MACROECONOMIC CONSEQUENCES OF LARGE ENVIRONMENTAL IMPACTS:
The Case of the Chernobyl Accident in the Soviet Economy

BY

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Acknowledgement

First of all I would like to note that this thesis is my tribute to the people of the former Soviet Union who have suffered and continue to suffer from the Chernobyl accident which occurred on April 26, 1986. Twelve years have passed by since the accident, however, its consequences are not completely understood. This study is a modest contribution to better understanding of these consequences.

Secondly, I am very grateful to all members of my thesis Committee. Especially I want to express my thanks to Dr. Norman Cameron for his quick reaction and invaluable comments that kept me going at a high speed. I also appreciate technical remarks made by Dr. Wayne Simpson as well as his suggestions that eventually gave me ideas for chapter five. My thanks also go to Dr. George Chuchman for his time spent on reviewing my writing and for his criticism associated with analysis of the Soviet economy. In general I have to admit high professionalism of all members of my Committee.

I would also like to share my success with Joan Larsen who has patiently listened for my "crazy" ideas for two years. The fast completion of the thesis was due to very warm environment that has surrounded me in the Department of Economics. Fortunately enough, graduate students in the department present a kind of family, and I hope to carry this family attitude throughout my career.

Abstract

Based upon intensive literature review, major environmental consequences of the Chernobyl accident are identified as well as macroeconomic consequences as they were presented by Soviet officials and economists.

In order to study macroeconomic consequences of the accident in dynamics, a disequilibrium growth model of the Soviet economy is derived. The major assumptions behind the model are extensive economic growth and fixed prices set below equilibrium level. Extensive economic growth implies relatively constant technology and explicit treatment of natural resources as complement to conventional factors of production - capital and labour.

Further the derived model is approximated by linear stochastic difference equation which we call the basic dynamic equation. Stability of the basic dynamic equation is investigated and conclusion is reached about structural change in the Soviet economy in 1960 based upon econometric testing.

The Chernobyl accident represents an adverse supply shock in the Soviet disequilibrium economy. Direct impact from the shock is derived based on simulation using Vector Autoregression analysis. Dynamic properties of the shock are studied with the help from Impulse Response Function. It appears that the shock has permanent effect for the structure of the Soviet economy because this economy is described by non-stationary dynamic process at the time of the accident.

Aggregate value of the shock is derived quantitatively as a loss of potential real GNP over time. In doing so, two impacts - from restructuring of the Soviet economy since 1985 and the Chernobyl accident of 1986 - are separated.

In the end, strengths and limitations of the thesis are discussed and conclusion is reached about further research in this area.

Symbols

Y - aggregate output

Y^n - target level of aggregate output

S - natural resource stock

S^R - stock of renewable resources

S^N - stock of non-renewable resources

K - capital stock

L - labour

q - technological constant

α - share of factors of production in aggregate production function

R^R - flow of renewable resources (annual level of harvesting)

R^N - flow of non-renewable resources (annual level of extraction)

R^{AN} - new additions to non-renewable resources in a form of new discoveries

r_b - biological growth rate of renewable resources

r_n - growth rate of non-renewable resources

r - growth rate of natural resources, renewable and non-renewable

I^a - actual investment

I^d - desired level of investment

C^a - actual household consumption

C^d - desired level of consumption

b - investment's share in GNP

δ - capital depreciation

AD - aggregate demand

AS - aggregate supply

H - aggregate shortage

P - general price level

c_Y - marginal propensity to consume

c_H - quantity demanded per unit of shortage

c_P - quantity demanded per unit of general price level

d - depletion rate

g_K - growth rate of capital

g_N - growth rate of population

y - productivity of economy

h - relative shortage

u - inverse of GNP in physical units

x - vector of variables y, g_K, g_N

ϕ - impulse response function

t - time period (years)

Introduction

In 1992 Feshbach and Friendly wrote in their book *Ecocide in the USSR* that the Chernobyl accident of April 26, 1986 was the greatest environmental disaster in the former USSR; it released ten times the radioactivity of the Hiroshima atomic bomb. They call the accident *"the epitome of the complex relationships among the Soviet economic system, the political system, damage to the environment, and the impact on the health of the population"*. This statement explicitly points at important macroeconomic problems caused by the accident. Consequences of the accident are very significant, and, therefore, they must be studied at the macroeconomic level.

This study is dedicated to the economic aspects of the Chernobyl accident. The idea is to draw a broader picture of the accident as a large environmental impact on the Soviet economy. It is necessary to acknowledge the importance of some microeconomic issues associated with the accident, however, macroeconomic issues prevail in this particular case.

The justification of the framework and the choice of techniques to analyse macroeconomic consequences of the Chernobyl nuclear accident are presented below to answer the main question: *is it possible in principle to analyse consequences of the large environmental impact such as the Chernobyl accident through macroeconomic considerations, and if it is, what pre-conditions should be met?*

Macroeconomic issues have been introduced to discussion of environmental impacts in the context of *humanitarian emergencies.* The concept of *humanitarian emergencies* has become very popular among specialists in the field of development economics[1]. The term was defined by United Nations for situations in which large numbers of people in an economy are affected as a result of civil wars and severe policy crises on the one hand, and natural disasters such as earth quakes, floods, droughts, famines on the other.

Another definition of humanitarian emergencies (see, for example, Helina Melkas, 1996) includes any social crisis when a large number of people suffer from man-made and/or natural disasters. In this regard large environmental impacts, which are results of human activity, are the man-made disasters. Hence, it is necessary to consider the large environmental impacts as emergencies because they do affect large numbers of people.

First of all it is necessary to define the term *emergency*. Emergency means that it relates to an occurrence that is sudden, unpredictable, threatening and outside the control of those affected. The large environmental impacts are exactly of this nature. Specialists in humanitarian emergencies suggest we study changes in macroeconomic system as results of these emergencies. Therefore, when a large environmental impact occurs, its consequences should be traced at the macroeconomic level as well.

What is the difference between this approach and existing approaches to analyse environmental impacts? There is a branch of economic science which is called *Environmental Economics*. This is applied microeconomics which studies market failures such as public or environmental goods, externalities, open-access resources, etc. Environmental economics considers any environmental accident in terms of social costs. In order to calculate social costs one has to construct a damage

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[1] See, for example, proceedings of the conference "The Political Economy of Humanitarian Emergencies", 6-8 October 1996, Helsinki, Finland

function usually in terms of pollution based on empirical evidence. This process involves specialists in different fields such as biology, geology, physics, medicine, etc. Many methods were designed to evaluate the environmental damage. Mainly these methods are based upon valuation of non market goods such as components of the natural environment (air, water, soil) and human health. Valuation is realized through two major approaches: (i) direct valuation through people's willingness to pay (for example, Contingent Valuation Method); (ii) indirect valuation through artificial markets (for example, Wage Differential Approach, Hedonic Price Approach). The main reason for application of these methods is as follows: usually changes in the natural environment are not detectable through conventional economic market analysis. Therefore, environmental economists create artificial and/or hypothetical markets instead and employ a concept of weak complementarity. The concept was introduced by Lancaster in 1960's. It implies that an individual does not consume a good itself, but rather a set of attributes associated with the good. Environmental quality is one of these attributes. Therefore, price of the good is a composition of partial prices of the attributes which allows one to derive the partial prices statistically.

Once valuation of a non market good is realized, it can be used to construct marginal damage function which relates levels of pollution to the changes in the derived value of a non-market good in monetary terms. Social costs are equal to the total environmental damage. Then these costs are incorporated in benefit-cost analysis or its modifications such as cost-effectiveness analysis, life-cycle costing approach, risk-assessment analysis, economic impact analysis, etc. All these methods use the concept of *present value* to capture dynamic character of a problem. However, they do not take into account possible changes to the macroeconomic path of the economy.

On the other hand, as any emergency, the large environmental impact causes dramatic changes in the entire macroeconomic system. In general these changes are of two types: (i) increased deviations of macroeconomic variables over time; (ii) structural changes. The first type is associated with deterioration of stability conditions of a dynamic economic system while the second one is associated with a regime switch. Both must be studied in terms of system's dynamics when all relevant macroeconomic variables are related to each other.

So, as an intermediate conclusion, all methods designed within Environmental Economics can be used to assess small local environmental impacts when direct consequences are unobservable or rather undetectable through conventional economic analysis. In turn, large environmental impacts being emergencies and causing dramatic changes in the entire macroeconomic system produce consequences which are directly observable and are reflected in significant changes in macroeconomic variables. These changes are dynamic in nature on the one hand, and detectable through market analysis on the other. Therefore, large environmental impacts can be studied with the help of conventional macroeconomic theory because they may cause regime changes or, at least, deterioration of dynamic properties of an economic system.

The large environmental impact is associated with two major consequences: (i) direct damage to the natural environment with spillover effect on all inputs of a macroeconomic system - natural resources, human resources, capital resources - during the impact period; (ii) long-lasting consequences for the structure of the macroeconomic system after the impact period. It implies that initial impact not only affects all areas of human activity through spillover effect, but it also has autoregressive causal character afterwards (speaking in mathematical language). In such a sense the large environmental impact is a one-time quantity shock to the natural resource stock with spillover and autoregressive effects on macroeconomic flows afterwards. Therefore, a macroeconomic model has to reflect these attributes through indicators of the economy's dynamics.

However, it is well known that a socialist economy differs from a market economy in many very important aspects including institutions of property rights, management, economic mechanism, psychology of individuals, etc. Therefore, we need a theory which captures distinguishing features of a socialist economy in general and Soviet economy in particular. Moreover, such a theory should reflect these features in dynamics at the macroeconomic level.

The plan of the thesis is as follows. Chapter one describes the environmental and economic situation in the former Soviet Union after the Chernobyl accident. In chapter two we analyse existing approaches to the modelling of socialist economies and derive our macroeconomic model of the Soviet economy as a disequilibrium growth model. Chapter three discusses Soviet macroeconomic data and presents statistical and econometric analysis of the Soviet economy's dynamics based upon the data and on the growth model developed in chapter two. Major dynamic properties of the Soviet economy are identified. Chapter four is dedicated to simulation of the Chernobyl accident as an adverse supply shock in the Soviet disequilibrium economy. Macroeconomic attributes of the shock are specified and incorporated in the simulation. Chapter five presents an interpretation of the results of this simulation and compares the consequences of the large environmental impact in the Soviet economy with those to be expected in a market economy, and discusses limitations and possible extensions of the study.

CHAPTER ONE

ENVIRONMENTAL AND ECONOMIC SITUATION IN THE SOVIET ECONOMY AFTER THE CHERNOBYL ACCIDENT

The chapter is dedicated to describing environmental and economic consequences of the Chernobyl accident in the former USSR based upon literature review. More than 100 literature sources were identified in this regard. Four of them were extensively used in this study: works by Canadian historian David Marples (1986, 1988), work by Ukrainian scientist in the field of risk assessment analysis of the nuclear accidents Vladimir Georgievskii (1994), and report of the Organization for Economic Cooperation and Development (1995).

The work by Marples presents a very comprehensive information on the direct consequences of the Chernobyl accident. The work by Georgievskii is a good example of dynamic nature of these consequences. However, both scientists based on their information reach conclusions which are not consistent with existing economic theory. OECD's (1995) report contains more sophisticated data based on recent analysis of the environmental consequences of the Chernobyl accident. Therefore, I use the mentioned above sources to reach my own conclusions about macroeconomic consequences of the accident. Also some facts from the Soviet and Western media are presented as well as my own impression and experience of the accident.

The second half of the chapter is a survey of the real changes in macroeconomic variables of interest in the Soviet economy after the Chernobyl accident, as desribed by Soviet economists. The idea is to show the dramatic changes for the structure of the macroeconomic system as they were presented by Soviet specialists.

1.1. Environmental consequences of the Chernobyl accident

Chernobyl itself is a small town of 12,500 people in the former Ukrainian republic of the Soviet Union. It is located about 105 kilometres north of Kiev, the capital of the Ukraine with population about 3 million people. The Chernobyl nuclear power plant (ChNPP) is located 15 kilometres to the north-west of the town of Chernobyl. To the south-east of the plant, an artificial lake of some 22 km situated beside the river Pripyat, a tributary of the Dnieper river, was constructed to provide cooling water for the reactors. Three kilometres away from reactors the town of Pripyat with 49,000 people is located. The Dnieper River which provides 80% of the water supply for the Ukraine flows through the area on its way to the Kiev Reservoir.

At the time of accident, the USSR generated about 10% of the world's nuclear power from 43 operating reactors with capacity of 27 billion watts of electricity. By 1986 the ChNPP accounted for 10% of the USSR's total electricity-generating capacity and 15% of nuclear-generating capacity, and was , along with Leningrad NPP, the Soviet Union's largest nuclear plant at 4 thousand million watt of capacity. It consisted of four units. Unit 1 and 2 were constructed between 1970 and 1977, while Units 3 and 4 were completed in 1983.

The accident itself occurred at 1:23 AM on April 26, 1986. The explosion of the 4th Unit released about 18 tones of radioactive matter (Radio Free Europe Special, May 22, 1986). The first Soviet report to the International Atomic Energy Agency (IAEA) noted that there were two major periods of radioactive fallout: April 26-27 and May 2-6, 1986. According to the report the ground became severely contaminated to the west, north-west and north-east of the ChNPP while the plume affected the Ukrainian, Byelorussian and Russian republics.

However, political considerations combined with the lack of environmental monitoring equipment in the former USSR resulted in significant underestimation of the consequences of the Chernobyl accident in the above mentioned report. Borovoi and Sich (1995) state:

"Investigation conducted during 1986 to 1989 showed that previous notions concerning the extent of damage within Unit 4 as a result of the accident in the most cases did not correspond to the actual state of the destroyed reactor" (Borovoi and Sich, 1995, p.8)

Sich (1996) gives the release estimate for the eight most significant volatile isotopes as 92 million curie (MCi) which is "... *substantially more than a total release of 50 MCi claimed by the Soviets in Vienna in August 1986... If the contribution of all other longer lived radioisotopes are added, the total release may approach 150 MCi" (Sich, 1996, p.208).*

According to the OECD's (1995) report, during the first ten days of the accident, meteorological conditions changed frequently, causing significant variations in release direction and dispersion parameters. The largest fuel particles were deposited essentially by sedimentation within 100 kilometres of the reactor. Small particles were carried by the wind to large distances and were deposited primarily with rainfall. The radionuclide composition of the release and of the subsequent deposition on the ground also varied considerably during the accident due to variations in temperature and other parameters during the release.

Three main spots of contamination resulting from the Chernobyl accident have been identified. The Central spot was formed during the initial, active stage of the release to the west and north-west. Ground depositions of cesium-137 covered large areas of the northern part of Ukraine and the southern part of Belorus. The Bryansk-Belarus spot, centred 200 kilometres to the north-northeast of the reactor, was formed on 28-29 April as a result of rainfall on the interface of the Bryansk region of Russia and the Gomel and Mogilev regions of Belarus. The Kaluga-Tula-Orel spot in Russia, centred approximately 500 km north-east of the reactor, was formed from the same radioactive cloud that produced the Bryansk-Belarus spot, as a result of rainfall on 28-29 April. In addition, outside the three main hot spots, in the greater part of the European territory of the former Soviet Union there were many areas of high radioactive contamination.

According to Soviet figures, the highest radiation levels in the city of Kiev were 0.5-0.8 millirems/hour in early May 1986. It represents an increase over the average radiation norm in 160-300 times which shows that the 30-kilometre special zone marked around the ChNPP by the Soviet authorities was a somewhat arbitrary area that was mainly considered sufficient for the purposes of evacuating the population. For example, according to the mentioned Soviet report to IAEA, the level of external radioactivity 15 days after the accident remained at 1,000 times higher than the normal at a distance of 60 kilometres away from the plant.

The OECD's (1995) report summarizes the direct consequences of the Chernobyl accident as follows:

"The area affected was large due to the high altitude and long duration of the release as well as the change of wind direction. However, the pattern of deposition was very irregular, and significant deposition of radionuclides occurred where the passage of the plume coincided with rainfall. Although all the northern hemisphere was affected, only territories of the former Soviet Union and part of Europe experienced contamination to a significant degree" (OECD, 1995, p.5)

In this study the primary focus is on real damage to the environmental stock and, therefore, a consideration of negative effects to the elements of the natural environment is presented. It is possible to subdivide the natural environment into the following elements: renewable resource stock - water resources with fish stock, land and crops, forestry, livestock; non-renewable resource stock - conventional energy resources such as oil, natural gas and coal. Thus the analysis presented below shows direct and indirect damages to these elements as a result of the nuclear accident.

Health problems associated with the Chernobyl accident are very complicated. They are not part of this study. Direct damage to the human health is not possible to evaluate because there is no agreement among physicians as to how many people were and are affected by the accident. Existing medical assessments are very controversial and based upon probabilities with huge deviations, which makes them worthless for the purpose of this study. Instead it is assumed that nuclear contamination of the environment eventually affects humans through partial damages to the elements of the natural environment (for example, through food, breathing air, drinking water, etc.) which results in decrease of labour productivity in the long-run. Therefore, from the economic standpoint, negative consequences of the accident for human health are a long-run problem with negative accumulative effect over time which manifests itself through decrease in labour productivity.

