Empirical Evidence of Aggregate Behaviour in a Huge Economy

(Non-monetary analysis of monetary statistics)

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Prelude

This work was done at the Institute for High Temperatures of the AS USSR in 1983. Primary data were compiled by N.A. Lavrenov, a postgraduate student at the Central Mathematical Economics Institute of the AS USSR who worked under the auspices of GOSPLAN (State Planning Committee). The data were contained in numerous reports coming to GOSPLAN from thousands sources to be aggregated into an input-output structure. The aggregation took a great deal of perseverance in obtaining smooth and sustained dynamic series. What had been got was the cumulated formal knowledge of the economy. Matching it with informal knowledge would answer the question: "What part of the truth is contained in mathematics?". It is very important because informal knowledge brews from mathematical facts.

Non-monetary indicators

Energy trade-offs

The following idea was used to calculate energy trade-offs. Each product was supposed to be equivalent to the cumulative energy vector that was consumed to produce the product. But each element of the energy vector in its turn is a product and can be represented by another energy vector. So substituting some elements of the first energy vector for their corresponding energy vector representations one can obtain many energy vectors representing the chosen product which would be all equivalent to each other.

Among these vectors we choose the one which is collinear to the vector of output energy. The relation of this collinear vector to the output energy vector yields a scalar that indicates the energy content of the product if multiplied by the energy output of the system. This energy content depends both on cumulative energy consumption and the structure of the system. If we divide it by the standard energy content we obtain the energy trade-off indicator which depends only on structure. Its measuring unit reads: 1 / year and can be interpreted as system power content of the product. Its average value seems to be 1 implying that all products are emanations from a unique power source.

Low trade-off indicators imply that corresponding products don't use the whole power structure of the system for their production. In case of high indicators the corresponding products obviously use power structure in excess of average value. If much electricity is consumed the trade-off indicator is high because electricity penetrates the whole system and if production seems to be supported by a sole energy carrier (as in gas industry) the indicator is low.

Leaping and flexibility

An input-output matrix establishes mutual dependence between output product vector and input (consumed) product vector. The difference of the vectors is the end product vector. Such is the static description. But in dynamic aspect the input vector exists earlier than the output vector with the same input-output matrix. So the static description includes dynamic qualities contained in the input-output matrix. It is well known that these qualities are described by the spectrum of the matrix. Most important of them shows how the system responds to a standard input impulse. One possible response may be a monotonous transition to a new state. This type of response is known as non-periodical and is conditioned by all eigenvalues being real.

Another type of response is oscillatory when the system leaps towards a new state unconstrained with inertia but soon cumulative chains of the matrix push the motion in the opposite direction forming oscillatory movement. For the response to be oscillatory some eigenvalues must have imaginary components and the largest relation of the imaginary component to the real one (tangent) accounts for the amplitude of oscillatory movement.

The spectrum of an input-output matrix bears many other meaningful impressions. As far as an input-output matrix is a statistical projection of some inaccessible economic operator it is likely to bear some impressions of the operator on its spectrum. We believe that the economic operator is non-linear and can be approximated with a time sequence of linear operators that describe momentary fragments of the system .

The more dispersed are the fragments the more sensitive the economic operator should be to output variations. If the operator is low sensitive to output variations we'd call it flexible. A flexible operator is supposed to yield less fragmented statistical projections observed via the spectrum of input-output matrices. So a criterion of flexibility can be chosen and we practiced the following one:

$$\lambda_0/(\lambda_0-\lambda_1), \text{ where}$$

λ_0- the largest eigenvalue (it is always real)

λ_1 - the next to the largest eigenvalue (practically always real).

A smoothing homomorphism

Spectrum calculation on an empirical matrix use to give frustrating results: eigenvalues seem to be chaotic and many of them are just noises generated by vague primary data. A smoothing procedure is obviously needed to develop meaningful values against noisy background. The procedure was constructed on the basis of the following idea.

From the production viewpoint each product is ultimately energy and different qualities of products correspond to different structures of energy forms sequestered in the product. So the space of all products can be projected into the space of energy forms without loss of essential qualities of products. This homomorphism is an axiom used in all our calculations.

For spectrum calculations instead of the input-output matrix a 4-dimentional matrix was used which was obtained by proportional adding cumulative energy contents of all products to the energy sub-matrix of the input-output matrix.

Application of this axiom imparted justifiable stability to numerical results.

Couplings

This term denotes pairs of sectors involved in observation of structural architecture. If a

coupling exists it means that some production proportions have been duplicated in measurements. As long as measurement procedure stays invariant it is the structure that changes when couplings appear or disappear. Measurement procedure can also affect couplings but only in conjunction with the structure (see data partitioning). So no matter what is the meaning of couplings they are sure to register structural dynamics. In Appendix one can find formal description of couplings.

Overhead

It was found out that the structure of the artificial sector #19 was partially contained in many other sectors and when all replicas of the sector #19 happened to be extracted in favour of the sector #19 (by searching with negative b - (see Appendix)) the output #19 increased X times. The value X we call overhead.

Data partitioning

Economic data originate in reports issued by producers and consumers. The reports contain information on demand that may not be comfortable to the reporter. So the information uses to be distorted and biased within possible limits. Compilation of such information into aggregate categories involves classification of many qualities on many levels. It cumulates uncertainty that depends both on inadequacy of measurements and political prejudice. It is a well-known fact that over 20% of tubes shipped to West Siberia in 70s as capital investments in oil production were actually used for construction purposes despite official statistics. A lot of military oriented projects were classified as civil undertakings to say nothing of blunt misinformation.

However the GOSPLAN knew the truth but had to succumb to the official language. After collecting data from Ministries GOSPLAN officers had to compile them with respect to technologies using their know-how. The result was dependent on the overall state of social conscience that we call data partitioning.
Data partitioning includes objective and subjective factors.

Input-output calculus

Statistical data were aggregated according to the following concept of segmentation. The mathematical model used for calculations would refer to the chosen segments as numbered sectors and any use of the sign # prefixed to a number would mean the corresponding sector.

#1. Electricity sector **includes production of electric and thermal forms of energy. The thermal form (heat) was not (for simplicity) sequestered in a separate sector so input-output coefficients which related to electricity implicated heat as well. Output measured in kWh.**

#2. Oil sector **includes both oil production and oil processing. Output measured in tce (tonnes of coal equivalent, standard heat capacity of coal was 7000 kCal/kg).**

#3. Coal sector **- production of solid fuels. Output measured in tonnes.**

#4. Gas sector **- production of gas measured in cubic metres.**

Outputs of all other sectors were measured in roubles.

#5. Non-ferrous metals sector includes all stages of production of non-ferrous metals.

#6. Chemistry - includes production of artificial substances.

#7. Machinery - production of machines and industrial equipment.

#8. Ferrous metals sector - all stages of production of steel and cast iron.

#9. Forestry - production of wood materials and paper products.

#10. Building materials - production of cement, bricks, ferro-concrete items, roofing, other elements of buildings.

#11. Light industry - production of commodities for mass use.

#12. Food industry - processing of agricultural products into end use nutrition products.

#13. Miscellaneous industry - a collection of small scale industrial capacities not included in the above mentioned sectors.

#14. Construction - a capital forming sector. Its row in the input-output matrix is empty. #15. Agricultural sector.

#16. Transportation sector.

#17. Residential infrastructure sector - includes trade and house catering.

#18. Miscellaneous economy - a sector accumulating non-industrial forms of production such as privat farming, handicraft, hunting as well as small scale manufacturing.

#19. Labour reproduction - this sector was added beyond standards for analytic purposes. In the primary segmentation it was contained in the end product and included the following items in monetary measures:
personal consumption + societary consumption + export - import. Output of the sector was measured with a scalar proportional to population. The row #19 was empty.

