international trade cause impacts directly on Δu.

As with Δu, Δv does not represent an important contribution. A higher participation of capital expenditure in GDP usually means an increase of energy requirements due to its implications over construction. If the government decides to invest in the social wellbeing of society, increasing expenditures for public administration (education and health) will likely lead to a higher energy use as well.

5. Conclusions

This study calls on the attention of governments and policy-makers in the sense that decision-making and policy design always entail indirect effects that are hidden from many conventional policy appraisals. The most important implication appears to be that the physical dimensions of economic activity are not separable from limitations of energy supply. The inclusion of indirect final demand effects permits one to discover where the real energy use occurs in the production chains. This leads one to consider that, paradoxically, in a time of energy shortage it is important to assess carefully some policies aiming at reducing energy use in final demand, so as not to exacerbate the shortage. Also, that the proper time to implement actions with broad impacts over the full energy chain is when "energy is still abundant". For example, policies aiming at improving public transportation to reduce energy use in private cars will probably save less energy than expected, if the proper infrastructure is not in place and, as such, energy will be needed to build the new infrastructure. Or, policies aiming at making industry more energy-efficient by substituting standard electric motors by energy-efficient electric motors without taking proper care of the lifetime still available for the standard motors may reduce the direct electricity consumption by those industries benefited by the program at a cost of increasing energy consumption somewhere else in industry, due to the need to produce more steel and ferroalloys to build the new, energy-efficient motors. Or, policies aiming at making some exporting sectors more competitive in the international market may do so at a cost of creating inefficiencies somewhere else in the economy, for example when incentives are given to some energy-efficient (from a technological point of view), though energy-intensive, sectors of the economy, which will increase total energy use of the economy, when less-energy-efficient (also from a technological point of view), though non-energy-intensive, sectors could add more value to the economy with less energy use.

Results from this study show that the energy implications of the current trend towards a more services-oriented economy in Brazil does not lead, necessarily, to a decline in energy use in the country, as there is a strong relation between embodied energy and economic activity, as energy is required to produce all products and services in an economy. Between 2000 and 2007, Brazil's GDP grew by some 25%, with growth rates varying between 1% and 6% per year. Even if these rates did not reach those of the early 1970s, they affected the increase in energy demand in that period, that grew by 12% between 2000 and 2006. To which extent this new rise is caused by changes in GDP per capita, population, energy intensity and/or intersectoral dependencies should be carried out by additional research for the period 1996–2006.[12]

Appendix A

From [16]: The basic approach to additive structural decompositions of a function $y(x_1, x_2, \ldots, x_n)$ of n determinants is through its total differential

$$\mathrm{d}y = \frac{\partial y}{\partial x_1}\mathrm{d}x_1 + \frac{\partial y}{\partial x_2}\mathrm{d}x_2 + \cdots + \frac{\partial y}{\partial x_n}\mathrm{d}x_n$$

In case $y(x_1, x_2, \ldots, x_n) = x_1 x_2, \ldots, x_n$ (with the x_i being scalars, vectors or matrices),

$$\begin{aligned}\mathrm{d}y &= \prod_{j=1,j\neq 1}^{n} x_j \mathrm{d}x_1 + \prod_{j=1,j\neq 2}^{n} x_j \mathrm{d}x_2 + \cdots + \prod_{j=1,j\neq n}^{n} x_j \mathrm{d}x_n \\ &= \sum_{i=1}^{n}\left(\prod_{j=1,j\neq i}^{n} x_j \mathrm{d}x_i\right)\end{aligned}$$