The main damage to the water resources was associated with Dnieper River which extends for 246 kilometres within Kiev region, its main tributaries the Pripyat, the Teterev, the Irpen and the Kiev and Kaniv Reservoirs. The first priority was the Dnieper river itself which is the Ukraine's most important water supplier and the main source of the republic's agricultural wealth. Water from the Dnieper river is consumed by some 32 million people.

Small lakes and ponds were another water resource contaminated by the radioactive matter. Usually in an accident, radionuclides contaminate bodies of water not only directly from deposition from the air and discharge as effluent, but also indirectly by washout from the catchment basin. Radionuclides are quickly redistributed in water and tend to accumulate in bottom sediments, benthos, aquatic plants and fish. A hydrogeological study of ground water contamination in the 30-km special zone (Vovk, 1994) has estimated that strontium-90 is the most critical radionuclide, which could contaminate drinking water above acceptable limits in 10 to 100 years from now. Even though the Soviet authorities reassured that there was no threat to the water resources, governments of Switzerland, Finland, Sweden, Norway have banned fishing on their lakes. Moreover, the governments admitted that the restrictions on fishing and fish consumption would be in place for a long time. Belorussian authorities banned fishing on their territory as well.

Direct and indirect contamination of lakes is still causing many problems within and outside the former Soviet Union, because the fish in the lakes are contaminated above the levels accepted for sale in the open market. Therefore, as a conclusion, fish stock in the former Soviet Union was significantly affected with probability one. In economic sense this fact implies increase of depletion rate of the fish stock on the one hand, and extra costs associated with protection from the further contamination of water resources on the other. For example Marples (1988) wrote:

" By October 1986, with the use of soil-machine, an underwater dam had been constructed, which was 450 metres in length. At the front of it was created a groove of 100 metres in width and 16 metres deep. Its purpose was to catch radionuclides entering the Kiev Reservoir from the tributaries of the Pripyat River. A second silt trap was created in front of the dam at the Kiev hydroelectric station, made of crushed stone and again with a wide groove at its front point. Water-retention structures were constructed on the rivers Sakhan, Veresnya, Berezhest, Radyanka, Braginka, Nesvich and others that empty into the Uzh and Pripyat rivers" (David Marples, 1988, pp.65-66)

And one more example from Marples:

"... a 30-metre wall was built into the ground at the reactor No 4 that reportedly blocked the movement of ground water toward the Pripyat river. At the entrance to the latter a drainage screen was established" (David Marples, 1988, p.66)

In addition, the whole of Mediterranean sea basin was affected by nuclear contamination. The Black Sea whose large area belongs to the former USSR, was impacted the most. It was still showing the cumulative effects of the Chernobyl accident in 1990 (see Aarkrog, Angelopoulos, Calmet, and others, 1993). Even though it is difficult to detect this negative effect economically, nonetheless methodologically it has to be accounted for.

Forestry suffered as well. Because of the high filtering characteristics of trees, deposition was often higher in forests than in agricultural areas. Close to Pripyat a forest with tall pine trees absorbed the highest fallout, turning into a rust-colour as a result. It was named the "Red Forest" by local people. An area of about 375 hectares was severely contaminated. Radio Free Europe admitted: *"There were two main areas of concern: forest fires which could quickly spread radioactive cesium; and falling pine needles that might contaminate the forest vegetation in the vicinity"*. Marples, cited above, writes: *"Over the course of more than a year, part of the redwood pine forest near Pripyat was chopped down by construction machines... By June 1987 about half of this forest had actually been chopped down..."*

The OECD's (1995) report states:

"The top 10-15 centimetres of soil were removed and dead trees were cut down. This waste was placed in trenches and covered with a layer of sand. A total volume of about 100,000 m was buried" (OECD, 1995, ch. VI, p.4)

This is just a small example of damage to the timber biomass as renewable resource stock. Actually a lot of forests north, north-west and west of the ChNPP suffered from the radioactive fallout which, of course, decreased timber stock available for production and consumption on a large scale. On the other hand, forests are highly diverse ecosystems whose flora and fauna depend on a complex relationship with each other as well as with climate, soil characteristics and topography. They may be not only a site of recreational activity, but also a place of work and a source of food. Wild game, berries and mushrooms are a supplementary source of food for many inhabitants of the contaminated regions. Timber and timber products are a viable economic resource. Therefore, timber biomass as well as non-timber products were significantly affected in addition to the fish stock.

Even though, according to Marples (1986, 1988), the northern part of Kiev region that is located within the 30-kilometre special zone was not a significant area for agricultural production, the contamination of soil as a result of the accident did affect agriculture. It is helpful to present some interesting facts, again from Marples (1988). In March 1987 CIA estimated that at least 1,000 square kilometres of land was affected. The direct losses of harvests were as follows: 25,000 tones of grain; 70,000 tons of potatoes; 30,000 tons of milk and 1,000 tons of flax (Politicheskoe samoobrazovanie, 10, October 1986). Marples writes: *"In terms of Ukrainian output only the losses to the potato crop constituted about 0.35% of total production for the 1986 year"*. In the summer of 1986 the Soviet authorities admitted that the wheat in the fields around the damaged reactor was contaminated and would not be harvested. Moreover, the Vice-president of the Soviet Academy of Sciences Evgenii Velikhov emphasized that agricultural cultivation within the 30-kilometre zone was out of question (Interview to Reuter, May 25, 1986). This area accounts for 282,000 hectares.

This is direct negative effect on agriculture through contamination of soil within the 30-kilometre special zone. However, according to Richards (1995), the releases during the Chernobyl accident contaminated about 155,000 km^2 (15.5 million hectares) of land in Belarus, Ukraine and Russia. About 53,000 km^2 (5.3 million hectares) of this total were in agricultural use; the remainder was forest, water bodies and urban centres. Table 1.1 below presents the sizes of contaminated territories within the former USSR, as estimated by Soviet specialists.

Table 1.1. Contaminated areas in the former USSR due to the Chernobyl accident

States	Sizes of contaminated territories, km^2
Russia	55,990
Belorus	46,450
Ukraine	40,540
Moldova	50

Source: Aarkrog, A., Tsaturov, Y. And Polikarpov, G.G. Sources of environmental radioactive contamination in the former USSR. Riso National Laboratory, Rockilde, Denmark, 1993

The OECD's (1995) report states:

"...it is not possible to predict the rate of reduction [in soil contamination] as this is dependent on so many variable factors, so that restrictions on the use of land are still necessary in the more contaminated regions in Belorus, Ukraine and Russia. In these areas, no lifting of restrictions is likely in the foreseeable future" (OECD, 1995, ch. VI, p.3)

Ukrainian scientist Vladimir Georgievskii (1994), considering the entire chian of food consumption, subdivides soil contamination into: (i) crops itself; (ii) soil under crops; (iii) grass on pastures; (iv) soil under pastures. It shows transitory negative effect from contamination as well as long term effect. From his assessment it is possible to derive relative damages to some elements of the ecological system as a result of nuclear contamination. It appears that the grass on pastures is the major threat. If damage to the grass is assumed to be 100%, then the relative damages to the other elements of ecosystem associated with agriculture are: crops itself - 61.6%; soil under crops - 9.7%; soil under pastures - 12.7%. Therefore, as a result of the nuclear accident livestock was affected as well as agricultural stock in terms of soil productivity and land use. For example, only in the first few days of the accident 15,000 cows were slaughtered in Ukraine (OECD, 1995); eight years after the accident 2,640 km^2 of agricultural land in Belorus have been excluded from use (The Republic of Belorus Information Bulletin, Minsk, Belorus, 1994); within 40-km radius of the power plant 2,100 km^2 of land have been excluded from use for an indefinite duration (OECD, 1995).

Moreover, Georgievskii (1994) emphasizes dynamic, accumulative character of such effects. It suggests that the biological growth of renewable natural resources was slowed down which means: immediate damage to the renewable resource stock is followed by decrease in renewable resource flows. Therefore, the overall effect on agriculture is significant if we consider ecological system as a whole. Support for such a claim is found in Marples (1988). He writes:

"The Swedish government has stipulated a maximum limit of 300 becquerels per kilogram for the concentration of radioactive products in reindeer meat... The Nuclear Regulatory Commission's report on the Chernobyl accident states that the level of contamination in reindeer meat in Scandinavia reached 20,000 becquerels per kilogram, and that concentrations well above maximum limits will persist for several years... The consequence was the burial of 75% of the reindeer slaughtered in Sweden or the sale of the reindeer meat as animal feed..."

One more example:

"Early in May 1986, there were heavy thunderstorms over the mountain regions of Cumbria, North Wales and western Scotland that resulted in the contamination of between 2 and 4 million sheep.

Even with the passage of time the levels of cesium remained higher than anticipated, probably because the cesium element moved from grass into the soil more quickly than had been foreseen... In August 1987, new restrictions were imposed on 69 highland farms in Scotland, involving 124,000 head of sheep. Altogether at this time, the embargoes on the slaughter of sheep in Britain encompassed 564 farms with 560,000 sheep" (Financial Times, August 13, 1987)

The above facts show significant impact on Scandinavia and Britain which are quite distant from the ChNPP. Therefore, we can expect even more significant impact on the Soviet Union's renewable resource stock which is eventually manifested itself through the loss of agricultural production. Even Marples could not resist from a conclusion: "*...Since the majority of its [the Chernobyl's reactor] fallout occurred in the region around the plant itself, it is evident that the effects of the fallout on Ukrainian and Byelorussian agriculture were even more severe than in Scandinavia and Britain".* However, the overall conclusion here should be as follows: the renewable resource stock in the Soviet Union was affected in all areas north, north-west and west of the ChNPP as a result of the accident. This region includes good arable land as well as pastures to raise livestock.

So, it is necessary to admit that the Chernobyl accident significantly affected the renewable resource stock in the former Soviet Union. The damage resulted in decrease of biomass available for production and consumption. The general term biomass here has broader meaning and it includes fish stock, timber biomass, forest products (mushrooms, berries, etc), agricultural stock in terms of land productivity and land use, livestock. There also exists a secondary effect which is decrease in the natural growth of the renewable resource stock because the lower resource stock generates the lower resource flows.

It is also possible to justify impact on non-renewable resource stock. This is implicit or indirect effect. Once again the works by Marples (1986, 1988) are good reference points. He provides facts which show that the Chernobyl accident brought about energy crisis in the former USSR in the late summer and fall of 1986 and lasted until spring of 1987. For example, Marples writes:

The accident brought into question the viability of the existing RBMK-type nuclear reactor. The short-term effect was that retrofittings were made to the 14 Soviet reactors of this type which necessitated their temporary shutdown... It does seem from the evidence available that all the RBMKs were shut down simultaneously, thereby depriving the Soviet Union of not 8-9%, but around 55% of its nuclear-generated electricity as the summer of 1986 drew to a close" (David Marples, 1988, p.91)

Such a situation caused two immediate negative effects: (i) serious electricity shortage; (ii) decrease in the designed frequency of the power grid. The second effect implied a necessity to shut down motors in numerous factories. In September 1986 Soviet authorities admitted that loss of capacity would not be easy to make up. Moreover, on September 29, 1986 a Soviet newspaper *Pravda* announced that the Soviet Union was facing a shortfall of energy for the winter because of the Chernobyl disaster. Chernobyl also delayed construction of three new Ukrainian nuclear reactors. As Marples states, the construction work had fallen behind schedule not only at the three Ukrainian nuclear plants, but also at the water-driven boilers of the thermal power stations in Vinnytsya, Lviv and Kharkiv regions of the Ukraine.

Later on the Soviet media informed that the Chernobyl accident caused a necessity to compensate for the electricity shortfall by burning more coal than it was planned. In general, according to the media, *"electricity supply fell by over 500 million kilowatt-hours in the first half of 1986. The picture has not changed in the second half of the year" (Sovetskaya Rossiya, November 27, 1986).*

Based on the above facts Marples makes the following conclusion:

"Thus Chernobyl brought about a short-term electricity crises in the USSR that lasted into the spring of 1987. Other factors contributed to the dilemma, but had Chernobyl not occurred, it is safe to say that the situation could not have been labelled a crisis" (Marples(1988), p.98)

However, from macroeconomic standpoint two negative effects can be identified based on the above facts: (i) decrease in the electricity production which resulted in greater shortages in production and consumption; (ii) increase in depletion rate of the non-renewable resource stock associated with extraction of extra coal to make up for the shortfall of the nuclear-generated electricity.

The last claim can be supported by the following fact. In his TV interview on June 5, 1986 the Chairman of the USSR State Committee for the Utilization of Nuclear Energy A.M.Petrosiants said: *"200,000 waggons of coal or 12 million tons would be needed simply to match the output in kilowatt-hours of the Leningrad nuclear power plant in a single year"*. The capacity of the ChNPP was equal to the capacity of the Leningrad NPP. The shortage of electricity, therefore, was made up by at least this amount of extra coal which corresponds to the previously mentioned facts. However, it is also necessary to include the amount of coal required to make up for the loss of nuclear electricity due to shut down of the other nuclear reactors.

As overall conclusion, there are four aggregate negative effects as results of the Chernobyl nuclear accident. Three of them are purely environmental:

1. Decrease in available renewable resource stock.

2. Decrease in the natural growth rate of the renewable resource stock.

3. Increase in depletion rate of the non-renewable resource stock.

The fourth effect is purely economic:

4. Increase in shortages in production and consumption.

In this study all four are taken into account. The following chapters two, three and four describe: (a) theoretical framework that will incorporate the above negative effects; (b) estimations of the effects and consequences for the Soviet economy. However, before proceeding with the theoretical framework, the remainder of this chapter presents the conclusions reached by Soviet analysts about the macroeconomic impacts of the Chernobyl accident.

1.2. Analysis of the Soviet economy's performance in 1986-1990

As it was stated earlier, the large environmental impacts caused significant changes in macroeconomic aggregates. Analysis of such changes in the Soviet economy since 1986, using Soviet official statistics, supports such a claim. It is useful to begin with comparison of planned (expected) values of some macroeconomic variables with real.

The period of 1986-1990 was associated with 12th five-year plan in the Soviet economy. It was expected that national income would increase in 1.5 times or by 3.5-4% annually. The absolute increase of national income should have been 96-111 billion rubles. However, later on even Soviet officials had to admit that they had never seen such decreasing patterns of macroeconomic aggregates since World War II. Gross Social Product (GSP) increased by 13.2% (2.5% annually) in comparison with 19.5% (3.6% annually) in 1981-1985. National income increased by only 6.8% (1.3% annually) in 1986-1990 in comparison with 17% (3.2% annually) in 1981-1985 (Stepanov, 1991). Stepanov (1991) also claims that in general the Soviet economy lost around 78 billion rubles of national income as a difference between expected and real values. In his opinion, the most significant decrease during 1986-1990 has been observed in machine-building sector (by 18.6%) and mining sector (by 7%). He blames the investment policy of the Soviet government who increased aggregate subsidies in the economy by 105 billion rubles.

However, let us not to forget that such an increase was mainly associated with desire to quickly overcome the consequences of the Chernobyl disaster. Unfortunately, at that time no one of the Soviet officials admitted this fact. And only later in the article written by the head of the Soviet Statistical Bureau (Gosplan) Kirichenko was it stated that:

"Budget deficit was 14 billion rubles at the beginning of 1986, 42 billion rubles at the end of 1986 and 81 billion rubles in 1989. Mainly the budget expenses were associated with liquidation of the consequences of the Chernobyl accident" (V.Kirichenko, 1991, p.5)

However, official data published by the Government Bulletin in 1989 revealed the following numbers for budget deficit: 1985 - 18 billion rubles; 1986 - 47.9 billion rubles; 1987 - 57.1 billion rubles; 1988 - 90.1 billion rubles. In IMF's (1991) report the following dynamics of the increasing budget deficit is presented:

Table 1.2. Budget deficit in the USSR in 1985-1989

Years	Budget deficit, % of Gross Social Product
1985	2.4
1986	6.2
1987	8.4
1988	9.2
1989	8.5

Source: The economy of the USSR: conclusions and recommendations by IMF. Voprosy Ekonomiki, 3, 1991, pp.6-72

Regardless of what data set one choses, the following conclusion is obvious: budget deficit increased in almost 3 times within the year of 1986 - the year of the Chernobyl accident.

So, the dramatic increase in government spending was partially due to the Chernobyl accident given constant tax structure. And if we further accept the assumption of autoregressive nature of the accident for macroeconomic system, we would expect the problems to pile up. First of all, according to Kirichenko (1991), the most alarming problem in 1986-1990 period has been significant decrease in the natural basis[2] for production of food production. As a result, growth rate of agricultural products has been decreasing: it was 2.1% in 1986-1988 and 0.6% in 1989-1990. Planting decreased by 4.3% by 1990 and meat production by 0.8%. The following agricultural production also decreased: potatoes, vegetables, fruit. Eventually economic situation in the former USSR became very bad by 1989 and, once again according to Kirichenko, in 1990 the economy faced the absolute decrease in aggregate production, which was later supported by official data.