Throughout the calculations the quantity of energy contained in a product was understood in the net form:
the energy minus the loss of energy in energy production.

Values of energy content obtained with such algorithm prove to be some 15% lower as compared with the traditional method.

Observations

First have a look at energy contents as most vivid indicators. Fig.1 refers to sectors where energy contents were monotonously falling down. The energy content in other sectors (Fig.2.) were either rising or having an extremum. A distinction catches one's eye - the falling down curves (Fig.1.) seem to be purposely controlled while the others (Fig.2.) look like free dynamic

series. It is but natural for a planned economy which focussed its control on heavy industry. The ragged look of #18 and #13 is due to their being balancing categories in data compilation though the point 1974 in #18 is probably an error.

Positive trends in #12, #15, #17 and #18 make one guess that energy consumption gradually shifts from physical means of life support to biological means of life support. But it is not quite so. If we multiply energy contents by corresponding outputs of sectors in Fig.1 (to obtain energy flows) and compare the result with the energy flow of sectors in Fig.2 (excluding #19 and #13) we obtain linear tendencies shown by their end points in table 1.

Table 1. Energy flows in 0utput

Years	1950	1970
Energy flow to physical means of support of life (Fig.1.), Million GCal	**1948**	**5686**
Energy flow to biological means of support of life (Fig.2.), Million GCal	**628**	**3267**
Ratio	**0.32**	**0.57**

Sector #19 was excluded from the calculations because it doesn't represent a technology. It is just an extraction from outputs redirected to labour reproduction purposes. It can be tackled the same way as a sub-output and table 2 shows the corresponding trends.

Table 2. Energy flows in #19.

Years	1950	1970
Energy flow from physical means of support of life (Fig.1.) directed to labour reproduction, Million GCal	**126.9**	**428.5**
Energy flow from biological means of support of life (Fig.2.) directed to labour reproduction, Million GCal	**352**	**1480**
Ratio	**2.77**	**3.45**

Now the picture of structural macro-shifts acquires a new connotation. Industry of biological means of life support consumes more and more energy as compared with technologies for physical support of life. The ratio increased 1.78 times. But redistribution of end product (#19) shows a weaker tendency (Table 2.). The ratio increased 1.24 times. It possibly indicates that an ever-growing part of physical means of life support was used for labour reproduction. Biological means of life support were relatively falling.

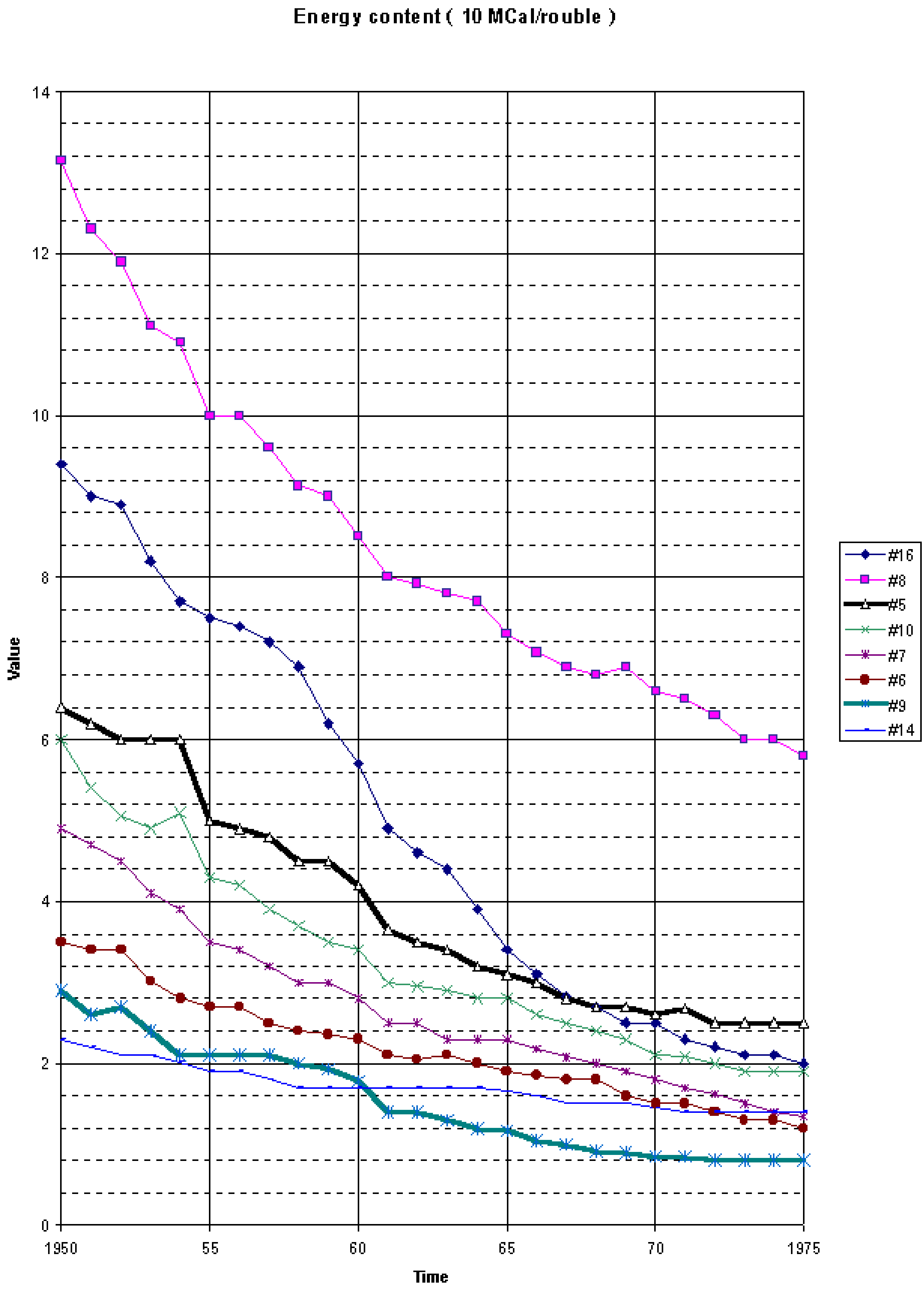

Energy content (10 MCal/rouble)
Value
Time
14
12
10
8
6
4
2
0
1950
55
60
65
70
1975
#16
#8
#5
#10
#7
#6
#9
#14

Fig.1.