Analysing discrete time series with a divisia decomposition approach, differences Δy are obtained by integrating infinitesimal changes $\mathrm{d}y$:

$$\begin{aligned}\Delta y &= \int_{y_0}^{y_1} \mathrm{d}y \\ &= \int_{x_{1,0}}^{x_{1,1}} \prod_{j=1,j\neq 1}^{n} x_j \mathrm{d}x_1 + \int_{x_{2,0}}^{x_{2,1}} \prod_{j=1,j\neq 2}^{n} x_j \mathrm{d}x_2 + \cdots + \int_{x_{n,0}}^{x_{n,1}} \prod_{j=1,j\neq n}^{n} x_j \mathrm{d}x_n \\ &= \sum_{i=1}^{n}\left(\int_{x_{i,0}}^{x_{i,1}} \prod_{j=1,j\neq i}^{n} x_j \mathrm{d}x_i\right) = \sum_{i=1}^{n}\left(\int_{x_{i,0}}^{x_{i,1}} \prod_{j=1}^{n} x_j \frac{\mathrm{d}x_i}{x_i}\right) \\ &= \sum_{i=1}^{n}\left(\int_{x_{i,0}}^{x_{i,1}} y(\ldots, x_i, \ldots)\frac{\mathrm{d}x_i}{x_i}\right) = \sum_{i=1}^{n} \bar{y}([x_{i,0}, x_{i,1}]) \ln\frac{x_{i,1}}{x_{i,0}}\end{aligned}$$

In order to compute the integral one has to know what average values y assumes while the x_i change from $x_{i,0}$ to $x_{i,1}$ (the "integral path"). The logarithmic mean divisia (LMD) formulation traces this path as the logarithmic mean $\bar{y}^{\lambda} = \Delta y / \Delta(\ln y)$, resulting in

$$\Delta y^{\mathrm{L}} = \sum_{i=1}^{n} \frac{\Delta y}{\Delta(\ln y)} \ln\frac{x_{i,1}}{x_{i,0}}$$

Now for our system, the decomposition by factor becomes (firstly for industrial fuel coefficients)

$$\begin{aligned}\Delta e(N) &= \int \sum_{mn} \frac{\partial e}{\partial N_{mn}} \mathrm{d}N_{mn} = \sum_{mn} \int \frac{\partial\left(\sum_{ijklh} N_{ij} L_{jk} u_{kl} v_l YP + r_h P\right)}{\partial N_{mn}} \mathrm{d}F_{lm} \\ &= \int \sum_{mnopq} (N_{mn} L_{no} u_{op} v_p YP + r_q P) \frac{\mathrm{d}N_{mn}}{N_{mn}}\end{aligned}$$

which after integration is

$$= \sum_{mnop} \overline{N_{mn} L_{no} u_{op} v_p YP}^{\lambda} \ln\frac{N_{mn,1}}{N_{mn,0}},$$

and similarly for the other factors (Leontief)

$$\Delta e(L) = \sum_{mnop} \overline{N_{mn} L_{no} u_{op} v_p YP}^{\lambda} \ln\frac{L_{no,1}}{L_{no,0}}$$

and final demand mix

$$\Delta e(u) = \sum_{mnop} \overline{N_{mn} L_{no} u_{op} v_p YP}^{\lambda} \ln\frac{u_{op,1}}{u_{op,0}}$$

and final demand destination

$$\Delta e(v) = \sum_{mnop} \overline{N_{mn} L_{no} u_{op} v_p YP}^{\lambda} \ln\frac{v_{p,1}}{v_{p,0}}$$

and affluence

$$\Delta e(Y) = \sum_{mnop} \overline{N_{mn} L_{no} u_{op} v_p YP}^{\lambda} \ln\frac{Y_1}{Y_0}$$

and residential fuel use

[12] Recent input–output tables (from 1997) are announced for August 2008.

$$\Delta e(r) = \sum_q \overline{r_q P}^\lambda \ln \frac{r_{q,1}}{r_{r,0}}$$

And population, being common to both terms

$$\Delta e(P) = \sum_{mnopq} \overline{(N_{mn} L_{no} u_{op} v_p Y + r_q) P}^\lambda \ln \frac{P_1}{P_0}$$

Reiterating: $\bar{y}^\lambda = \Delta y / \Delta(\ln y)$

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