Let us present some evidence of piling up problems. The increased spending on the liquidation of the consequences of the Chernobyl accident caused re-distribution of investment. Social sphere became the first victim. Since 1989 the housing construction has decreased by 3%, construction of schools, kindergartens and medical facilities fell by 10-17%. The overall efficiency of investment in the Soviet economy fell by 7% during 1986-1990 in comparison with 1981-1985. The unfinished construction reached 200 billion rubles in 1990 against 120 billion at the end of 1985. The growth of investment in 2.7 times exceeded the growth of production of means of production (Kirichenko, 1991).

In 1991 Levin wrote down: "*Shortage has become chronic and this may lead and already has*

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[2] natural resource stock (YY)

led to deep negative socio-economic consequences" (Levin, 1991). Soviet assessments of shortages are very controversial and there are deviations in their absolute values. Usually aggregate shortage or unsatisfied demand is calculated as follows:

unsatisfied demand = total household savings + current labour income - existing stock of consumer goods - total production of consumer goods and services.

However, regardless of variability in estimates, the overall picture is clear: shortages have been increasing dramatically in the Soviet economy during 1986-1990. For example, Levin (1991) analysed the scale of shortage by analysing the growth of savings. According to his assessment, unsatisfied demand in 1989 was 25 billion rubles and around 40 billion rubles in 1990 in comparison with 3-4 billion rubles in 1981-1982. The accumulated stock of savings during 1986-1990, estimated by Levin, was 100 billion rubles not counting cash holdings by population. Bogochev (1990) presents his calculation of savings and available goods stock as follows: *"In 1965 total household savings were 19 billion rubles which accounted for more than 50% of available goods stock. In 1985 the amount of savings of 221 billion rubles was supported by 98 billion rubles of the goods stock. By 1989 total household savings increased to 338 billion rubles while the goods stock was just 80 billion rubles" (Bogochev, 1990, p.7)*. Both authors, Levin (1991) and Bogochev (1990), point out that the process of exhaustion of the accumulated goods stock has begun since 1986. The volume of the stock decreased by 33% in 1986-1989.

Shatalin and Yavlinskii (1990) estimated total forced savings including cash holdings by population as being equal to 400 billion rubles in 1990 or around 40% of the Gross Social Product. They call this amount *inflation gap* which, in their opinion, exceeded a similar indicator in the United States in 1929 before the Great Depression. Shmelev (1990) reports an amount of 500 billion rubles as "spare" money held by population in savings and cash plus savings of enterprises. Orlov (1990) presents his own indicator of shortages - degree of shortage. He writes: "*We found out that only 106 items of consumer goods out of 989 were available in the state trade sector which indicates degree of shortage as 89%*".

Eventually increasing shortages in the Soviet economy during 1986-1990 led to two negative consequences: (i) increasing share of the second economy[3]; (ii) increasing inflation. Concerning the first one, Koryagina (1990) wrote: "*Unbalanced supply and demand or huge deficit of consumer goods is the major factor for appearance and functioning of the second economy... The overall gap between demand and supply at the beginning of 1990 reached 165 billion rubles. At the same time the size of the second economy was approximately 100 billion rubles according to our calculation" (Karyagina, 1990, p.117).*

Another problem was increase in the level of inflation. If previously economists had talked about hidden inflation in the Soviet economy, in 1986-1990 they had to admit the existence of explicit inflation. For instance, Levin (1991) reports the following increase in prices of some goods during 1985-1989: meat and meat products - 10%; bread - 19%, potatoes - 40%, vegetables - 26%, clothes - 23%, colour TV sets - 12%, refrigerators - 14% (Levin, 1991, p.32). According to Levin's (1989) assessment in 1989 alone the overall price level increased by more than 10% (Levin, 1989). In turn, Stepanov (1991) reports levels of inflation in the Soviet economy for period of 1986-1990 which were calculated by two Soviet research institutes - the Gosplan Economic Research Institute (GERI) and the Central Bank Research Institute (CBRI). Table 1.3 below shows these estimates.

[3] Shadow economy in the Soviet literature

Table 1.3. Levels of inflation in the Soviet economy during 1986-1990

Year	Inflation GERI, %	Inflation CBRI, %
1986	6.2	6.2
1987	7.3	7.3
1988	8.4	10.0
1989	10.0	12.0
1990	18.6	18.6

Source: Stepanov, Yuri, Narodnoye Khozyaistvo, March 1991, pp.56-65

Increasing budget deficit, decreasing levels of production accompanied by unfounded increase in wages caused dramatic increase in money supply at that moment. Kirichenko reports the following dynamics of increase in money supply: 1981-1986 by 18%; 1988 by 100%; 1989 by 56%; 1990 by 50% (Kirichenko, 1991, p.5). There is another interesting fact reported by the head of Goskomstat - the dynamics of unsatisfied demand. Table 1.4 represents the dynamics.

Table 1.4. Unsatisfied demand in the Soviet Union during 1985-1990

Years	Unsatisfied Demand, billion rubles
1985	24.4
1986	28.0
1987	32.0
1988	41.9
1989	61.8
1990	80.5

Source: Kirichenko, Victor, Narodnoye Khozyaistvo, March 1991, p.5

These figures show 3.3-time increase in the unsatisfied demand over 1985-1990 or approximately by 27% per year. If the unsatisfied demand is taken into account, the overall inflation level would be even higher than reported above. Based on the above numbers Kirichenko concludes: *"Since mid-1990 shortage has become a general phenomenon" (Kirichenko, 1991, p.7).* In this regard, in economic terms 1990 was the worst year in the Soviet post World War II history indicating the accumulated problems in the Soviet economy. Based on publications by Kirichenko (1991) and Nazarov (1991) as well as Soviet official data the following economic indicators of that year were derived:

Growth of national income: -4%

Increase in labour productivity: -3%

Increase in money supply: 21.5%

Increase in external debt: 11.1%

Increase in budget deficit: 71.7%

Inflation: 19%

Increase in unsatisfied demand: 30.3%

Moreover, all these problems led to the external debt of $60 billion in 1990 which was 11.5% of GDP. Table 1.5 presents dynamics of the accumulation of the external debt in the USSR.

Table 1.5. USSR: External debt in 1985-1990

Years	External Debt, billion US$
1985	28.9
1986	31.4
1987	39.2
1988	43.0
1989	54.0

Years	External Debt, billion US$
1990	60.0

Source: The economy of the USSR: conclusions and recommendations by IMF. Voprosy Ekonomiki, 3, 1991, pp.6-72

According to Volkov (1991) internal debt accounted for 550 billion rubles at the beginning of 1991 or around 40% of Gross Social Product.

Earlier in 1987 Gorbachev wrote in the prominent Soviet newspaper *Pravda:*

"... the economic growth rates fell to a level which actually approached economic stagnation. We started evidently falling behind in one way after the other. The gap in the efficiency of production, quality of products and scientific-technical progress began to widen in relation to the most developed countries and not to our benefit" (Gorbachev, Pravda, June 26, 1987).

Khrylev (1991) compared energy content of national income in the USSR, Japan, Germany and USA. His conclusion is *"The energy content of the Soviet national income is 3.2 kilograms of conditional fuel per 1 ruble of national income. It is in 3 times higher than in Japan, in 1.8 times than in Germany and in 1.6 times than in USA"*. This statement is a good characteristic of the wasteful nature of the Soviet economy at that time.

So, from the analysis presented above, it is possible to claim that there have been obvious and dramatic changes in all major macroeconomic indicators during 1986-1990. Even though the Soviet economy has faced many difficult problems associated with wrong management and mistakes in macroeconomic policy, nonetheless some of these problems were undoubtedly caused by the Chernobyl accident.

In 1997 in his speech to the session of United Nations dedicated to the environmental problems, the president of the Ukraine Leonid Kuchma admitted that annually the Ukraine spends US$1 billion on liquidation of the consequences of the Chernobyl accident. The persistent character of these consequences is reflected in two more facts. Since 1986 the Ukraine has introduced ***the Chernobyl tax*** and *the Ministry of Chernobyl*. Both facts point at a desire of the Ukrainian government to deal with consequences of the accident on a permanent basis.

In conclusion, the above analysis shows that there have been dramatic changes in performance of the Soviet economy since 1986. These changes were reflected in significant downward trends of all major macroeconomic indicators. Moreover, the overall situation in the Soviet economy has significantly worsened during 1986-1990. Therefore, it is possible to conclude that the Chernobyl accident not only affected the Soviet economy on a large scale in 1986, but it also has had accumulative, negative effect afterwards. Thus, in order to study the macroeconomic consequences of the Chernobyl accident it is necessary to investigate the process in a dynamic framework. The main focus should be on changes in dynamic patterns of the major macroeconomic variables as well as changes in stability conditions of the entire economy as a result of the accident. Two questions arise in this regard:

1. What macroeconomic variables best indicate the consequences of the environmental impact in the Soviet economy?
2. How are these variables affected over time?

The next two chapters provide answers to the first question. In turn, chapter four investigates the second question in detail.

CHAPTER TWO

DYNAMIC ANALYSIS OF THE SOVIET MACROECONOMIC SYSTEM

This chapter presents general analysis of existing theoretical approaches to the modelling of socialist economies. Based on this analysis a choice is made in favour of neoclassical growth theory with adjustments for specific features of the Soviet economy. As a result, a disequilibrium growth model of the Soviet economy is derived.

The derived disequilibrium growth model incorporates major distinguishing features of the Soviet economy over period of 1950-1985 or before the Chernobyl accident. Natural resources are introduced into aggregate production function as complement to conventional factors of production, capital and labour, along with assumption of fixed technology. Also decision rules of central planners are specified based upon planning system in the Soviet economy.

Centralized management, fixed prices and slow technological progress lead to appearance of net aggregate shortage which underlies the dynamics of the Soviet economy. Depletion of the natural resource stock is a longer-term driving force behind dynamics of such an economy. Both forces are reflected in the final version of the basic dynamic equation.

Further the basic dynamic equation is analysed to study dynamic properties of the Soviet economy. It appears that there is a steady state in this economy associated with normal shortages which are due to steady depletion rate of natural resources. The steady state path of the Soviet economy is parallel to the Walrasian steady state. Stability conditions for such an economy are derived. The main theoretical result of this chapter is: extensive depletion of natural resources and increase in shortages worsen the dynamic properties of an economy. In general, the chapter provides a theoretical framework for analysis of the consequences of the Chernobyl accident in the Soviet economy.

2.1. Two approaches to the modelling of the Soviet-type economies

The most popular approach in modern macroeconomic analysis is modelling within a general equilibrium framework. However, this approach is not appropriate for the Soviet-type economies (STE). One particular outstanding feature of STE is the pervasiveness of disequilibria. Supply problems have plagued state enterprises throughout Soviet history, and shortages of consumer goods and services have been a special problem for households and economy as a whole.

The socio-economic system created in the USSR made it possible even in 1930s to reduce the share of population's consumption to a half of the GDP (Volkonskii, 1991). In the 1970s and 1980s it fluctuated around 60%. However, about 8% of the 60% comprise cost-free services for households. If an indicator of personal expenditures for consumption is taken into consideration instead, then the difference between consumption's share in the USSR and market economies turns out to be very impressive. For example, in 1980 this share in USA came about 65% while in the USSR it came about 55%. The existence of shortages of consumer goods and services on the one hand and gluts[4] of consumer and some other goods on the other hand can be shown with the help of the following facts. Total monetary income of households in the USSR increased from 195 billion rubles in 1970 to 415 billion rubles in 1985 indicating 5.2% annual increase. During the same period total household savings increased from 73 billion rubles to 314 billion rubles or by 10.2% annually (Steinberg, 1990). Most of these savings occurred because Soviet people were unable to make purchases of goods and state provided services of their choice. On the other hand, despite the large

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[4] Hungarian economist Janos Kornai whose ideas we use in this study introduces term "slack" for gluts. We will use the same term from now on to keep consistency of terminology.

increase in total household savings, stocks of inventories of unsold finished consumer goods and other commodities more than doubled during the same period from 64 to 150 million rubles. Therefore, for example, savings represented 56.8% of GNP in 1985 while consumption was 49.2% which indicates shortage. However, inventories of unsold finished consumer goods and other commodities accounted for 27% of GNP which, in fact, is slack.

The data mentioned above point directly at persistent disproportions in the Soviet economy. Mainly these disproportions have arisen because of: (i) first-priority development of heavy industry to the detriment of light industry and infrastructure sectors; (ii) capital investment designed for repayment over long periods of time (i.e. low efficiency of investment); (iii) extensive utilization of material and human resources; (iv) wasteful consumption of non-renewable resources; (v) artificial cutoffs in household consumption. Therefore, in order to model Soviet economy we have to look for appropriate tools within a disequilibrium framework.

There are two major approaches to modelling a STE as a disequilibrium economy. The first one is associated with non-Walrasian school of economic thought and mainly is associated with names of Grossman, Barro, Malinvaud, Benassy, Portes and others. The second one is associated with work by Hungarian economist Janos Kornai. Both approaches consider a socialist economy as an excess demand economy. Both use quantity adjustments instead of price adjustments as the major indicators of economy's dynamics. However, there are some conceptual differences which we find analysing these two approaches.

The disequilibrium theory developed by the non-Walrasian school starts with re-interpretation of Keynes. In Keynes (1936) we find that disequilibrium in the labour market is due to insufficient aggregate demand. However, the key concept in Keynes' disequilibrium theory is his consumption function. Keynesian consumption is a function of aggregate income (GDP). On the other hand, consumption also enters into the equation for effective aggregate demand. Therefore, it appears to be in Keynes' IS-equation that aggregate income plays the role of dependent variable and the role of independent variable at the same time. In a mathematical sense income depends on itself or simply quantity is a function of quantity. Therefore, we observe quantity adjustments first and only afterwards price adjustments as in a Walrasian general equilibrium framework. In Walrasian framework actual transactions take place at equilibrium prices only, however, in reality we do observe transactions taking place at disequilibrium prices. According to Clower (1965) in such a case the problem of influence of quantities (actual transactions) arises immediately. He concludes that under these circumstances the actual transaction is equal to the minimum of planned (desired) demand and supply, and that the usual (notional) demand functions are irrelevant since the realized-income constraint will reduce actual consumption below the level predicted by the neoclassical orthodox economic theory. Moreover, if such a situation occurs in one market it will affect all other markets. This generalization was made by Grossman (1972). Grossman concludes that it is necessary to bring quantity constraints in all markets into decision process. As an intermediate conclusion we can admit two major distinguishing features of the non-Walrasian approach: (i) some markets do not clear (excess demand or excess supply); (ii) adjustments in quantities in the short-run.

Kornai's (1971, 1980, 1982, 1986) approach is similar to the non-Walrasian approach in that he also considers quantity adjustments. However, instead of "quantity signals" of the non-Walrasian school he introduces concepts of shortages and slacks which are also quantity signals. Moreover, in contrast to proponents of the non-Walrasian school who allow adjustments in aggregate supply to match aggregate demand in the short run, Kornai considers a persistent mismatch between the two in form of shortages and slacks. According to Kornai (1982) the phenomenon of shortage plays a central role in his analysis. He points out that if we consider a single elementary purchasing action of a buyer, we end up with the following well-known relationship:

Demand	-	*Actual purchase*	*= 0 if purchase intention is fulfilled*
(Ex-ante variable)		*(Ex-post variable)*	*> 0 if excess demand*

According to Kornai, standard microeconomic theory stops at this point. Let us quote Kornai:

" In my own "vocabulary" shortage is a category comprising a large group of phenomena. It includes not only the divergence between purchasing intension and realization ("excess demand"), but also the various forms of forced adjustment. The shortage syndrome is experienced by households living in a chronic-shortage economy. And it is also felt constantly by firms, both in the process of acquiring material inputs, and in their utilization in the course of production" (Janos Kornai, 1982, p. 12)

The shortage syndrome in Kornai's view is the aggregate phenomenon of forced adjustment, forced substitution, queuing, searching, postponement, etc. He calls these elementary events partial shortages and goes on with construction of macroeconomic index of shortages and slacks. Eventually he comes up with two major conclusions:

1. Shortages lower household's and firm's purchases or aggregate demand is decreasing function of shortage.

2. Shortages raise production or aggregate supply is increasing function of shortage.

Thus, instead of Marshallian cross Kornai suggests to consider Kornai's cross where we have shortages instead of prices as signals.