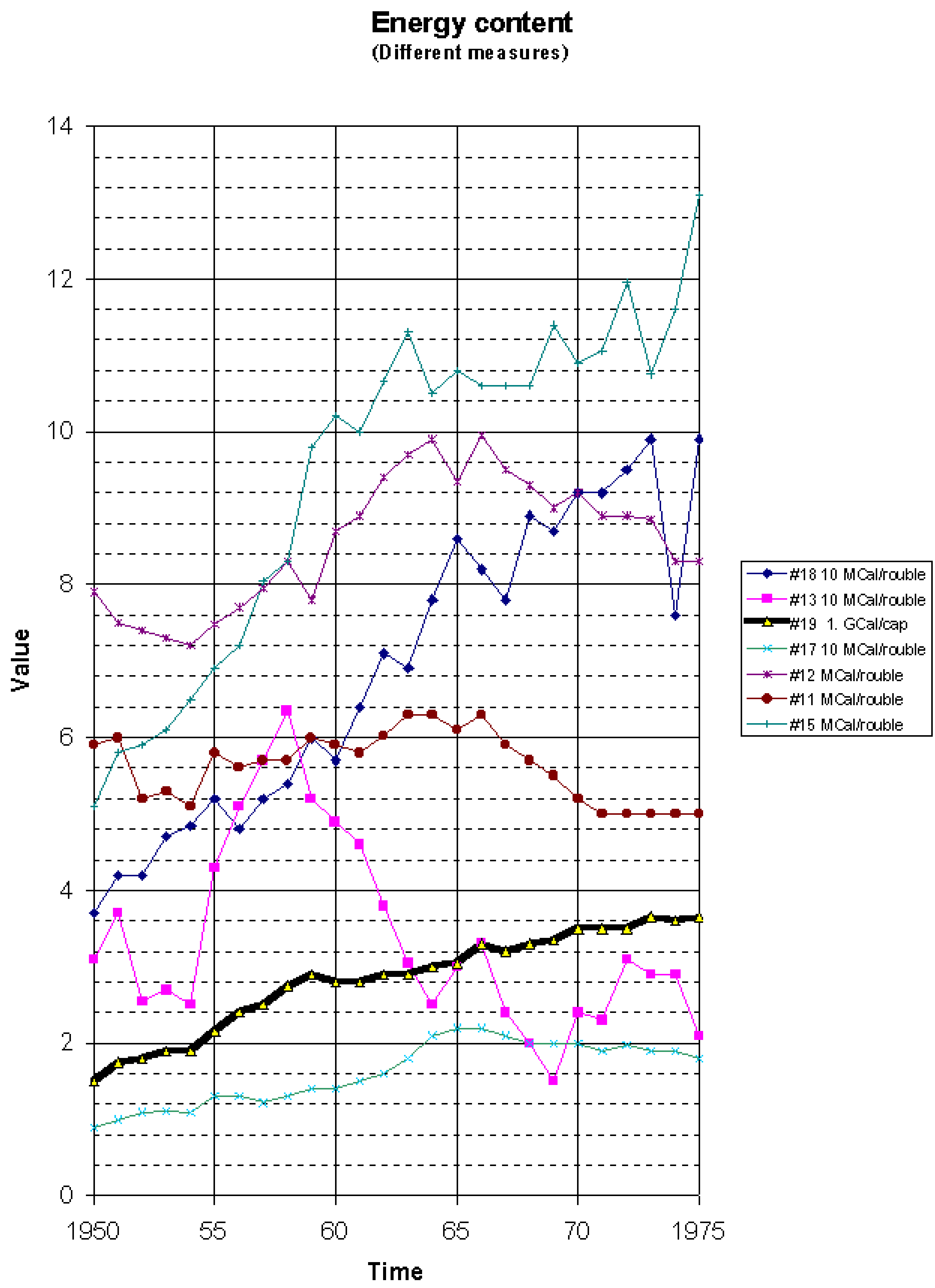

Energy content
(Different measures)
Value
Time
14
12
10
8
6
4
2
0
1950
55
60
65
70
1975
#18 10 MCal/rouble
#13 10 MCal/rouble
#19 1. GCal/cap
#17 10 MCal/rouble
#12 MCal/rouble
#11 MCal/rouble
#15 MCal/rouble

Fig.2.

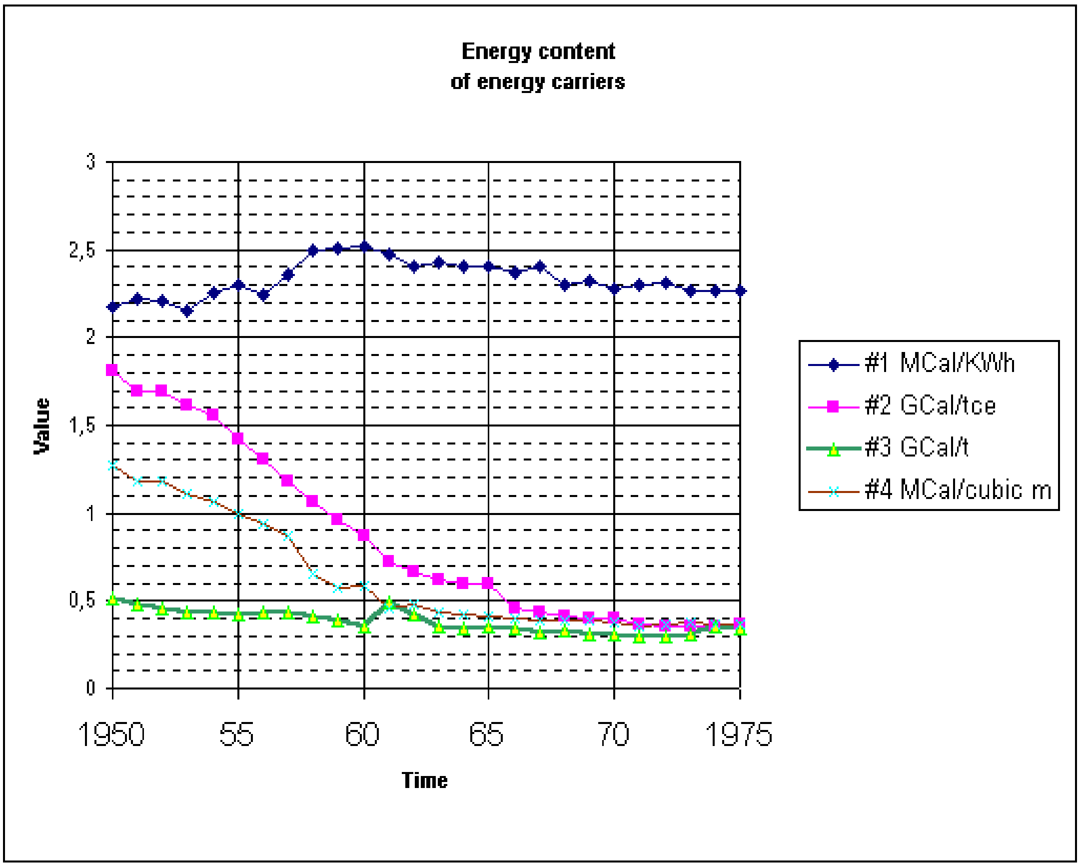


Fig. 3.

Much of the tendencies was due to energy sectors (#1 - #4). Fig.3 shows that fuels were sloping down in energy costs while electricity cost stayed practically invariant. Most probable explanation of the fact lies in heat energy being included in sector #1. Combined heat generation took ever-growing consumption of fuels referred to electricity. Very high energy costs of oil and gas in the early 50s are probably due to heavy investing in drilling and tubing.

Energy trade-off indicators

Trade-off indicator is a very formal numerical function that is sensitive to the structure of technological description of a product. Fig. 4 shows how trade-off indicators changed during the observed period. Insignificantly changing indicators were left out.

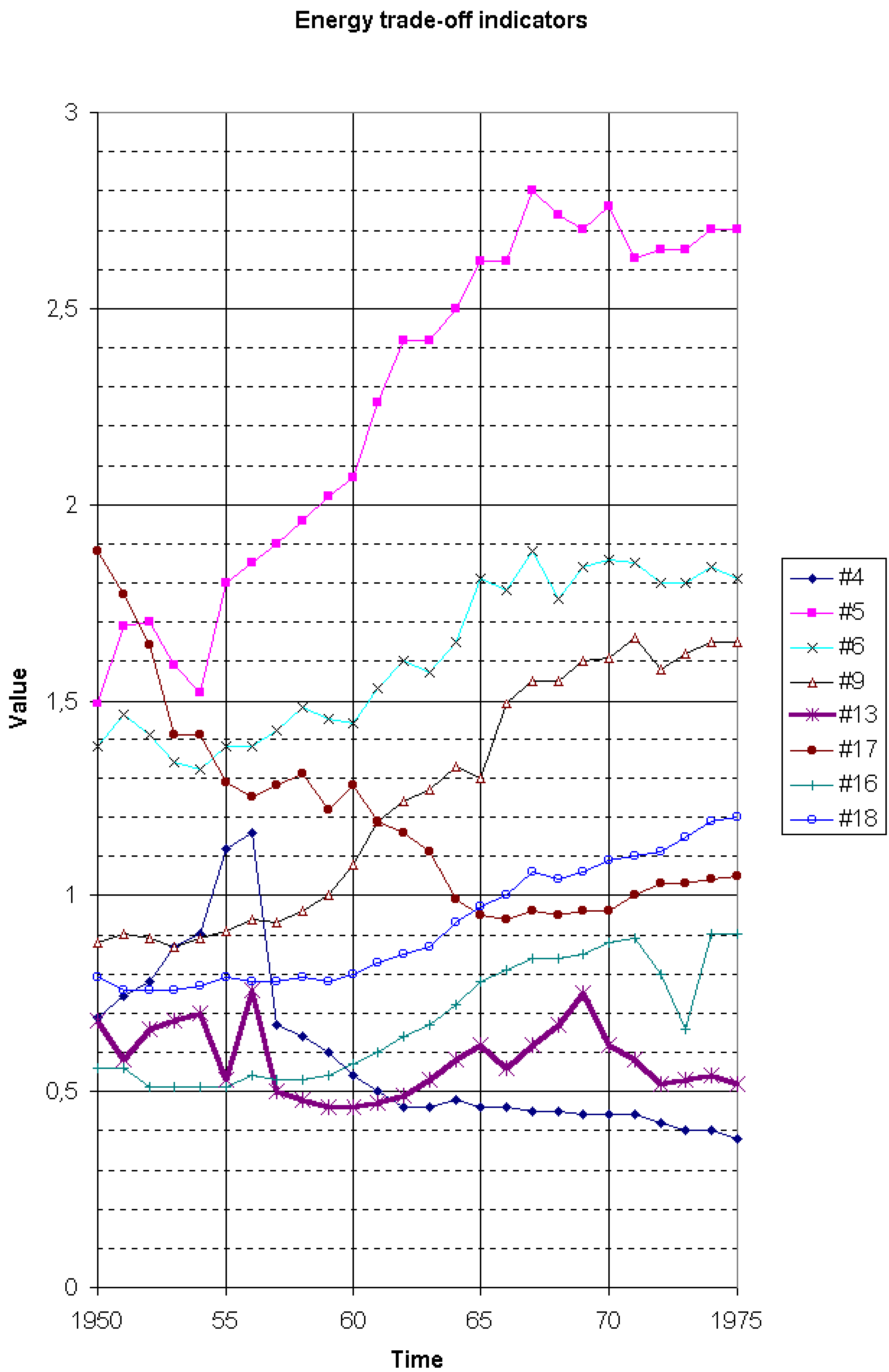

Energy trade-off indicators
Value
Time
3
2,5
2
1,5
1
0,5
0
1950
55
60
65
70
1975
#4
#5
#6
#9
#13
#17
#16
#18

Fig.4.

In order to make general observation of the curves depicted in Fig. 4 we have first to understand the properties of the utilized criterion. Trade-off indicator of a product approaches 1 when the energy vector of the product is approximately collinear to the vector of energy output of the economy. If the energy vector is not collinear it is to be substituted with an equivalent collinear vector, its components being traded off (exchanged via technological transformations) with each other. If a higher quality form of energy is to be traded off in favour of a lower quality one the indicator would exceed 1 because exchange of a higher quality energy for a lower quality energy would demand for the return of energy losses. In a vice versa case the indicator would be below 1.

In our model there are roughly only two levels of quality - electricity and fuels. So when the energy vector of a product is skewed in favour of electricity (or in shortage of a fuel) the indicator is high. In the opposite case it is low.

What is remarkable about trade-off indicators is their capability of tracing economic cycles. Most vividly it happened to appear in case #13. This sector is a collection of industrial technologies and for that reason reflects macro-properties. The smooth span between 1957 and 1965 is certainly a point of wonder. How could it have happened? Surely it could not have been tailored up during data compilation because no man could grasp the termination of an algorithm tackling with hundreds of independent numbers. The only explanation that comes to one's mind is the following.

From 1957 to 1965 the Soviet Union economy was controlled on territorial principle (as opposed to ministerial principle) with strict partitioning industrial and agricultural information. Perhaps the indicator caught up this macro-quality. It revealed a cycle with a period of 18 years. Other cycles could be felt in agriculture (#15) - more that 25 years, in transportation (#16) chemistry (#6), forestry (#9) and miscellaneous economy (#18) - in excess of 40 years if the observed fragment should happen to cycle.

Curious trajectory of the indicator could be observed in gas industry (#4). The pike in 1955-56 may be caused by relatively high proportion of electrically powered gas pumping stations which in later period were overwhelmed by gas powered ones.

Flexibility, leaping and overhead

These terms denote qualities that are surely emergent because they can not be noticed in any distinct part of the system. Flexibility indicator (Fig. 7.) revealed its emergence immediately. It was constant in the interval 1970 - 75 because only data on energy flows were available and all other input-output coefficients had to be fixed on 1970 level.

A period of 18 years could be discerned in the zigzag curve where 1964 seems to be a critical year. This year is known as the time of Khruschov's dismissal and it makes one guess that economic statistic data were permanently influenced by political situation. If this is true all emergent indicators may have unpredictable impressions on their dynamic sequences so that one may rightfully suspect a meaning in apparently stochastic displacements. Such an example we see in the evolution of leaping. The point 1957 (see Fig. 5.) looks absurdly irregular but having in mind that eigenvalues can swiftly jump from one symmetry pattern to another it doesn't seem improbable that 1957 was the point of transition from one kind of instability to another.

The slump of leaping in 1961 - 62 coincides with that of overhead (Fig.6.). There must be some common cause. Could it be the monetary reform (denomination) of 1961? Hardly so. First

because it left no other impressions on dynamic series (both primary and evolved). Second because prior to 1961 overhead (as well as leaping) seemed to have ramped up to some dangerous limit and decisive control actions had to be applied in order to bring the economy in a state of dynamic equilibrium. This dynamic equilibrium was the Cold War race.

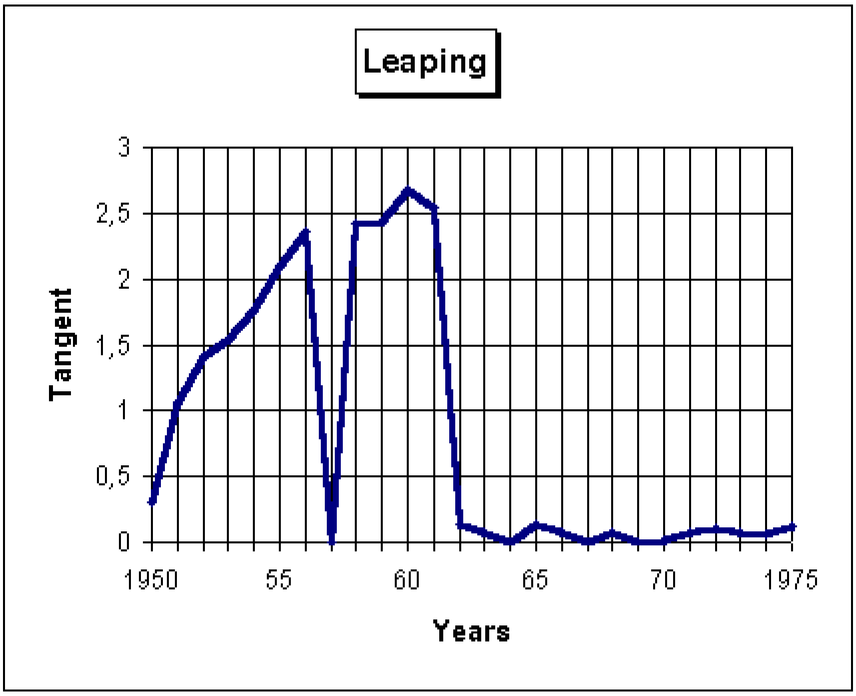


Fig.5.