The above description gives us the major differences between the two approaches to the modelling of STE. The proponents of the non-Walrasian school, in particular Malinvaud, Barro, Grossman, Benassy, apply the so-called "short-side rule" in their considerations of a disequilibrium economy. The rule states that actual purchases and sales are equal to the smaller of demand and supply. The rule assumes existence of either excess demand or excess supply. For example, Portes and Winter (1980) applied the rule for several socialist economies. Their findings are: *9 excess demand years for Czechoslovakia, 13 for GDR, 6 for Hungary and 5 for Poland.* Based on this analysis Portes and Winter concluded that excess supply was the dominant regime in three of four mentioned above countries. According to the short-side rule, the proponents of the non-Walrasian school usually choose aggregate excess demand function for their analysis. If this function is positive then we have excess demand. Otherwise, the economy experiences excess supply. So, according to this approach, a socialist economy "jumps" around Walrasian state. In case of excess supply, according to Malinvaud we have "buyers market" whereas in case of excess demand we have "sellers market" but only one at a time. The process of rationing takes place and actual purchases and sales always coincide with supply.

In turn, Kornai chooses two macro variables - shortages and slacks. He also defines normal shortages and slacks which always deviate from the Walrasian state. Actual shortages and slacks fluctuate around normal values remaining always distant from the Walrasian state. Kornai claims that *"at the macro-level excess demand and excess supply occur simultaneously. Normal shortage and normal slack operate in parallel" (Janos Kornai, 1982, p.35).*

Therefore, according to the non-Walrasian school at least one party out of two - buyer or seller - fulfils its intention. According to Kornai, neither buyer nor seller fulfils his or her intention. Kornai himself explains similarities and differences between his macro index of shortages and excess demand function of the non-Walrasian school as follows:

"They are clearly related to each other in content, for both seek to express the general degree of shortage at the macro-level. At the same time, there are important differences. One important difference is that aggregate excess demand only captures one (though very important) aspect of shortage: the purchase intention frustrated because of shortage. As opposed to this, the index comprises the multitudinous components of shortage phenomena, including various forms of forced adjustment. There is another important difference between the two categories. The definition of aggregate excess demand is as follows: the sum of individual excess demands minus the sum of individual excess supplies. This is, therefore, the net balance of deviations in both directions from the Walrasian balance. As contrasted with this, our index reflects only shortage side, without deducting surpluses from it. In a chronic-shortage economy shortage and slack coexist" (Janos Kornai, 1982, pp. 18-19).

Based on his analysis Kornai regards the short-side rule as being one-dimensional adjustment while his own approach as two-dimensional. Anyone having understanding and experience of the Soviet economy, would find it difficult to disagree with Kornai. The entire structure of the Soviet economy was designed in a way such that the Walrasian state simply becomes incentive-incompatible. Therefore, instead of the Walrasian steady state it is necessary to find another point of origin associated with socialist economy only. For Kornai this point is a point of normal shortages and slacks. This is a kind of steady state of a socialist economy.

However, let us analyse how Kornai constructs his aggregate index of shortages (or slacks). The overall index consists of elementary (partial) shortages. Once again it is helpful to quote Kornai directly:

" *Each partial shortage indicator measures the intensity of certain definite shortage phenomena in a particular field (for example, residential construction, pharmaceutical production, food purchase). Some examples: the share of forced substitution in total purchases or in total consumption; the number of those queuing up or queuing time; the number of selling establishments visited or the search time; the number of orders refused; time lost in production due to shortage of inputs, and so on" (Janos Kornai, 1982, p.13).*

Based on these theoretical considerations Kornai concludes: *a comprehensive and regular observation of partial shortage indicators is possible.* Therefore, in principle, it is possible to derive the aggregate macroeconomic index of shortages. Kornai even suggests to consider the index as being a latent variable[5] .

In general Kornai (1971, 1980, 1982, 1986) argues that STE is characterized by a non-price mechanism, paternalistic relations between superiors and subordinates, simultaneous co-existence of shortages and slacks, soft budget constraints. The pervasive shortage environment eventually affects activity of all economic agents, and it is possible to construct macro index of shortages as a latent variable. Prices play only a secondary role in explaining developments in the shortage economy which implies a very important conclusion for this research: *in a Soviet-type economy most shocks are quantity shocks.* We will emphasize the idea again and again. However, some very important elements of Kornai's methodology seem to be inconsistent.

Kornai points out that all partial shortages are measured in their own units and their interaction gives rise to the macroeconomic index of aggregate shortage. A question arises immediately: how

[5] Latent variable = unobservable directly. Can be derived econometrically through observable variables.

in economy where reliable statistics is only a dream, could one collect data on partial shortages and then use statistical analysis[6] to estimate this latent variable? In order to consistently measure aggregate shortages and slacks. it is necessary to distinguish between their net and gross values. Net aggregate shortage in a socialist economy arises due to mismatch between pre-planned level of aggregate production and quantity of consumer goods and investment demanded at fixed prices usually set below equilibrium. In this regard, slacks or gluts can be viewed as unsold inventories of finished goods and services and. hence, they are part of gross and net investment.

Nonetheless, Kornai's approach to modelling socialist economies is more appropriate for our goals than that of the non-Walrasian school. His idea of "own point of origin" for a socialist economy as being constantly distant from the Walrasian steady state, seems to be a very fruitful one for dynamic analysis of the Soviet economy. The Walrasian steady state of an economy is an equilibrium state of a dynamic macroeconomic system at which all variables are invariant with respect to time and market-clearing conditions are fulfilled. On the other hand, for a socialist economy market-clearing conditions are never fulfilled because of some specific features of such an economy which are analysed later, and, therefore, the Walrasian state is unattainable in principle. Instead, there is another steady state around which dynamic paths of macroeconomic variables fluctuate. However, in applied work it is almost impossible to construct the macro index of shortages and slacks based on Kornai's definition because of two main reasons: (i) a necessity for extensive data collection mainly based on interview approach; (ii) very subjective character of the data required.

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[6] Such an analysis should be based on logit or probit models which require comprehensive and reliable data set

Therefore, it is necessary to design a framework that allows one to incorporate the main features of STE on the one hand and that gives an opportunity to apply it in practice on the other. We are looking for general principles in the development of the Soviet economy. Also we are looking for a framework within which a meaningful empirical research can take place. It appears that modern growth theory reflects both goals. Therefore, later in this chapter we apply the neoclassical approach to growth (developed in works by Solow (1956), Swan (1956), Morishima (1964, 1969), Hicks (1965), Sraffa (1960). Stiglitz (1974) and others) to the Soviet economy using some ideas of Kornai (1982) and Simonovits (1992).

We also need a dynamic model that reflects environmental variables because our focus is on consequences of large environmental impacts. The best reference in this area is work by John Pezzy (1992) who presents a good analysis of macroeconomic growth models which incorporate different environmental variables. The other one is work by Wei-Bin Zhang (1990) who presents an overview of different growth models including those with exhaustible resources from mathematical standpoint.

2.2. Assumptions for the growth model of the Soviet economy

In order to design a growth model of the Soviet economy, it is necessary to specify some important preconditions associated with choice of right macroeconomic indicators. Macroeconomic indicators provide an interpretation of the current state of an economic system as well as past and future trends. It is well known that, in general, there are two types of economic indicators: (1) *monetary variables* such as prices, wages, money, inflation, interest rates, etc., and (2) *real variables* such as quantities of goods and services, population, labour force, natural resources, etc. Monetary variables have not played any significant role in the development of the Soviet economy, and, therefore, analysis of this economy must be realized in terms of real variables or from quantitative perspective.

However, the right choice of real macroeconomic variables also depends on quality of available data, intertemporal comparability of indicators and their usefulness. The Soviet data are very selective and inaccurate which suggests to apply a principle of simplicity if a consistent macroeconomic model is the major goal. In other words, quality of the Soviet data restricts one's choice of suitable macroeconomic indicators. Therefore, only aggregate indicators can be used to analyse the Soviet economy. This statement leads to the following assumption: the growth model of the Soviet economy in this study is a one-sector model with one durable aggregate good.

The growth model created in this study reflects existing macroeconomic processes in the Soviet economy for period 1950-1985 or before the Chernobyl accident. Thus, it is based upon consumption-investment and resource utilization decisions expressed through stock-flow relationships. Extensive exponentional growth of all resources (human, capital, natural), given exogenously, is assumed, because economic growth in the Soviet Union has been achieved by involvement of more and more resources available at any given point in time. It means that increase in aggregate production was mostly due to increase in quantities of aggregate inputs and not due to growth of productivity which is further supported by analysis of the Soviet economy's performance during 1950-1985 in section 3.3. Aggregate inputs include natural resources (renewable and nonrenewable), physical capital and labour force.

Moreover, it was not technological progress that has driven economic growth in the Soviet economy. Technological progress played significant role only in space and military related industries. Also the Soviet economy did not make any significant use of the Western technology and inflow of scientific-technical information. Therefore, constant technology is assumed in this study.

Extensive growth of all resources and constant technology assumption reflect the so-called *extensive economic growth* as a distinguishing feature of the Soviet economy.

Extensive economic growth points at a necessity to explicitly include natural resources into Soviet production function. We call natural resource stock an environmental variable. In this study a weak separability between economic variables (capital and labour) and environmental variable (resource stock) is assumed. This concept was employed by several authors in the field of environmental economics. For example. Tahvonen and Kuuluvainen (1993) define the concept as follows: "*Weak separability between economic variables (capital and labour) and environmental variables means that marginal rate of substitution between capital and labour is independent of resource stock (environmental) variable. This assumption allows the consideration of the interactions between aggregate conventional factors [of production] and the environmental resource*". Weak separability here implies complementarity of natural resources on the one hand, and capital and labour on the other. Frequently a concept of weak substitutability between environmental and economic variables is employed (see, for example. Stiglitz, 1974). Such a concept is useful for problem of optimal resource allocation (for example, in sustainable development context), but not for the growth model.

Therefore, the assumptions presented above underlie the following form of aggregate production function:

$$Y_t = qS_t^{\alpha_1} K_t^{\alpha_2} L_t^{\alpha_3} \tag{1}$$

where q is technological constant; S_t is resource stock; K_t is capital stock; L_t is labour.

Furthermore, we assume constant return to scale which implies

$$\alpha_1 + \alpha_2 + \alpha_3 = 1 \qquad (2)$$

Resource stock S_t includes renewable resources and non-renewable resources. It can be increasing over time (new discoveries of non-renewable resources, high natural growth of renewable resources), constant (sustainable utilization of all natural resources) or decreasing (depletion of resource stock through intensive harvesting of renewable resources and high levels of extraction of non-renewable resources). It is possible to introduce resource flows into (2), however, resource flows are related to the resource stock through the following intrinsic-dynamic equation:

$$S_{t+1} = (1 + r_b)S_t^R - R_t^R + S_t^N - R_t^N + R_t^{AN} \qquad (3)$$

where r_b is natural (biological) growth rate of renewable resources; S_t^R is stock of renewable resources; S_t^N is stock of non-renewable resources; R_t^R is harvesting of renewable resources; R_t^N is extraction of non-renewable resources; R_t^{AN} is new additions to the non-renewable resources in a form of new discoveries. These new additions to the non-renewable resources can be tied to the stock of non-renewable resources S_t^N as follows:

$$R_t^{AN} = r_n S_t^N \qquad (4)$$

where r_n is growth rate of the stock of non-renewable resources due to new discoveries. The equation (3) becomes

$$S_{t+1} = (1 + r_b)S_t^R - R_t^R + (1 + r_n)S_t^N - R_t^N \qquad (5)$$

If we further assume that $S_t^R = a_1 S_t$ and $S_t^N = a_2 S_t$, where a_1 and a_2 are fixed shares of renewable and non-renewable resources in total resource stock S_t or $a_1 + a_2 = 1$, then

$$S_{t+1} = (S_t^R + S_t^N) + (r_b a_1 S_t + r_n a_2 S_t) - (R_t^R + R_t^N) \tag{6}$$

In order to generalize the last equation we combine resource flows R_t^R and R_t^N into one variable R_t which is quantity of all resources (renewable and non-renewable) utilized annually. On the other hand, the sum $(S_t^R + S_t^R)$ equals total resource stock S_t and, therefore, equation (6) becomes

$$S_{t+1} = (1 + r)S_t - R_t \tag{7}$$

where $r = a_1 r_b + a_2 r_n$ is growth rate of natural resources, S_t is natural resource stock and R_t is natural resource flow.

Two very important assumptions must be added to describe the dynamics of the Soviet economy: (1) constant prices set below equilibrium level in the short-run as well as in the long run; and (2) centralized management. Constant prices set below equilibrium level point in the Soviet economy as excess demand economy at the macroeconomic level which is associated with existence of net aggregate shortage H_t defined later. Centralized management implies that all major production decisions are made by high authority. Production contracts are concluded at higher levels of the macroeconomic system and introduced to the industry in a form of plans. Plans are adjusted annually and at the end of each five-year period. It means that there is quantity constraint in addition to the price rigidity. Therefore, individual firms do not make decisions based on constrained profit maximization principle, because objective function is target level of output Y_t^a.

Furthermore, as our calculation shows, the investment ratio I_t to Y_t has been high and stable over period 1950-1985. It was around ***0.24*** in 1950s and ***0.28*** since 1961. It points at the long-run policy to keep the high share of investment in the national income in order to achieve economic growth. For example, in 1928 Stalin wrote that the higher growth rate in a socialist economy can be achieved because the communist regime provides for *"maximum capital investment in industry"*. The idea was further developed by famous Soviet economist Feldman in the late 1920s - early 1930s, and later on used by central planners for decades. Based upon Marxists view that economic growth depends on the rate of growth of equipment, the producer sector or group A in Soviet terminology has been a primary recipient of investment whose share has been artificially kept high. Spulber (1991) comments on this policy as follows: *"Feldman's model was not entirely applied by the central planners, but* ***postulates*** *that the output of sector A must exceed that of sector B (consumer goords) and that A must absorb most of its own output remained unchallenged for decades to come"*.

Therefore, we assume that the share of investment in national income is chosen exogenously or

$$\frac{I_t^a}{Y_t^a}=b \qquad \textbf{(8)}$$

where I_t^a is actual level of investment and Y_t^a is target level of output. The last expression gives us the following relationship for actual investment

$$I_t^a=bY_t^a \qquad \textbf{(9)}$$

In turn, actual level of personal consumption C_t^a is determined residually as

$$C_t^a=(1-b)Y_t^a \qquad \textbf{(10)}$$

Hence, once Y_t^a is set. both I_t^a and C_t^a follow recursively. Accumulation of capital stock is given by the following intrinsic-dynamic equation

$$K_{t+1}=K_t+I_t^a-\delta K_t \tag{11}$$

or

$$K_{t+1}=(1-\delta)K_t+bY_t^a \tag{12}$$

where δ is capital depreciation.

The above duscussion suggests that K_t and Y_t^a move together as econometric time series, and later on in this study we make use of this fact to remove time trend from the productivity series y_t^a.

The target fixed level of output Y_t^a defines aggregate supply AS_t which is incensitive to the price level P_t. On demand side we have two components: desired level of consumption by private agents C_t^d and desired level of investment by managers of enterprises I_t^d. Therefore, aggregate demand is defined as

$$AD_t=I_t^d+C_t^d \tag{13}$$

Moreover, we allow aggregate demand to depend on price level. Price sensitivity of aggregate demand follows from consideration of households' behaviour. The desired level of consumption depends on real wealth and disposable labour income. Real wealth is the ratio of nominal wealth to the general price level. In the short run nominal wealth of the Soviet people was fixed, and any price increase could cause decrease in the real wealth with decrease in quantity demanded by households.

On the other hand, increase in the level of aggregate shortage H_t decreases consumption demand C_t^d as well. Increase in general price level decreases shortage (for example, decrease in time cost associated with the search for substitutes) which eventually leads to increase in quantity demanded.

According to the above discussion consumtion demand C_t^d is positevely related to output and negatively to both, general price level P_t and aggregate shortage H_t which produces the following consumption function

$$C_t^d = C(Y_t^a, H_t, P_t) \tag{14}$$

with partial derivates $C_Y > 0$, $C_H < 0$ and $C_P < 0$. Linear version of the function is

$$C_t^d = c_Y Y_t^a - c_H H_t - c_P P_t \tag{15}$$

where c_Y is marginal propensity to consume out of income, c_H is quantity demanded per unit of shortage and c_P is quantity demanded per unit of price.

In contrast to consumption, investment demand I_t^d coincides with actual investment I_t^a because both are fixed by central planners. In fact managers of enterprises are well familiar that in any case they receive pre-planned level of investment and that nothing depends on their desire. Therefore we set

$$I_t^d = I_t^a \tag{16}$$

Equations (9), (15) and (16) combined produce the following expression for aggregate demand function

$$AD_t = C_t^d + I_t^d = c_Y Y_t^a - c_H H_t - c_P P_t + bY_t^a \tag{17}$$

or

$$AD_t = (c_Y + b)Y_t^a - c_H H_t - c_P P_t \tag{18}$$

Therefore, it appears that in addition to inelastic aggregate supply there is downsloping aggregate demand which is shown on diagram 2.1 below.