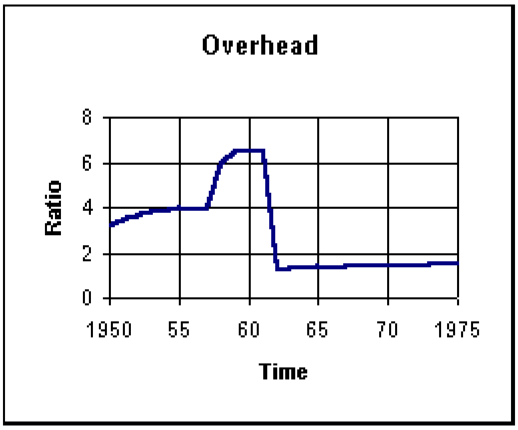


Fig. 6.

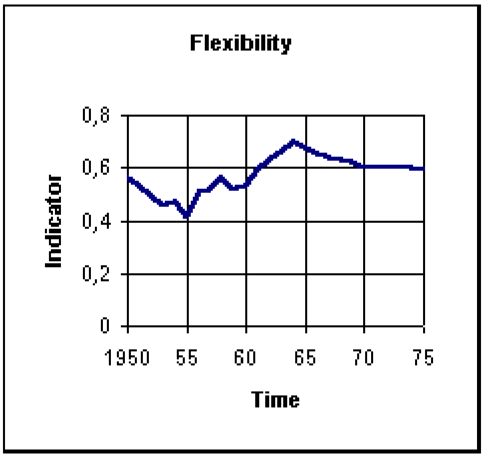


Fig. 7.

Evolution of couplings

Before analysing the picture of couplings one has to adopt some interpretation of their meaning. The algorithm of their calculation (Appendix) provides us with facts that should shield us from wanton thinking.

- **Appearance of a coupling testifies to the fact that mixing the structures of two sectors**

increases asymmetry of the input-output matrix.

- **Appearance of a coupling is a quazi-random phenomenon that was made stable by a proper choice of calculation parameters that took into account the vague nature of primary data. So appearance of a misleading coupling is possible but improbable.**

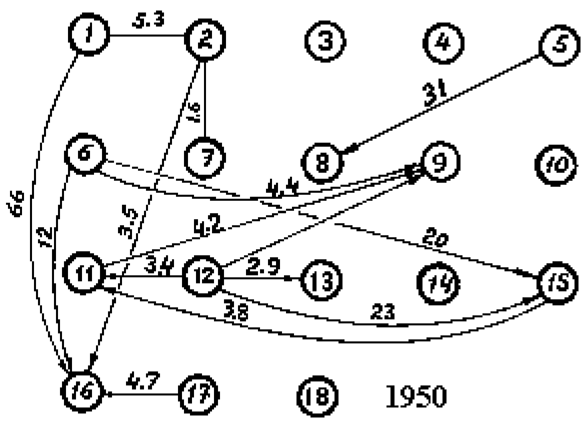
The hidden asymmetry of an input-output matrix on macro-level is believed to be its natural property that follows both from theoretical concepts and empirical evidence (the works of Novosibirsk Economic Institute of the late 1960s edited by Prof. K.K. Val'tuh).

With respect to the above facts we should interpret a coupling the following way:

> **An arrow with weight X% pointing from sector #i to sector #j means that the process of data compilation uses a wrong partitioning of sectors and in order to restore the right partitioning the X% of output #i should be included in output #j.**

So the pictures of couplings shown below are empirical representations of disparity between the structure of technologies and the structure of economic thinking. When couplings appear or disappear it may be due to changes in either technologies or economic thinking.

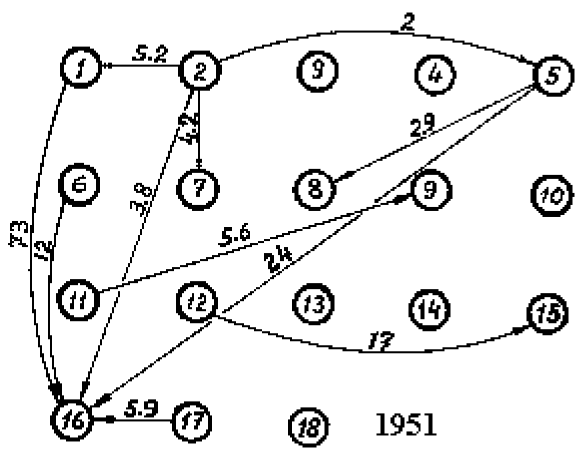
1950



Plenty of couplings show that the economy was conscious about transportation (#16) and agricultural (#15) problems. 23% of food industry was viewed in the context of agriculture. Transportation sector was apparently given great priority. The coupling 1 ===> 16 accounts for the idea of railway electrification. Non-ferrous metals industry resembled the ferrous industry in 31% of its output. Chemistry structure contained a 20% part of agriculture.

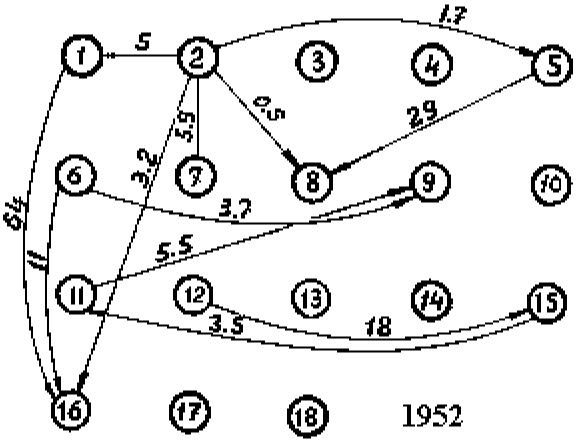
In later years this coupling would not appear and it is most probable that in 1951 the partitioning was changed. Disappearance of many small couplings supports this conjecture.

1951



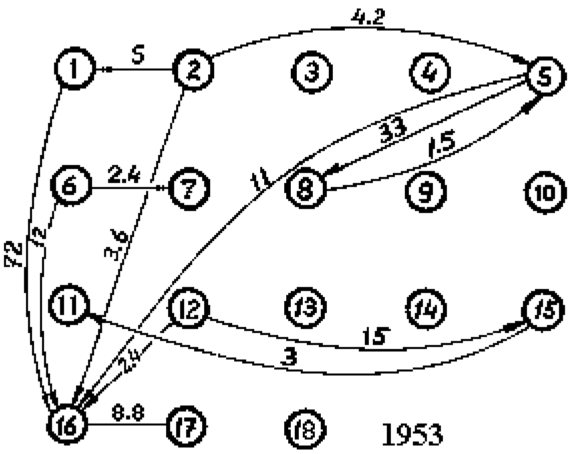
Drastic changes began. Disappearance of many couplings showed a distinct structural move. A strong coupling leapt from non-ferrous sector (#5) to transportation (#16) as if copper production was related to electricity powered trains. The coupling from oil (#2) to machinery (#7) gained more force.