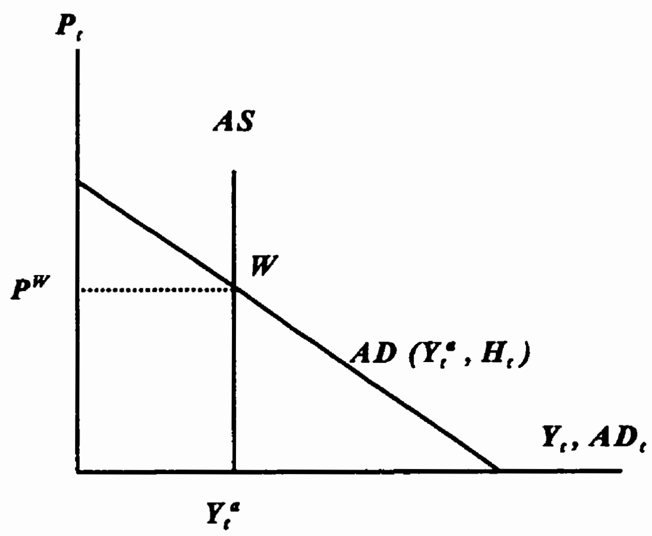

Diagram 2.1. Aggregate supply and aggregate demand in Soviet economy

Price level P^W is associated with equilibrium condition $AD_t = AS_t$. However, at any price other than P^W there is either excess demand or excess supply. In this regard, we define net aggregate shortage as the gap between aggregate demand AD_t and inelastic aggregate supply $AS_t = Y_t^a$ or net aggregate shortage H_t is

$$H_t = AD_t - AS_t \tag{19}$$

It is obvious from the diagram 2.1 that $H_t > 0$ (shortage) if $AD_t > Y_t^a$ and $H_t < 0$ (slack) if $AD_t < Y_t^a$. Point W on the diagram 2.1 represents a shortage-free state of an economy or what Kornai (1982) calls *the Walrasian state*. As it was stated earlier, in Soviet economy the price level is fixed by the central planners at the level P below the equilibrium level P^W. As a result, there is a specific level of shortage associated with such a fixed price P. We consider such a shortage as equilibrium value of shortage at the fixed price or what Kornai (1982) calls *normal shortage*.

Now all relevant macroeconomic variables are specified and we proceed with the growth model of the Soviet economy.

2.3. The growth model of the Soviet economy

The growth model consists of eight equations, derived in the previous section and restated here for convenience:

$$Y_t^a = qS_t^{\alpha_1} K_t^{\alpha_2} L_t^{\alpha_3} \tag{20}$$

$$K_{t+1} = K_t + I_t^a - \delta K_t \tag{21}$$

$$I_t^a = bY_t^a \tag{22}$$

$$H_t = AD_t - Y_t^a \tag{23}$$

$$S_{t+1} = (1+r)S_t - R_t \tag{24}$$

$$I_t^d = I_t^a \tag{25}$$

$$C_t^d = c_Y Y_t^a - c_H H_t - c_P P_t \tag{26}$$

$$AD_t = I_t^d + C_t^d \tag{27}$$

Let us reduce the system of equations (20) - (27) to one difference equation. Substituting (22) into (21) and rearranging

$$Y_t^a = \frac{1}{b}[K_{t+1} - (1-\delta)K_t] \quad \textbf{(28)}$$

Equations (27), (25), (22) and (26) combined produce the following result

$$AD_t = (c_Y + b)Y_t^a - c_H H_t - c_P P_t \quad \textbf{(29)}$$

Substituting (29) into (23)

$$H_t = (c_Y + b)Y_t^a - c_H H_t - c_P P_t - Y_t^a \quad \textbf{(30)}$$

or

$$H_t = (c_Y + b - 1)Y_t^a - c_H H_t - c_P P_t \quad \textbf{(31)}$$

Substituting value of Y_t^a from (28) into (31)

$$H_t = (c_Y + b - 1)\frac{1}{b}[K_{t+1} - (1-\delta)K_t] - c_H H_t - c_P P_t \quad \textbf{(32)}$$

or

$$\frac{c_Y + b - 1}{b}K_{t+1} = \frac{(c_Y + b - 1)(1-\delta)}{b}K_t + (1 + c_H)H_t + c_P P_t \quad \textbf{(33)}$$

Dividing by Y_t^a

$$\frac{c_Y+b-1}{b}\frac{K_{t+1}}{Y_t^a}=\frac{(c_Y+b-1)(1-\delta)}{b}\frac{K_t}{Y_t^a}+(1+c_H)\frac{H_t}{Y_t^a}+c_P\frac{P_t}{Y_t^a} \qquad \textbf{(34)}$$

Rearranging

$$\frac{K_{t+1}}{Y_t^a}=(1-\delta)\frac{K_t}{Y_t^a}+\frac{(1+c_H)b}{(c_Y+b-1)}\frac{H_t}{Y_t^a}+\frac{c_P b}{(c_Y+b-1)}\frac{P_t}{Y_t^a} \qquad \textbf{(35)}$$

Let us write down aggregate production function for two consecutive periods ***t*** and ***t + 1***:

$$Y_{t+1}^a=qS_{t+1}^{\alpha_1}K_{t+1}^{\alpha_2}L_{t+1}^{\alpha_3} \qquad \textbf{(36)}$$

$$Y_t^a=qS_t^{\alpha_1}K_t^{\alpha_2}L_t^{\alpha_3} \qquad \textbf{(37)}$$

Dividing (36) by (37):

$$\frac{Y_{t+1}^a}{Y_t^a}=(\frac{S_{t+1}}{S_t})^{\alpha_1}(\frac{K_{t+1}}{K_t})^{\alpha_2}(\frac{L_{t+1}}{L_t})^{\alpha_3} \qquad \textbf{(38)}$$

If in equation (24) we divide all terms by S_t, we end up with

$$\frac{S_{t+1}}{S_t} = 1 + r - \frac{R_t}{S_t} \tag{39}$$

Let us introduce depletion rate d_t as follows

$$d_t = \frac{R_t}{S_t} \tag{40}$$

Hence equation (39) becomes

$$\frac{S_{t+1}}{S_t} = 1 + r - d_t \tag{41}$$

The ratio K_{t+1}/K_t is growth rate of capital g_K. The ratio L_{t+1}/L_t is growth rate of labour force which in case of the Soviet economy is equal to the growth rate of population g_N. Both are given exogenously.

Therefore, equation (38) becomes

$$\frac{Y_{t+1}{}^{a}}{Y_t{}^{a}} = (1 + r - d_t)^{\alpha_1} g_K{}^{\alpha_2} g_N{}^{\alpha_3} \tag{42}$$

or

$$Y_t{}^{a} = \frac{Y_{t+1}{}^{a}}{(1 + r - d_t)^{\alpha_1} g_K{}^{\alpha_2} g_N{}^{\alpha_3}} \tag{43}$$

Substituting (43) into (35):

$$(1+r-d_t)^{\alpha_1} g_K^{\alpha_2} g_N^{\alpha_3} \frac{K_{t-1}}{Y_{t-1}^a} = (1-\delta)\frac{K_t}{Y_t^a} + \frac{(1+c_H)b}{(c_Y+b-1)}\frac{H_t}{Y_t^a} + \frac{c_P b}{(c_Y+b-1)}\frac{P_t}{Y_t^a} \tag{44}$$

Introducing $y_{t+1}^a = Y_{t+1}^a / K_{t+1}$ and $y_t^a = Y_t^a / K_t$ as actual productivity of the Soviet economy, equation (44) becomes

$$\frac{(1+r-d_t)^{\alpha_1} g_K^{\alpha_2} g_N^{\alpha_3}}{y_{t-1}^a} = \frac{(1-\delta)}{y_t^a} + \frac{(1+c_H)b}{(c_Y+b-1)}\frac{H_t}{Y_t^a} + \frac{c_P b}{(c_Y+b-1)}\frac{P_t}{Y_t^a} \tag{45}$$

Let us re-write ratio H_t / Y_t^a as follows

$$\frac{H_t}{Y_t^a} = \frac{H_t}{K_t}\frac{K_t}{Y_t^a} \tag{46}$$

Introducing $h_t = H_t / K_t$ as relative shortage, the last equation becomes

$$\frac{H_t}{Y_t^a} = \frac{h_t}{y_t^a} \tag{47}$$

It is also necessary to admit that the ratio P_t / Y_t^a is inverse of GDP in physical units which is fixed by central planners in a given period of time. Therefore, let

$$\frac{P_t}{Y_t^a} = u = const \tag{48}$$

Substituting (47) and (48) into (45)

$$\frac{(1+r-d_t)^{\alpha_1} g_K^{\alpha_2} g_N^{\alpha_3}}{y_{t-1}^a} = \frac{(1-\delta)}{y_t^a} + \frac{(1+c_H)b}{(c_Y+b-1)} \frac{h_t}{y_t^a} + \frac{c_P bu}{(c_Y+b-1)} \tag{49}$$

Let us introduce the following coefficients:

$$g_K^{\alpha_2} g_N^{\alpha_3} = z_1 \tag{50}$$

$$\frac{(1+c_H)b}{(c_Y+b-1)} = z_2 \tag{51}$$

$$\frac{c_P bu}{(c_Y+b-1)} = z_3 \tag{52}$$

Re-arranging (49) and taking into account (50), (51) and (52)

$$(1+r-d_t)^{\alpha_1} z_1 y_t^{\,a} = (1-\delta) y_{t+1}^{\,a} + z_2 h_t y_{t+1}^{\,a} + z_3 y_t^{\,a} y_{t+1}^{\,a} \tag{53}$$

Solving for y_{t+1}^a

$$y_{t+1}^{\,a} = \frac{(1+r-d_t)^{\alpha_1} z_1 y_t^{\,a}}{(1-\delta) + z_2 h_t + z_3 y_t^{\,a}} \tag{54}$$

Equation (54) is our basic equation which describes dynamics of the Soviet macroeconomic system. Three facts directly follow from this equation:

1. With increase in depletion rate d_t, next year productivity of economy y_{t+1}^a decreases.
2. With increase in shortage h_t , next year productivity of economy y_{t+1}^a decreases.
3. In a shortage free economy when $h_t = 0$, productivity y_{t+1} is higher. Following Kornai (1982), we call such a state Walrasian.

All three are consistent with common economic sense which implies that equation (54) is a good working model.

2.4. The basic dynamic equation

According to the model derived in the previous section, dynamics of the Soviet economy is expressed in terms of non-autonomous non-linear difference equation of the form[7] :

$$y_{t+1} = f(y_t, d_t, h_t) \tag{55}$$

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[7] From now on we drop superscript *a*

Let us approximate this equation with first-order Taylor's expansion around steady state:

$$y_{t+1} = a_1 + a_2 y_t + a_3 h_t + a_4 d_t \quad \textbf{(56)}$$

where

$a_1 = f(y, h, d) - f_y(y, h, d)y - f_h(y, h, d)h - f_d(y, h, d)d$

$a_2 = f_y(y, h, d)$

$a_3 = f_h(y, h, d)$

$a_4 = f_d(y, h, d)$

and f_y, f_h, f_d are partial derivatives of function *f(.)* evaluated at steady state values ***y***, ***h***, ***d***.

Let us take expectations through equation (56)

$$E(y_{t+1}) = a_1 + a_2 y_t + a_3 E(h_t) + a_4 E(d_t) \quad \textbf{(57)}$$

As it was admitted earlier, there is specific value of shortage associated with fixed price set below equilibrium level. Therefore, it is possible to set

$$E(h_t) = h \quad \textbf{(58)}$$

where ***h*** is equilibrium value of shortage or what Kornai (1982) calls *normal shortage*. If in addition we assume stable depletion rate ***d***, then

$$E(d_t) = d \quad \textbf{(59)}$$

Taking into account (58) and (59), equation (57) becomes

$$E(y_{t+1}) = a_1 + a_2 y_t + a_3 h + a_4 d \tag{60}$$

or

$$E(y_{t+1}) = a_0 + a_2 y_t \tag{61}$$

where $a_0 = a_1 + a_3 h + a_4 d$.

Let us add y_{t+1} to both sides of equation (61)

$$y_{t+1} + E(y_{t+1}) = a_0 + a_2 y_t + y_{t+1} \tag{62}$$

Rearranging

$$y_{t+1} = a_0 + a_2 y_t + y_{t+1} - E(y_{t+1}) \tag{63}$$

In the last equation the difference $y_{t+1} - E(y_{t+1})$ represents deviation of actual value of productivity from its expected value which is stochastic term and we call it e_{t+1}. Therefore, we can re-write equation (63) as follows

$$y_{t+1} = a_0 + a_2 y_t + e_{t+1} \tag{64}$$

Due to extensive economic growth of the Soviet economy stochastoc disturbance e_{t+1} is driven by shocks to the depletion rate d_t.

Therefore, equation (64) is stochastic linear difference equation which reflects dynamics of the Soviet economy. Stability condition requires

$$a_2<1 \tag{65}$$

In fact

$$a_2=f_y(y,h,d) \tag{66}$$

Therefore, any dramatic change in d_t not only affects productivity y_t through disturbance e_t, but also affects it through change in the value of coefficient a_2. It means that in such a case the dynamics of the economy is affected. Obviously enough environmental shock should significantly increase value of the depletion rate d_t which would affect stability of the economy.

On the other hand, equation (64) shows that if $a_2 < 1$, then there is a steady state associated with specific values y, h, d. However, this steady state is different from Walrasian when $h = 0$. Therefore, the model derived in this chapter is a disequilibrium growth model because in economic literature (see Wei-Bin Zhang, 1990 for complete review) disequilibrium is defined as follows: *disequilibrium is a steady state which is inconsistent with the Walrasian equilibrium of the system.*

Conclusion

1. Artificially low price level, fixed by the central planners, makes it impossible to achieve the Walrasian steady state for the Soviet economy.

2. There is another steady state which is associated with specific value of shortage h_t which we call *normal shortage.* The normal shortage is a shortage that has stabilized with respect to the Walrasian steady state.

3. The steady state path of a shoratge economy is parallel to the Walrasian which follows from the above definition of the normal shortage.

4. Stability of the Soviet economy is heavily dependent on behavior of depletion rate d_t.

5. Environmental shock affects stability of the Soviet economy through dramatic changes in depletion rate d_t.

The analysis realized in this chapter suggests two possible approaches to assess macroeconomic consequences of the large environmental impact as a quantity shock to the resource stock S_t with following effect on resource flow R_t. The two are associated with availability of data after the shock. The first approach arises when there is sufficient data set before as well as after the shock. However, sometimes it is necessary to assess consequences of the shock right after it has occurred. Let us represent algorithms for both cases.

If there is sufficient data set before and after the environmental impact.

1. Derive steady state for an economy based on theoretical model and statistical estimation.

2. Derive deviations from the steady state.

3. Obtain dynamic process in deviations from the steady state.

4. Investigate residuals of the process to capture the environmental shock.

5. Investigate character of the environmental shock (permanent, temporary, autoregressive, moving average, etc.) based on step 4.

6. Remove the shock from the process in steps 3 and 4.

7. Compare two time paths - with shock and without - to derive the aggregate value of the shock.

If there is insufficient data set after the environmental impact

1. Obtain dynamic process in general form as in (54) or approximated form as in (64) for the data before the environmental impact.

2. Derive empirically the direct environmental impact as change in depletion rate Δd_t.

3. Impose the derived value of the direct impact on the process in step 1.

4. Obtain time paths of the major macroeconomic variables with shock.

5. Iterate the process in step 1 into the future to obtain potential time path without shock.

6. Compare two time paths from step 4 and step 5. The difference between the two is the aggregate value of the environmental impact.

In this study the second approach is chosen because the after-shock period for the Chernobyl accident includes only five years from 1986 until 1990. Even 1991 is not reliable year because the break-up of the Soviet Union occurred in August of 1991.

CHAPTER THREE

STATISTICAL ANALYSIS OF THE SOVIET ECONOMY'S DYNAMICS

The chapter presents the Soviet data used in this study for econometric estimation and inference. The data are derived using Steinberg's (1990) methodology which shows consistency in comparison with data sets derived by other analysts of the Soviet economy's performance over 1950-1985 period. The derived data are compared with the alternative data to reach a conclusion about the accuracy of the derived data.

At the same time the chapter presents a survey of econometric approaches to model disequilibrium economies. It also discusses the use of modern time series techniques to describe the dynamics of a macroeconomic system as well as to analyse shocks to the system. As it was emphasized in the end of chapter two, consequences of the environmental impact are modeled using Vector Autoregression analysis because there is insufficient data after the Chernobyl accident. The chapter discusses some advantages of this approach to simulate dynamics of the Soviet macroeconomic system without the shock and with the shock.

In the end, the derived data are used first to estimate the basic dynamic equation of the Soviet economy, analytically derived in chapter two, and then to analyse productivity fluctuations in the Soviet economy with the help from modern time series techniques. It appears that the Soviet economy underwent a structural break in 1960 due to too much extensive economic growth; the structural break started a non-stationary process in the productivity series over 1961-1985. It means that Soviet economy was already unstable as a dynamic system at the time of the Chernobyl accident.

In general the chapter provides basis for the further simulation of the consequences of the

Chernobyl accident which is carried out in chapter four.

3.1. The Soviet economic data

A major concern of all researchers in the field of analysis of the Soviet economy is with data collection and interpretation. Soviet national accounts statistics were designed in the mid-1950s. Its creators faced a very difficult problem. On the one hand, they should publish detailed information on economy's performance, but on the other hand it was necessary to conceal the true state of nature. According to Steinberg (1990) , Soviet experts overcame the above dilemma using the Marxian concept of productive labour. The concept states that national income is generated by material production sectors only. Therefore, it helped Soviet statisticians to conceal the data on non-productive sectors. Mostly these sectors have included defence, space, research, police and some banking activities.

Therefore, the major task of researchers in the field of Soviet statistics has been reconstruction of original national economic balance (NEB) tables. However, Goskomstat[8] has published a limited information which did not allow economists to completely restore NEB tables. It became more an art to combine distant pieces of limited information to interpret the Soviet data. Eventually such a situation led to the following two approaches to interpret the Soviet data:

(a) to compile GNP accounts from the data available;

(b) to reconstruct the original NEB accounts.

The first approach is associated with Bergson-CIA methodology (1990) while the second one is

[8] Goskomstat = Soviet Statistical Bureau

mainly associated with works by Soviet economists such as Khanin (1988). Belkin (1990), Birman (1983), Ivanov and Ryabyshkin (1988, 1989), Lavrovsky (1986), Volkonskii, Poduzov, Pavlov and Solov'ev (1991), Martynov (1990), Gallik, Kostinsky and Trempl (1983), Kirichenko (1990) and others.

It appears that methodology created by Dmitri Steinberg (1989, 1990) is the most complete and reliable in all aspects. He defined his task in analysis of the Soviet data for the period 1970-1990 as follows:

" In short, I integrated all available Soviet data on production, input-output, national income and financial flows as well as on capital and labour resources. Afterwards, I converted integrated Soviet national accounts into a GNP format " (Dmitri Steinberg, 1990, p.5)

In this regard the Steinberg's data are the most comprehensive set of economic indicators of the Soviet economy. Actually he presents three data sets: (i) in current established prices; (ii) in constant prices adjusted for hidden inflation; (iii) in factor cost prices. The second data set is used for statistical analysis in this study. In order to calculate deflators to derive the second data set, Steinberg evaluated economic parameters in the Soviet economy in terms of monetary values and physical quantities. Then he calculated "Paasche Price Index" which, in his opinion, is more reliable for such calculation in comparison with "Laspeyres Price Index"used by CIA analysts. Steinberg also converted producers' prices which have been usually reported by Goskomstat into consumers' or prices by end use. Altogether Dmitri Steinberg compiled an extensive data base on the output in both value and physical terms for around 165 industrial, 35 agricultural, 15 construction and 10 other production sectors of the Soviet economy. This procedure allowed him to conclude that the Bergson-CIA methodology to analyse Soviet economy is not reliable at all because it was never designed to analyse Soviet national accounts in current established prices as an integrated system. As a result, *"the CIA and other users of its methodology have had great difficulties in integrating the official statistics for the purpose of compiling Soviet GNP accounts"*[9]. Therefore, the CIA methodology has produced overestimation of the performance of the Soviet economy, and, for example, it did not detect the real change in the pattern of the Soviet economy in early 1970s. Those who have lived in the USSR during this period could feel the change by themselves from every day life experience, however, for outsiders this fact came as a surprise in late 1980s with Gorbachov's *perestroika*.

The Steinberg's methodology does reflect these features of the Soviet economy quite well and, therefore, his data set for 1970-1990 is used for statistical estimation in this study and his methodology is used to interpret Soviet official data for 1945-1969 in order to obtain a consistent post-war set of macroeconomic aggregates during 1945-1990. In fact, it is necessary to analyse data since 1950 because by this year the Soviet economy has reached its pre-war level and has begun to develop further. Thus, from now on 1950 is considered as a starting point for the Soviet economy's post-war development.

Unfortunately, it is not possible to realize such an extensive analysis on a disaggregated level as Steinberg did. Nonetheless, it is possible to analyse the most influential industrial sectors of the Soviet economy such as energy, mining, metallurgy, construction, machine-building, chemical and petro-chemical, light industry which account for 78.9% in the Soviet GNP. Below table 3.1 represents a summary of these calculations.

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[9] Dmitri Steinberg, 1990, p. 200

Table 3.1. Annual increase in Soviet production in 1950s by sectors

Industrial sector	Share in GNP, %	Annual increase in monetary values, %	Annual increase in physical units, %
1. Energy	6	13.7	12.3
2. Mining (coal, natural gas, oil)	7	9.3	8.3
3. Machine-building	16.3	15.4	8.2
4. Metallurgy	16.0	10.4	9.1
5. Chemical and petro-chemical	10.5	14.5	9.7
6. Construction	4.3	18.4	13.4
7. Light industry	18.8	9.6	6.2
Totals[10]	78.6	9.8	6.9

Adjusting for 100% GNP, annual increase in monetary terms is equal to 12.4% and 8.7% in physical units in 1950s. Annual inflation is the difference between the two parameters and it is equal to 3.7% in this case. However, monetary values of industrial sectors were calculated in producers' prices. In turn, we need to consider consumers' prices or prices by end use as well as prices in a secondary economy which were higher than officially reported producers' prices. Moreover, in 1949 producers' prices were subject to a one-time increase in 1.58 times. According to the official statement the increase was due to very high costs of production during World War II. Soviet authorities promised

[10] Total annual increase was calculated as weighted average. Weighted average of annual increase in production in monetary value: $W_1 = 0.06*13.7 + 0.07*9.3 + 0.163*15.4 + 0.16*10.4 + 0.105*14.7 + 0.043*18.4 + 0.188*9.6 = 9.8\%$. Weighted average of annual increase in production in physical units: $W_2 = 0.06*12.3 + 0.07*8.3 + 0.163*8.2 + 0.16*9.1 + 0.105*9.7 + 0.043*13.4 + 0.188*6.2 = 6.9\%$

to eventually decrease the prices to the 1948 level in five years by improvements in economy's efficiency. However, by 1960 prices decreased by 1.45 times which gives us real price increase of 1.092 in 1950s or 0.8% annually. Therefore, we can add this amount to the hidden inflation as well. Therefore, historical and economic facts point at annual inflation during 1950s as being at least 4% which is assumed for further calculations.

Table 3.2 below represents annual growth rates for GNP, gross output, investment and consumption reported by Goskomstat for 1950s.

Table 3.2. Annual growth rates of Soviet macroeconomic aggregates in 1950s, %

Years	Gross output	GNP[11]	Investment	Consumption[12]
1951	12.0	12.3	14.5	6.2
1952	10.4	10.9	11.4	7.4
1953	9.8	9.5	5.3	13.5
1954	11.3	12.2	18.2	9.7
1955	11.6	11.9	12.4	0.9
1956	10.4	11.3	14.8	5.9
1957	8.2	7.0	12.6	8.7
1958	9.7	12.4	16.2	5.9
1959	8.9	7.5	13.2	1.8
1960	7.6	7.7	8.5	6.4

Source: Narodnoye Khasyaistvo SSSR, 1922-1972. Moscow: Statistics, 1972, p. 56

Taking into account 4% annual inflation in 1950s, the real growth rates for Soviet macroeconomic

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[11] GNP follows the same pattern as Net Material Product (NMP). Actually GNP is equal to the NMP plus amortization and personal services. However, amortization was constant and personal services accounted for less than 1% in 1950s

[12] Growth of consumption is assumed to follow the same pattern as growth of real income of workers

aggregates become as shown in table 3.3.

Table 3.3. Real annual growth rates of Soviet macroeconomic aggregates in 1950s, %

Years	Gross output	GNP	Investment	Consumption
1951	8.0	8.3	10.5	2.2
1952	6.4	6.9	7.4	3.4
1953	5.8	5.5	1.3	9.5
1954	7.3	8.2	14.2	5.7
1955	7.6	7.9	8.4	-3.1
1956	6.4	7.3	10.8	1.9
1957	4.2	3.0	8.6	4.7
1958	5.7	8.4	12.2	1.9
1959	4.9	3.5	9.2	-2.2
1960	3.6	3.7	4.5	2.4
Averages	6.0	6.3	8.7	2.5

Table 3.3 shows that average annual growth of GNP in 1950s was 6.3% or high enough. However, this growth rate was due to sharp increase in investment in production of means of production or group A according to the Soviet terminology. Consumption has increased slowly and it is not surprising. There were forced cutoffs in consumption in 1950s: the Soviet government issued state bonds and paid significant part of everyone's salary in bonds. The bonds were not redeemable at that time. Only in 1980s the government decided to repay face value of the bonds which significantly depreciated by that time. Thus, table 3.3 reflects the true state of nature in the Soviet economy in 1950s. The data support the main conclusion made by the majority of the Soviet economists: in the entire Soviet history its economy has experienced its best times in the second half of 1950s.

However, as the table 3.3 also shows, by 1960 there appeared some undesired trends towards slowdown. Taking into account assumed 4% real annual inflation, increase in Consumer Price Index (CPI) was calculated to be 1.5 by 1960, which was a real threat for the economy of constant prices. Soviet economists did recognize the hidden inflation and, therefore, it was suggested to decrease scale of the Soviet currency by a factor of 10[13]. It was done in 1961 with confiscation of the so-called "excess of cash holdings" causing a wealth loss to the Soviet people. Therefore, the "monetary reform" of 1961 was a kind of demand shock for the Soviet economy which is again emphasized in chapter four.

Using our and Steinberg's calculations of hidden inflation, deflators for all macroeconomic aggregates were calculated. The data presented by Dmitri Steinberg assumes 3.4% for annual inflation in 1960[14]. Combining Steinberg's (1990) calculations for 1970-1990 deflators (table 1G, p.216) and assuming 4% annual inflation in 1950s and 3.4% in 1960s, we arrive at deflators for the period from 1950 to 1970 presented in table 3.4 below.

Table 3.4. Soviet deflators by end use for 1950-1970 period

Year	Gross output	GNP	Investment	Consumption
1950	0.45	0.45	0.42	0.47
1951	0.47	0.47	0.44	0.49
1952	0.49	0.49	0.46	0.51
1953	0.51	0.51	0.48	0.53

[13] In order to adjust for the hidden inflation (my conclusion)

[14] Steinberg reports deflators of 0.79 for 1965 and 0.93 for 1970 which gives us approximately 3.4% of annual inflation

1954	0.53	0.53	0.49	0.55
1955	0.55	0.55	0.51	0.57
1956	0.57	0.57	0.54	0.59
1957	0.59	0.59	0.56	0.62
1958	0.62	0.62	0.58	0.64
1959	0.64	0.64	0.60	0.67
1960	0.67	0.67	0.63	0.69
1961	0.69	0.69	0.65	0.72
1962	0.71	0.71	0.67	0.74
1963	0.74	0.74	0.69	0.77
1964	0.76	0.76	0.72	0.79
1965	0.79	0.79	0.74	0.82
1966	0.82	0.82	0.77	0.84
1967	0.84	0.84	0.81	0.86
1968	0.87	0.87	0.84	0.88
1969	0.90	0.90	0.88	0.91
1970	0.93	0.93	0.92	0.93

Therefore, if we had all Soviet macroeconomic aggregates in established prices we could deflate them using our table 3.4 and Steinberg's table 1G. However, Soviet statistics is very tricky and confusing. It reports data with respect to different base years. Another difficulty is to convert Soviet accounting into GNP format for 1950-1969 period which requires very detailed data. Dmitri Steinberg had such comprehensive data for 1970-1990 which were revealed by Gorbachov and were published in Soviet journals in late 1980s. Unfortunately, there no comprehensive data available for 1950-1969 period and, therefore, another approach was chosen. Deflated annual growth rates for the Soviet macroeconomic aggregates reported in table 3.3 were used to recalculate all parameters reported by Steinberg back taking 1970 as a base year. Steinberg chose 1973 year's prices as constant prices and we follow the same path. According to this, real growth rates of major macroeconomic aggregates are presented in table 3.5 below.

Table 3.5. Growth rates of Soviet macroeconomic aggregates during 1950-1970

Year	Gross output	GNP	Investment	Consumption
1951	1.080	1.083	1.105	1.022
1952	1.064	1.069	1.074	1.034
1953	1.058	1.055	1.013	1.095
1954	1.073	1.082	1.142	1.057
1955	1.076	1.079	1.084	0.969
1956	1.064	1.073	1.108	1.019
1957	1.042	1.030	1.086	1.043
1958	1.057	1.084	1.122	1.019
1959	1.049	1.035	1.092	0.978
1960	1.036	1.037	1.045	1.024
1961	1.037	1.034	1.009	1.072
1962	1.039	1.023	1.015	1.037
1963	1.012	1.006	1.017	1.016
1964	1.040	1.059	1.054	1.036
1965	1.029	1.035	1.050	1.081
1966	1.045	1.047	1.036	1.042
1967	1.060	1.052	1.049	1.045
1968	1.065	1.049	1.045	1.079

1969	1.022	1.014	0.999	1.037
1970	1.046	1.056	1.082	1.037

Appendix 3A presents numerical values of GNP, investment and personal consumption in constant 1973 prices for the period from 1950 to 1985 or before the Chernobyl accident. Diagram 3.1 shows these variables as time series.

Deriving the complete set of macroeconomic aggregates for 1950-1985 for the Soviet economy in constant 1973 prices allows us to study the dynamics of the Soviet economy. In order to remove common time trend from macroeconomic series, we work with relative values. For this purpose in chapter two we divided the output series by the value of capital stock K_t. Another reason for this is: the ratio of real GNP Y_t to capital stock K_t in the Soviet economic analysis was known as *efficiency* of economy, and there existed a set of normative values of the ratio for each industry and economy as a whole. The ratio is a good measure of Soviet economy's productivity because it reflects the value of national product with respect to existing potential in terms of capital stock. The values of capital stock in respective years were derived from the yearbook of Soviet statistics *Narodnoye Khozyaistvo*. Using deflators reported in table 3.4 for period 1950-1969 and deflators reported by Steinberg (1990, p.216) for period 1970-1985, the values of capital stock K_t in constant 1973 prices were calculated. *Appendix 3B* presents numerical values of the derived series K_t. Diagram 3.2 shows capital stock K_t as time series.