1952



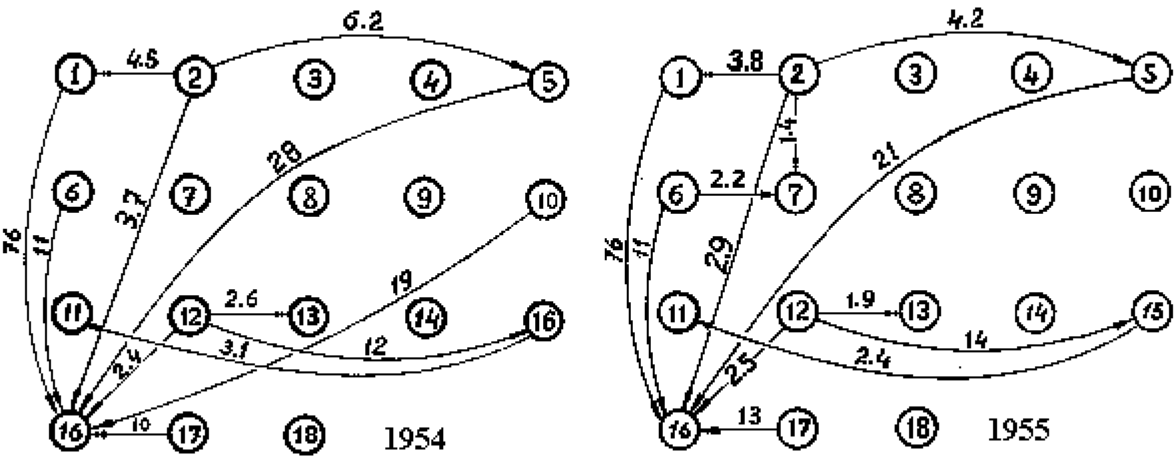
The structural jump of the previous year had been apparently too strong. A recess followed. Some couplings reappeared. The new role of sector #5 faded out but its coupling with #2 was left. The system took a little rest before further moving.

1953



The changes of 1951 renewed their progress. The coupling 5 ===> 16 reappeared with a lesser force but the coupling 2 ===> 5 became stronger. Machinery changed its relevance (6 ===> 7 instead of 2 ===> 7) as if this year chemical refinement of oil was more important than oil consumption. This idea of chemical relevance would hold on intermittently until 1958. The weak coupling 8 ===> 5 looks like a random noise but later we'll see that it was a forestalling signal.

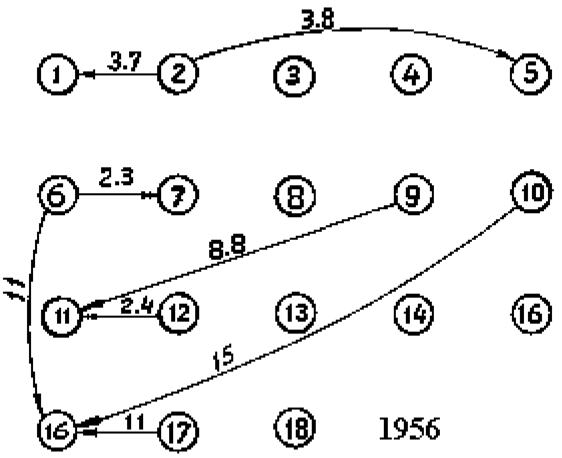
1954 -1955

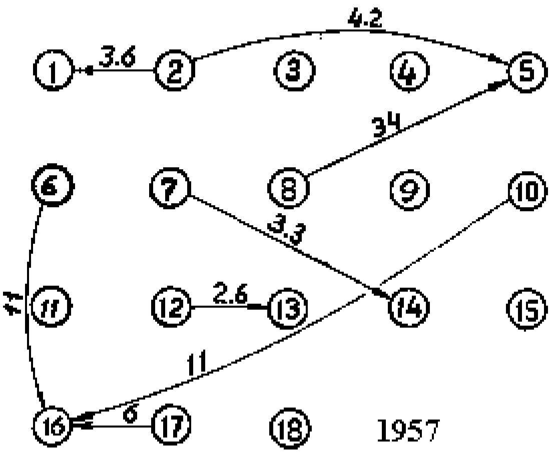


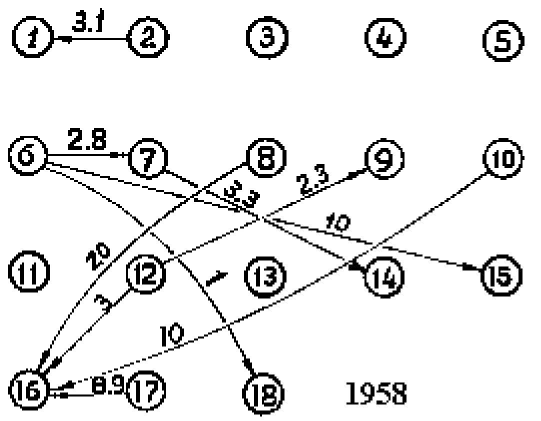
The structural shifts of the previous year kept their grasp. Disappearance of relevance between ferrous and non-ferrous metals and further activation of the food industry sector #12 were a new feature. This activation extended its relevance to miscellaneous industry #13 and in the longer run (1956 - 1958) gave successive impulses to #11, #13 and #16 + #9. It looked like sector

#12 being a stabilizing controller of the economy while it performed a heavy manoeuvre that terminated in 1958.

1956 - 58



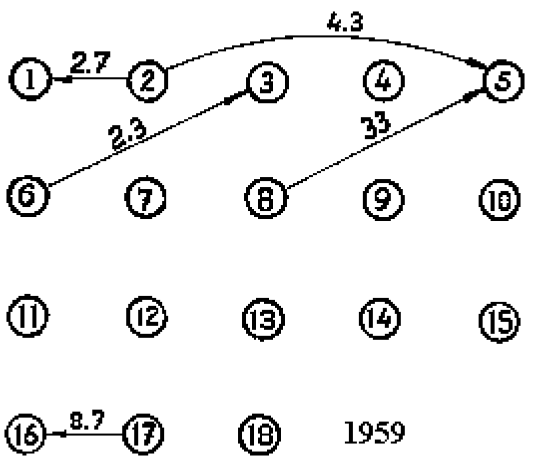




A finishing stage of the manoeuvre began. The idea of electrification faded out. The focus of attention was shifted to relevance between building materials (#10) and transportation (#16). This coupling first made its short appearance in 1954 forestalling the imminent building process. At the same time construction sector (#14) was involved in relevance to machinery (coupling 7 ===> 14).The economy was approaching a new very heavy stage of expansion that was first hinted at in 1953 by the coupling 8 ===> 5 and now clearly manifested by its reappearance with weight of 34%.

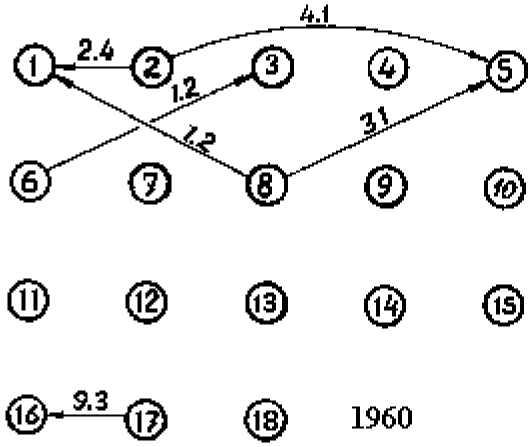
The year 1958 looks like a finishing touch to the reforming of transportation after which a distinctly new structural behaviour took place.

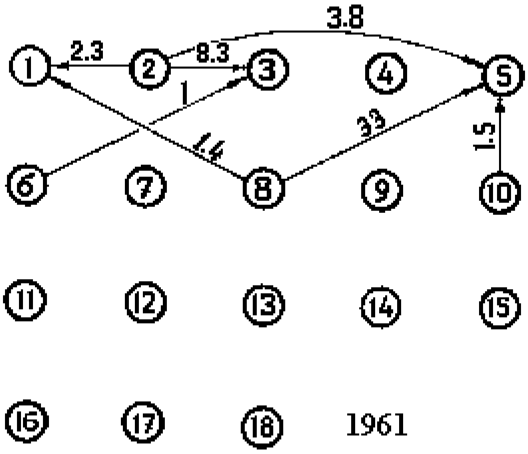
1959



The new structural behaviour was evidenced by the reversion of the coupling between #8 and #5 (as compared with 1950 - 53) and by the appearance of relevance between chemistry (#6) and coal (#3). Heuristically one can conclude that this was caused by the change of domination in the production of non-ferrous metals - the copper that dominated in the early 50s was taken over by aluminium and titan.