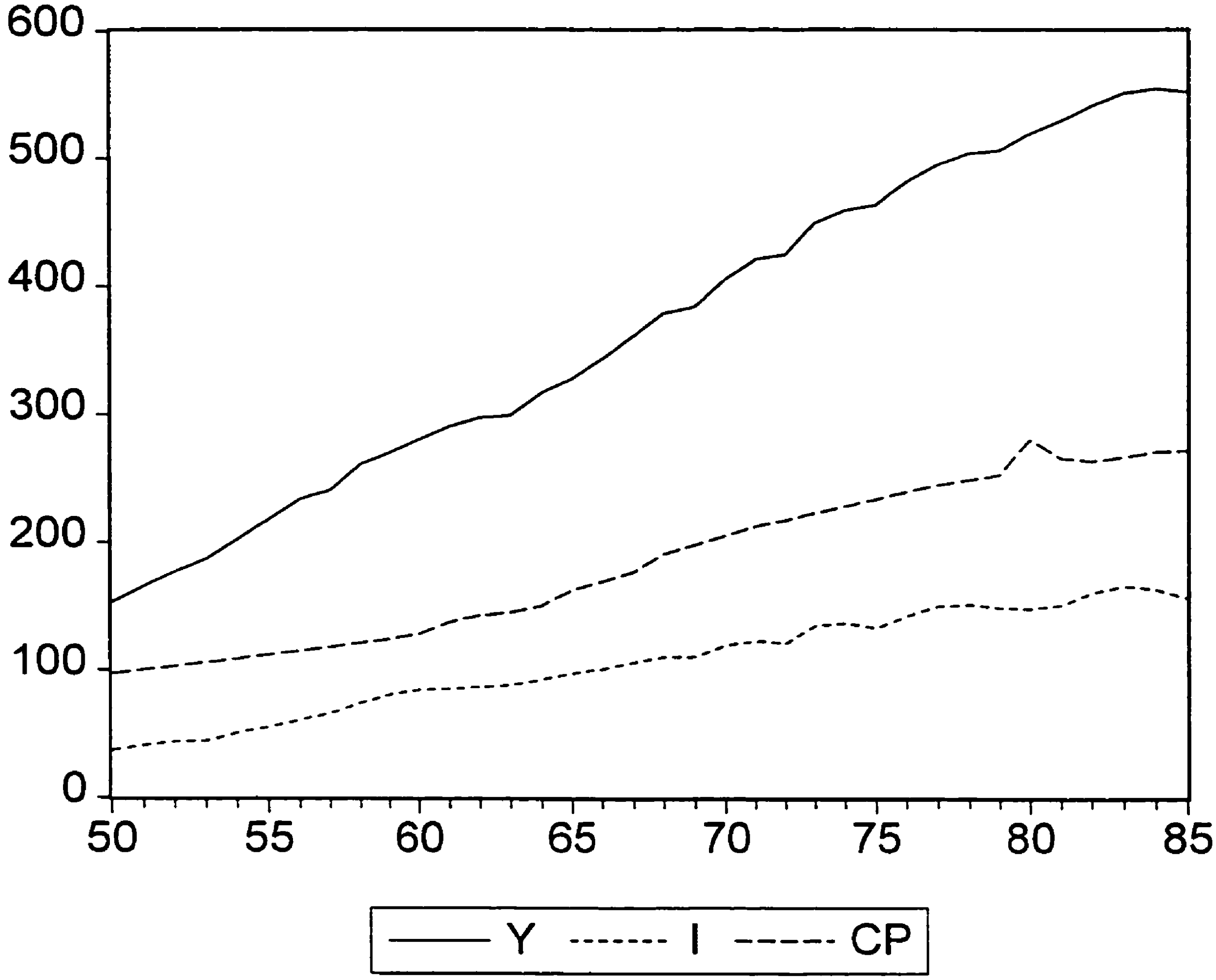

Diagram 3.1. GDP, investment and personal consumption series, 1950-1985

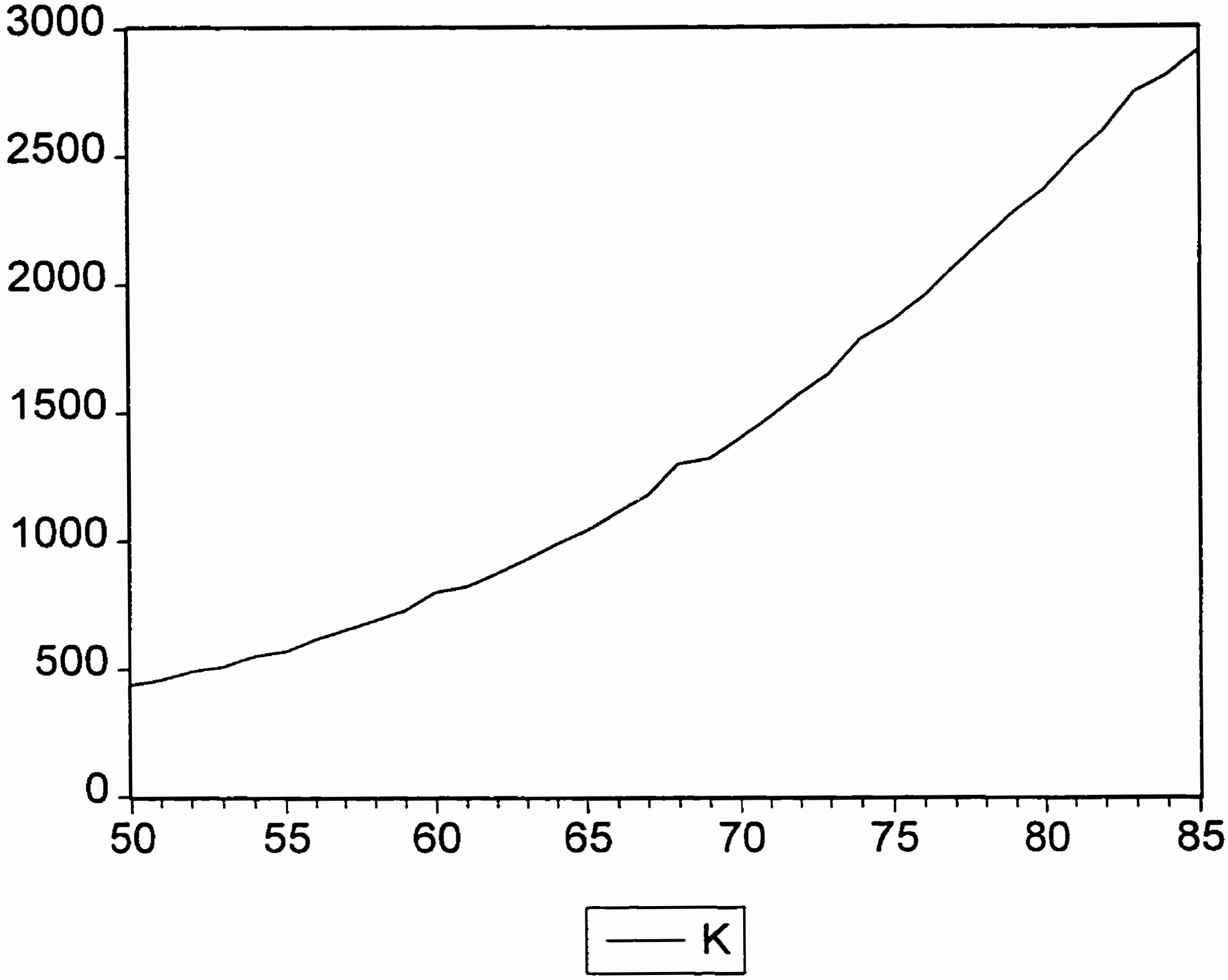

Diagram 3.2. Capital stock series, 1950-1985

3.2. Comparison of existing and derived indicators of the Soviet economy's dynamics

In order to justify the derived macroeconomic data used in this study, analysis of some existing estimates of the Soviet economy's dynamics was undertaken. In the beginning it is necessary to define major macroeconomic indicators that reflect economic growth in the Soviet Union. According to tradition and the Marxist approach, the Soviet system of accounting has been based on calculation of material product, particularly its net component that has been reported as national income (NI). In the late 1980s Soviet statisticians began to calculate the so-called Gross Social Product (GSP) in addition to NI. Let us present the structure of both indicators:

Gross Social Product = net output of material production (the value added in the branches of material production) + depreciation of fixed assets in the material and nonmaterial spheres + incomes received in the nonmaterial sphere + incomes received from foreign activities (Spulber, 1991).

National Income or Net Material Product at the production stage = gross output of material goods - intermediate consumption in the material sphere including depreciation (Spulber, 1991).

It appears that GSP exceeds NI by the cost of intermediate and capital goods. According to Steinberg (1990) the cost of capital goods is equal to capital depreciation plus the unamortized value of liquidated capital. Therefore, if the Marxist approach is accepted, then the GSP can be written as follows (see Steinberg, 1990):

$$GSP = c + v + m$$

where $\boldsymbol{c}$ is cost of intermediate and capital goods defined above; $\boldsymbol{v}$ is labour income from material production sector; $\boldsymbol{m}$ is revenues of enterprises employing the labour. In turn, NI is

$$NI = v + m$$

Steinberg (1990) fairly states that no division of national income into $\boldsymbol{v}$ and $\boldsymbol{m}$ components is performed in GNP accounts. Moreover, Volkonskii, Poduzov, Pavlov and Solov'ev (1991) stated that Soviet NI differs from world-wide accepted GNP by non-productive services and depreciation of fixed capital or

$$GNP = NI + \textit{non-productive services} + \textit{depreciation of fixed capital}$$

The same conclusion was made by the CIA who stated: *"In accordance with Marxist concepts, the Soviets have used net material product - a measure that excludes most services and capital stock depreciation " (CIA, 1991, p.10).* The above mentioned Soviet economists also noted that because of the higher growth rates of non-productive services and depreciation of fixed capital, the annual rates of GNP growth in the former Soviet Union have surpassed rates of NI growth during 1950-1985 by 0.5%. In fact the first attempt to calculate Soviet GNP was made as early as 1953 by American economist Abram Bergson (1953). He suggested computing the Soviet GNP in alternative prices which he called *factor cost prices.* They included a uniform charge in place of the officially determined profits and turnover taxes. Bergson (1953) developed deflators to convert current price values of each component of the Soviet GNP. Eventually this approach became known as the *Adjusted Factor Cost Standard*, and it has been used for years by the CIA to compute the Soviet GNP. Thus, analysis is presented below of all three indicators which reflect dynamics of the Soviet economy.

Having made the above introduction, it is possible to analyse different estimates of the Soviet economic growth during 1950-1985 and to compare them with derived estimates in the previous section. First of all, it is necessary to present the major tendencies in the Soviet economic growth. Khanin and Selyunin (1987) emphasize the following distinguishing feature of the Soviet economy: during all periods in the interval from 1928 to 1985 growth in utilization of natural resources and increase in capital stock have exceeded increase in NI. Their conclusion is: *"It is possible to develop economy this way only if you have plenty of natural resources"*. According to their calculations, which are presented later in this section, the Soviet economy has developed rapidly only in 1950s. They write: *"According to our estimates this period is the most successful in the Soviet economy. For the first time economic growth was achieved not only by increase in volume of all material resources, but also by their more efficient utilization. [For example], labour productivity increased by 62% or almost by 5% per year" (Khanin and Selyunin, 1987, p.193).*

The fact that in 1950s the Soviet economy has experienced its best times is supported by the majority of Soviet economists as well as CIA (1982, 1988, 1991) specialists. Data derived in section 3.1 of this study completely confirms this conclusion.

The first signs of slowdown in the Soviet economy can be found in the late 1950s. Let us quote Khanin and Selyunin (1987) once again: *"Usually appearance of negative tendencies in the Soviet economy is dated by the mid-1970s. According to our estimates, this happened 15 years earlier" (Khanin and Selyunin, 1987, p.194).* The derived data reflect the same trend: during 1960s economic growth has decreased in comparison with 1950s, however, remaining high enough. Moreover, there was an economic reform in 1965 associated with new Soviet leadership which caused even slight increase in economic growth in 1966-1970. This increase is supported by Soviet official data, CIA's estimates and estimates derived from Steinberg (1990). Khanin and Selyunin (1987) question this fact. In their opinion, economic growth in terms of NI growth in 1966-1970 has been 22% while it had been 24% in 1961-1965. This conclusion is due to high rates of hidden inflation assumed by the authors. For example, Khanin (1990) reports 4.6% annual inflation for this period. In turn, CIA (1982, 1988, 1991) estimated inflation for this period as 2.4%, Khachaturov

(1979) as 2.6%, and Steinberg (1989, 1990) as 3.4%. Therefore, Khanin's 4.6% inflation for the period 1966-1970 may be overestimation.

On the other hand, all estimates (Soviet official, CIA's, Khanin and Selyunin's, Steinberg's) reflect almost the same dynamics during 1971-1985 differing only in absolute values. This fact is appreciated in conclusion made by Spulber (1991). He writes:

"...What is important is that no matter what series one considers, the Soviet economy has been unmistakenly losing its dynamism since the end of the 1950s, that is, in relation to the reconstruction years and the high investment rates of the late 1940s and 1950s. The slowdown deepened after a spurt in 1966-1970, but by then the contractions had become increasingly alarming, reaching bottom in the early 1980s..." (Nicolas Spulber, 1991, p.159)

In this study exclusive reliance on extensive economic growth is viewed as one of the most important factors which has contributed to the slowdown of the Soviet economy since late 1950s - early 1960s. Even analysis of the Soviet official data revealed that the factors of extensive economic growth have been the major source of the NI growth during 1960-1985. According to the Soviet statistics (see, for example, Loginov and Novitskii, 1985), NI increased by 225% in 1961-1980 or by 4.1% annually. Of these 225% the factors of extensive growth accounted for 169.7%. By the factors of extensive economic growth we mean the following:

- involvement of additional natural resources (148.3%);
- increase in capital stock without technological improvements (16%);
- growth of labour force (5.4%).

Factors of intensive economic growth such as increase of labour productivity due to technological progress accounted for 55.3% out of 225% or only for 24.6% in total economic growth. This is according to the Soviet official data. However, Michael Hodges (1996) shows that growth of labour productivity has been declining since 1950. It was 3% in 1950s, 2.5% in 1960s, 2% in 1970s and 1% in 1980s. Contribution of technological progress in economic growth over period 1961-1980 calculated by Loginov and Novitskii (1985) was being equal to 16.8% or less than 0.8% annually.

Also it is helpful to present the increasing share of all natural resources in the structure of GSP: 1960 - 52.3%, 1970 - 54.9%, 1980 - 57.1%, 1983 - 57.6 (Fatelman, 1985, p.51). Eventually exhaustion of non-renewable resources as the major input in aggregate production function and extensive economic development led to decreasing economic growth. Marginal cost of extraction increased which resulted in decrease of efficiency in mining sector as well as in the economy as a whole. According to Fatelman (1985) productivity of mining sector in terms of profit to capital ratio has been 0.5 in 1960, 0.33 in 1970, 0.25 in 1980 and 0.16-0.20 in 1981-1985. According to derived data, productivity of the Soviet economy as a whole in terms of GNP to capital ratio has been 0.36 in 1960, 0.28 in 1970, 0.22 in 1980 and 0.18-0.21 in 1981-1985. Therefore, decrease in the productivity of the natural resources has been one of the major contributors to the slowdown in the Soviet economy. For example, Spulber (1991), based on his analysis of the Soviet economic data during period 1961-1985, concludes:

"The continuous contraction in the pace of growth was accompanied by increasingly deteriorating results in respect to actual volumes of investable resources, outputs, construction, and productivity" (Nicolas Spulber, 1991, p.159)

In 1985 the new secretary general of the Communist Party of the Soviet Union Mikhail Gorbachev accused previous Soviet leaders in failure *"to properly assess the changes in the objective conditions of the development of production, ... to shift in time from extensive to intensive uses of material and* *equipment, to hitch onto advancing technologies, and to discard inefficient methods of management" (Pravda, April 23, 1985 and February 26, 1986).*

Estimates presented in this analysis confirm both conclusions. A review of economic literature suggests three main sources of assessment of the Soviet economy's dynamics: Khanin and Selyunin (1987) and Khanin (1990) as the first source; CIA (1982, 1988, 1991) as the second source; Steinberg (1989, 1990) as the third source.

Khanin (1990) and Khanin and Selyunin (1987) estimated dynamics of two macroeconomic indicators - GSP and NI. Table 3.6 represents comparison between official growth rates of GSP and growth rates of GSP calculated by Khanin (1990).

Table 3.6. Annual growth rates of the Soviet GSP during 1950-1985

Subperiod	Official growth rate, %	Growth rate calculated by Khanin, %
1950-1960	9.9	9.6
1961-1970	6.9	8.1
1971-1980	5.2	5.1
1981-1985	3.7	6.3

Sources: Narodnoye Khozyaistvo SSSR za 70 let. Moscow: Finansy I Statistika, 1987, p.7; Khanin, G.I. Determining the dynamics of wholesale prices in the Soviet economy from 1929 to 1985. MATEKON, Summer 1990, p.65

In turn, table 3.7 presents comparison between official growth rate of NI and growth rate of NI calculated by Khanin and Selyunin (1987).

Table 3.7. Annual growth rates of the Soviet NI during 1950-1985

Subperiod	Official growth rate, %	Growth rate calculated by Khanin and Selyunin, %
1950-1960	10.7	5.7
1961-1965	6.5	4.4
1966-1970	7.8	4.1
1971-1975	5.7	3.2
1976-1980	4.3	1.0
1981-1985	3.6	0.6

Sources: Narodnoye Khozyaistvo SSR za 70 let. Moscow: Finansy I Statistika, 1987, p.7; Khanin, G. And Selyunin, V. Lukavyye tsifry, Novyy Mir, 2, 1987, p.195

However, as it was already noted, the two macroeconomic indicators GSP and NI differ from GNP. Using the conclusion of Volkonskii, Poduzov, Pavlov and Solov'ev (1991), that there is about 0.5% difference between the growth rates of NI and GNP, it is possible to convert Khanin and Selyunin's estimates presented in table 3.7 into GNP growth rates by adding 0.5%.

Here it is necessary to admit different degrees of precision of all three sources. Khanin (1990) admits:

"Macroeconomic estimates of the dynamics of GSP and NI were computed by three methods. Computation of these used the previously obtained final estimates of the dynamics of output of industry, construction, road transport, trade, public dining, suppliers and sales, and procurement as well as traditional estimates of the dynamics of output of those branches of material production which experience no or only weak influence of the hidden growth of wholesale prices and other factors of distortion of economic information... The calculations we have made make no claim to

precision, and they should rather serve as a point of departure for more thorough and detailed estimates" (Georgii Khanin, 1990, pp. 60 and 67)

In turn, CIA (1982, 1988, 1991) used a dual approach to estimating the Soviet economic growth: (1) estimation of total GNP growth by sector of origin, and (2) estimation of total GNP growth by end-use category for most, but not all, end use components. The actual estimation goes as follows:

"The CIA estimates Soviet GNP in several steps. First, it estimates the ruble value of GNP for a base year by both end use and sector of origin. The Agency initially prepares the base year estimate in Soviet established prices. It then recalculates the estimates in adjusted factor cost prices that, the CIA believes, better reflect the resource costs of Soviet production. After estimating base year GNP, the CIA calculates GNP for any given subsequent year by estimating the rate at which GNP has grown since the base year... The CIA therefore converts established prices into "adjusted factor cost" prices by (1) subtracting the value of indirect taxes and reported profits; (2) adding the value of subsidies, and (3) adding a return to capital - generally calculated at a uniform rate of 12% - for capital productivity" (CIA, 1991, pp. 10 and 12). Michael Boretsky (1987) comments on the 1982 CIA methodology:

"The first method is the basis for CIA estimates of total Soviet GNP growth... The essence of the CIA's sector-of-origin approach amounts to multiplying the estimated index of each sector's real growth by its weight in 1970[15]. Most of its estimates of growth indexes of industrial and transportation sectors are based on physical output data... Physical output data for an industry or a group of industries can rarely be comprehensive. Published Soviet data are very selective... The

[15] In later versions (1988, 1991) the base year is 1982

CIA's sample of "industrial observations" included only 312 products. More than 30% of this sample is constituted by 68 different models of automobiles and trucks. 9 excavators with different sizes of buckets, and 19 models of various locomotives. For service sectors other than trade, CIA uses essentially simple indexes of man-hours to measure their growth" (Michael Boretsky, 1987, p.518)

Table 3.8 represents all three sets of estimates of the Soviet economic growth made by CIA.