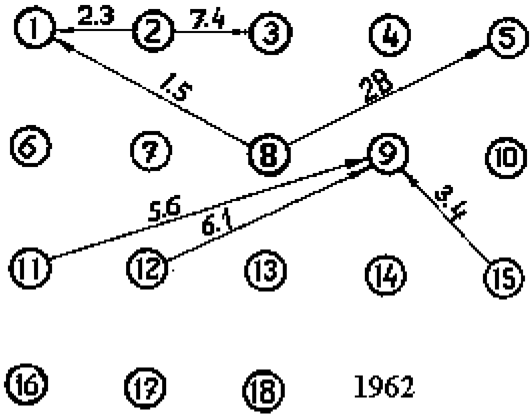
1960 -1961





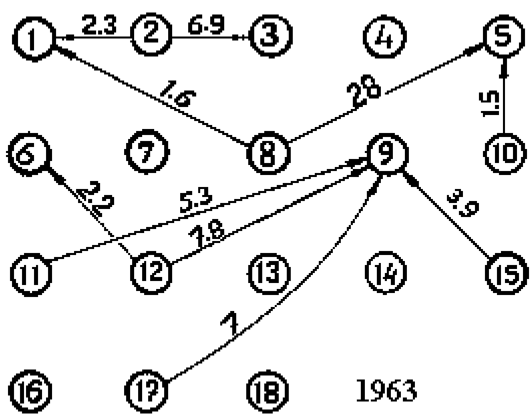
The appearance of relevance between the industry of ferrous metals (#8) and electricity (#1) supports the above mentioned heuristic guess because if some substructures of inputs to the production of ferrous metals replicate the structure of electricity production then the ferrous industry may conceal a vicarious use of electricity in favour of non-ferrous metals.

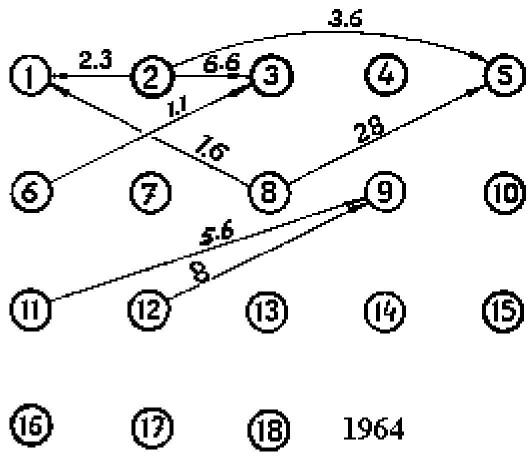
1962

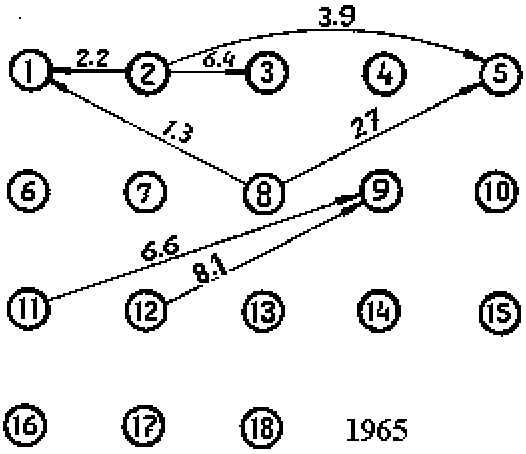


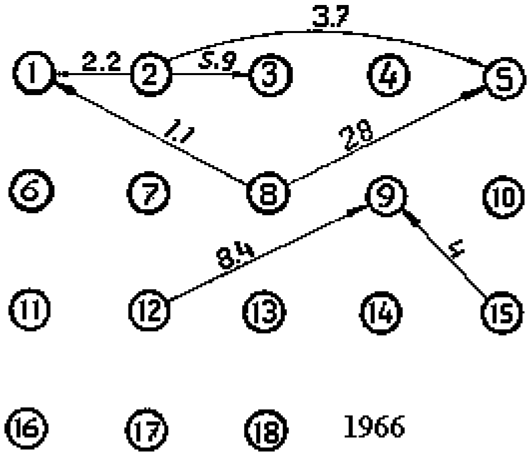
The new structural behaviour that started in 1959 on the metal industry swept other industries into the avalanche of sectoral interactions. This was registered by couplings related to the forestry sector (#9) where the production of cellulose was a key element of the technological infrastructure that supported the purposeful use of titan and aluminium. The couplings originated in mundane sectors (#11, #12, #15) because a side effect of cellulose usage increased the output of commodities for every day use.

1963 - 1966



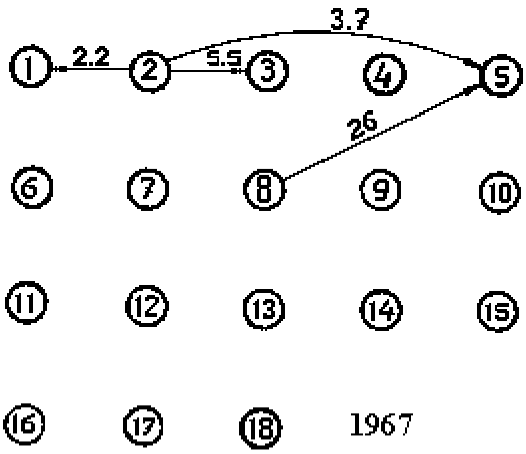


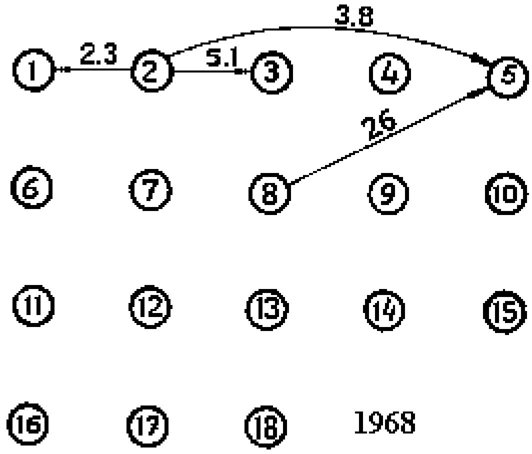




The described tendency kept up its momentum.

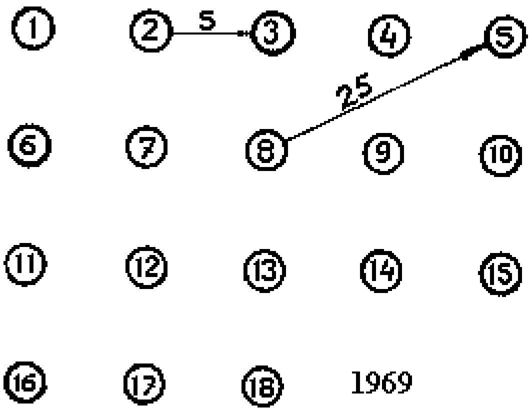
1967 - 1968





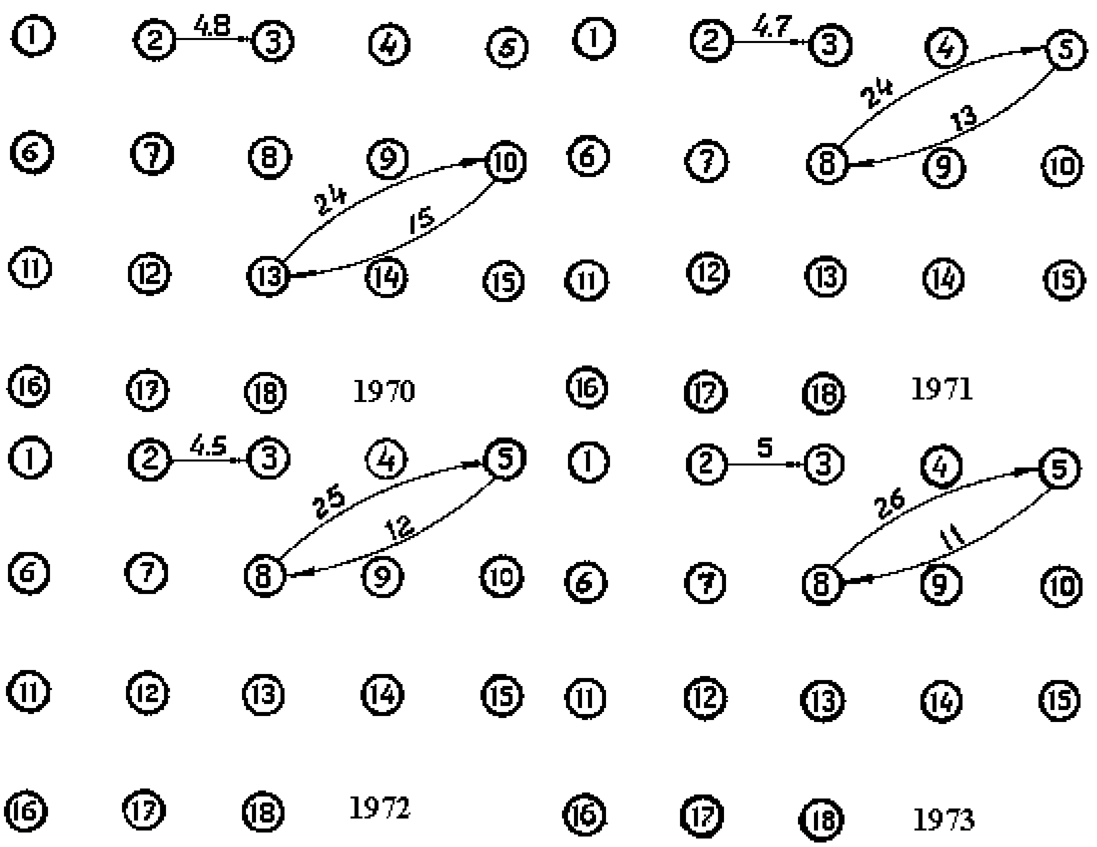
The stagnation phase began. Couplings of fundamental quality were still present.

1969



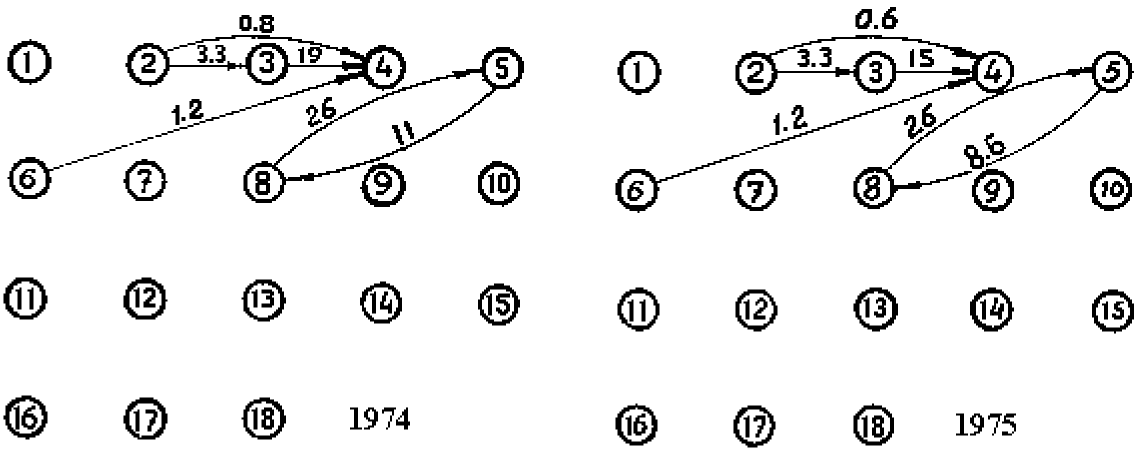
No evidence of structural movement.

1970 - 1973



A combination of qualities that were observed in metal production at terminal points of the structural evolution revealed itself in the feedback coupling between sectors #8 and #5. We are very constrained in interpretation of this phenomenon because during 1971 - 75 primary data about all sectors were not available and we could rely only on energy flows. So the feedback coupling was certainly energy meaningful. Perhaps it was due to more intensive use of gas in both industries.

1974 - 1975



Two more energy meaningful couplings appeared. Most likely it showed the intention of the economy to involve more gas in its export policy.

Conclusion

A structural analysis of an economy was done. The empirical data for the analysis were monetary and hence inadequate because monetary measures fail to describe the fundamental category of structural theory - the quality of a resource.

Nevertheless some structural phenomena were observed and interpreted to show how the system was manoeuvring during the analysed period. The results observed were not unexpected but the instrument that made them observable brings economics closer to the family of natural sciences.

APPENDIX

Couplings were calculated by rotating the coordinate axis of the empirical space to maximize a criterion of asymmetry. Empirical data were arranged in the standard input-output form:

$$(I - A)\, Y = P$$

where i/o matrix $A = \{a_{i,j}\}$,
output vector $Y = \{y_i\}$,
end product vector $P = \{p_i\}$, $i,j = 1,2,\ldots,19$

After rotation the vectors would acquire new proportions:

$$(I - \underline{A})\, \underline{Y} = \underline{P},$$

where $\underline{A} = R^{-1} A R$, $\underline{Y} = R\, Y$, $\underline{P} = R^{-1} P$.

The operator R was obtained as a succession of elementary rotations B (i,j), each one maximizing the criterion in the domain of elementary rotation:

$$R = \prod_{i,j} B(i,j)$$

The elementary rotation was determined by the matrix:

$B_{i,j} =$

r/c	1	2	·	·	·	·	j	·	19
1	1	0	0	.	.	.	.	.	0
2	0	1	0	.	.	.	.	.	0
·	.	.	.	.	.	.	.	.	0
·	.	.	.	.	0	.	.	.	0
i	0	0	.	.	1	.	b	.	0
·	.	.	.	.	0	.	.	.	0
·	.	.	.	.	.	.	.	.	0
·	.	.	.	.	.	.	.	1	0
19	0	0	0	0	0	0	0	0	1

The criterion was determined by the function:

$$F = \mathrm{SUM}\,(a_{i,j} * y_j / y_i - a_{j,i} * y_i / y_j)$$

By numerous tests the criterion was found to depend on parameter b in the way pictured in fig. A.

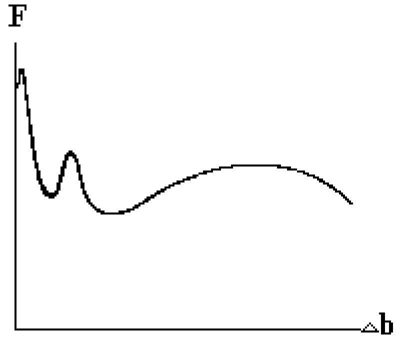


Fig. A.

This meant that small searching increments (steps) of b would produce great noise in the calculated results (what actually happened) and greater steps would lead to minimax domain where the algorithm was not sensitive neither to the value of steps nor to the order of sequencing the indices i,j. The minimax domain was chosen. Also $a_{i,j}$ were constrained to be positive.

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