Table 3.8. Annual growth rate of the Soviet real GNP during 1950-1985 calculated by CIA

Subperiod	1982 estimates, %	1988 estimates, %	1991 estimates, %
1950-1960	6.7	6.7	6.7
1961-1965	5.1	4.9	5.0
1966-1970	5.0	5.3	5.0
1971-1975	3.0	3.3	2.4
1976-1980	2.3	2.2	2.4
1981-1985	n/a	1.7	2.0

Sources: USSR: Measures of economic growth and development, 1950-1980. Joint Economic Committee of the US Congress. Washington, D.C., December 8, 1982; Revisiting Soviet economic performance under glastnost: Indicators of CIA estimates. Washington, D.C.: Directorate of Intelligence, September 1988; Soviet economy: Assessment of how well the CIA has estimated the size of the economy. Report to the Honorable Daniel Patrick Moynihan, US Senate, September 1991

Here it is necessary to present some conclusions made by US Senate Commission (1991) with respect to the CIA's estimates of the Soviet economic growth. In its report it was stated:

"The widely recognized inefficiency of the Soviet economy may result in overstated CIA estimates of Soviet growth... If the Soviet economy becomes increasingly wasteful or inefficient in using intermediate products to produce final output[16], the CIA's use of intermediate production data in

[16] And this study proves that it was the case

its proxies for value added could result in overstated growth estimates" (p. 22)

The following quotation from the report cited above shows the precision of the CIA's estimates even better:

"Earlier this year [1991] the CIA evidently concluded that for the first time its long-standing method for estimating Soviet growth had produced results that it did not consider credible. After finding that its estimate of Soviet growth in 1990 was very similar to the official Soviet estimate, the CIA made an ad hoc adjustment to its estimate - cutting it from about minus 2% to minus 4 or 5%. It reasoned that its original estimate was too high..." (p. 23)

The above presented quotations characterize the precision of Khanin and Selyunin's estimates and CIA's estimates. In turn, as it was stated in section 3.1, Dmitri Steinberg (1990) compiled an extensive data base on output for 165 industrial, 35 agricultural, 15 construction and 10 other production sectors of the Soviet economy. Therefore, his data set is the most comprehensive among all three. In order to compare all existing estimates of economic growth in the former USSR which are described in this section, the resulting table 3.9 was created in terms of GNP growth rates.

Table 3.9. Annual growth rates of the Soviet GNP during 1950-1985: comparative analysis

Subperiod	Official	CIA	Selyunin & Khanin	Steinberg
1950-1960	10.3	6.7	6.2	6.3
1961-1965	6.6	4.9	4.9	3.2
1966-1970	9.3	5.3	4.6	4.3
1971-1975	5.3	3.3	3.7	2.7
1976-1980	5.2	2.2	1.5	2.3
1981-1985	4.8	1.7	1.1	1.2

The official GNP growth rates were derived based on Steinberg's tables (1990, pp.170-171) plus our calculation for period 1950-1964. The CIA's estimates are averages derived from table 3.8. Khanin and Selyunin's estimates were obtained by adding 0.5% to the values in table 3.7. Steinberg's estimates are based on his calculation for period 1965-1985 and our additions for period 1950-1964.

Table 3.9 allows us to make the following conclusions:

- data set used in this study (the last column in table 3.12) consistently reflects dynamics of the Soviet economy which is confirmed by facts;
- real slowdown of the Soviet economic growth has begun since late 1950s- early 1960s with period of slight increase in 1966-1970;
- period of 1976-1985 can be characterized as a period of stagnation in the Soviet economy because economic growth was almost equal to population growth;
- by 1986 the Soviet economy has faced a deep economic crisis in terms of economic growth;
- the data set used in this study reflects a slower overall economic growth during 1950-1985 in comparison with all other estimates presented in table 3.9: cumulative growth index is 3.616 in comparison with 4.488 of CIA's estimates and 3.961 of Khanin and Selyunin's estimates;
- the size of the Soviet economy was significantly overestimated by CIA which follows from analysis presented in this study and conclusions made by US Senate Commission (1991).

3.3. Analysis of existing statistical approaches to the modelling of STE

Diequilibrium econometric models

The disequilibrium econometric models of STE are diverse in nature and can be subdivided into two big groups according to their methods:

- chronic (known) excess demand (or disequilibrium indicator) models
- testable excess demand models

The disequilibrium indicator modelling approach assumes the existence of excess demand and seeks to represent it by an observable synthetic indicator. An early application of this idea was made in the West by Green and Higgins (1977) in the consumption block of their econometric model of the Soviet Union. However, most work after that was carried out in Eastern Europe. The models were adapted from Fair and Jaffee (1972) and in their simplest form they consisted of supply, demand, and excess demand plus the minimum condition. This generated a condensed form model with observable variables that could be estimated using standard econometric techniques. The first example of such a model was Charemza and Gierusz (1978). The theory of disequilibrium indicator modelling was simultaneously developed in Welfe (1978) and Charemza (1981) and applied, for example, by Welfe (1985), Romanski and Welfe (1986), and Charemza and Gronicki (1988).

The testable excess demand models are derived from the theoretical work of Barro and Grossman (1976) and the econometrics of Maddala and Nelson (1975), and Goldfeld and Quandt (1975). These models make use of demand and supply equations plus the minimum condition, but without assumption concerning excess demand. The first application of these models to the analysis of STE was made by Portes (1978, 1979) and by Portes and Winter (1980) in their study of consumption markets in Eastern Europe. In subsequent years Portes and his colleagues refined their econometric models and analysed a variety of issues in STE (see , for example, Portes 1987). Several testable excess demand models were also developed and applied in Czechoslovakia (Dlouhy, 1981). Finally, the model was revised and the minimum condition was replaced by the assumption that the quantity transacted is lower than the minimum of demand and supply due to the existence of unsaleable supplies.

There are also a lot of models that do not fall into either of the two presented categories. These models were obtained in the East and West using a combination of the described methods and equilibrium properties of STE. It is also necessary to mention works by Soviet economists. Articles of a high theoretical standard were produced by Braverman (1972), Polterovich (1980, 1982, 1983, 1986) and Movshovich (1988). Braverman and Levin (1981) wrote the first Soviet book on disequilibrium models which was very mathematical in nature.

Other studies identified the existing investment process as a major source of disequilibrium in STE. Bauer (1978, 1981) offered numerous insights into the causes and consequences of investment cycles in socialist economies. Additional important disequilibrium related examinations of investment were Soos (1976), Simon (1980), Winiecki (1982), and Podkaminer (1985). The role played by central authorities and planners in the generation of disequilibria in STE was examined by a number of economists as well. Ellman (1979) provided a comprehensive, comparative assessment of the contribution of economic planning deficiencies to imbalances and instability in STE and Podkaminer (1986) analysed planners' responsibility for causing disequilibrium by establishing incorrect relative prices and for exacerbating their effects through inappropriate policies. In the case of consumption, Collier (1985, 1986) estimated the gap between notional and effective purchasing power of households in a quantity constrained economy.

Structural versus time series modeling

It appears that the majority of the above econometric models is based upon the so-called sectorial approach or modelling a macroeconomic system as an interaction of different sectors. In econometric literature such models are known as structural models. Mathematically they represent systems of simultaneous equations. Econometric techniques to estimate these models are well known. Mainly two-stage and three-stage least squares as well as limited and full information maximum likelihood methods are employed.

However, the major drawback of all structural models is a necessity of explicit specification of endogenous and exogenous variables as well as error terms. In order to estimate a structural model we have to solve the identification problem first. Usually order and rank conditions are applied to identify each equation in the system. The application of these conditions requires exact division of all variables into endogenous, predetermined or exogenous types. However, sometimes it is not possible to divide macroeconomic variables into the previously mentioned three categories, *a priori.* On the other hand, in order to understand dynamic properties of STE, it is necessary to consider macroeconomic variables as time series.

Fortunately there is a way around these problems: time series analysis in general, and Vector Autoregression (VAR) analysis in particular. For example, Simonovits' (1992) dynamic (growth) model of STE consists of a set of first order difference equations. The equations incorporate a number of very important interdependent variables. On the other hand, it is well known that usually economic data are measured with errors, and therefore, the error terms have to be incorporated in an econometric model to describe a real Data Generating Process (DGP). Therefore, the Simonovits' model is rather a set (vector) of stochastic difference equations. The basic dynamic equation (47) derived in chapter two is also a stochastic difference equation which stands behind the dynamics of the Soviet economy or which describes the real DGP.

Box-Jenkins versus Sims approaches

In general, there are two competing approaches to study time series behaviour. The first one is associated with the Box-Jenkins (1976) methodology, the other one is Sims' (1980) methodology. Box and Jenkins popularized a three-stage method aimed at selecting an appropriate model for the purpose of estimating and forecasting a univariate time series. A fundamental idea in the Box and Jenkins approach is the principle of *parsimony*. Box and Jenkins claim that parsimonious models produce better forecasts than overparametrized models. The aim is to approximate the true DGP but not to pin down the exact process. As a result ARMA or ARIMA models, which are based on the Box-Jenkins methodology, produce fairly accurate short-term forecasts. The ultimate objective of making accurate short-term forecasts is best served by purging insignificant parameter estimates from the model. According to this methodology, a time series has to be made stationary before estimation. Usually it is done by differencing the non-stationary series.

Sims' (1980) criticism of the principle of parsimony resulted in a different methodology. Its main idea is to find important long-run interrelationships among variables and not make short-term forecasts. In doing so the methodology recommends agains differencing even if a series is non-stationary. The main argument against differencing is that it "throws away" some valuable long-run information. The same is said about detrending.

In conclusion, the Box-Jenkins approach is appropriate for short-run models while the Sims' methodology is better for long-run models to capture long-run behaviour of an economic system. If a time series is non-stationary, it is said to exhibit some long-run persistence, and, therefore, it is necessary to understand economic forces behind this persistence. Technically general solution to a linear stochastic difference equation consists of the following three components (see Enders, 1995):

$$y_t = trend + seasonal + irregular$$

In this regard, ARMA or ARIMA models , based on Box-Jenkins methodology, are used to model the irregular and seasonal components. Sims' methodology helps to model trending variables. The key feature of the trend is that it has a permanent effect on a time series.

Advantages of the VAR approach

In this study Sims' ideas are used to understand dynamics of the Soviet economy. This choice comes from observation of the behaviour of the productivity series y_t in the Soviet economy over 1950-1985 (see diagram 3.3). The series exhibit an obvious trend which is later explained by some crucial economic features of the Soviet economy. Moreover, the Sims methodology led to the Vector Autoregression analysis which is used in this study as well.

A set of macroeconomic variables must be regarded as a vector of interdependent variables in a mathematical sense. The VAR approach is designed specifically for these cases. A distinguishing feature of the VAR approach is that it treats each variable symmetrically. In practice, it is not always known if the time path of a series designated to be the "independent" variable has been unaffected by the time path of the "dependent" variable. The most basic form of VAR does not make reference to the issue of dependence versus independence.

The concept of Granger causality fits well with the VAR approach. It helps to understand whether lags of one variable enter into the equation for another variable. In this regard, VAR representation of a model allows for a block exogeneity test as well. The test detects whether or not to incorporate a specific variable into VAR, which ,in fact, is a multivariate generalization of the Granger causality test.

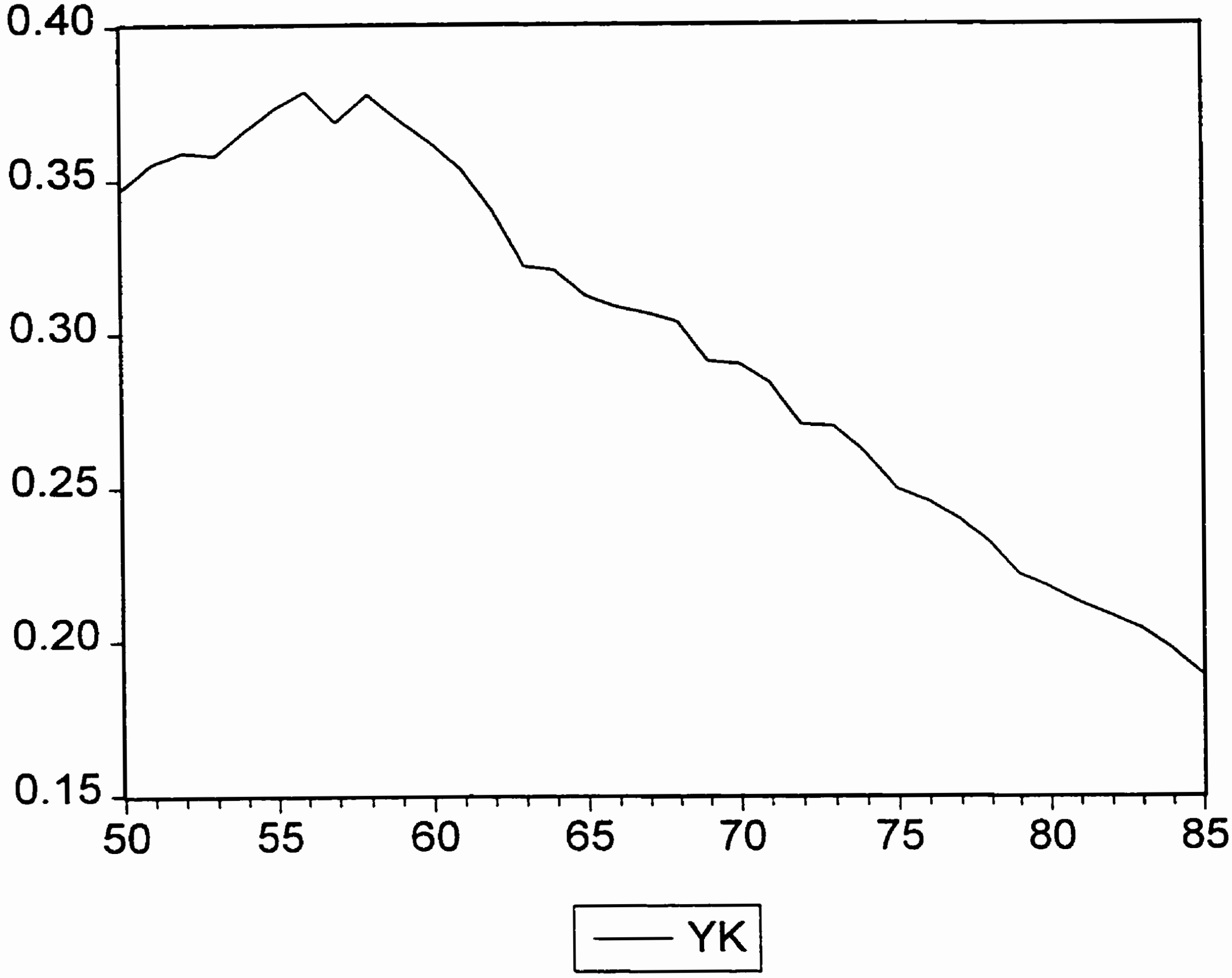

Diagram 3. 3. Productivity of the Soviet economy, 1950-1985

The next advantageous feature of VAR analysis is associated with the concept of cointegration. Cointegration helps us to find long run relationships among several economic variables as well as deviations around these relationships in the short run. The Johansen methodology (1988, 1991) based upon VAR representation is usually employed to find the so-called cointegrating vector. An Error Correction Model (ECM) is employed to find the short run deviations and speed of adjustment to the long run values (see, for example, Davidson and MacKinnon, 1993).

VAR analysis also considers error terms as being pure innovations or shocks. This is a very fruitful idea particularly for this research because it produces a moving average representation of VAR. In the literature (see Enders, 1995) it is called a Vector Moving Average (VMA). Such a representation of a dynamic system leads us to the most important concept for this research - the concept of the Impulse Response Function (IRF), which is based on VMA . It helps us to investigate the nature and consequences of shocks imposed on dynamic systems. The IRF takes into account the interdependent nature of shocks in the system: a shock to one variable in the system affects all other variables in the system, and IRF gives the magnitudes of all these variables after shock over time.

Of course, the VAR approach has its drawbacks as well. One of them is associated with the identification problem or the problem of "extraction" of the structural (initial) model from a standard VAR model. There are at least seven econometric techniques to deal with the problem; however, all these techniques are based on some decompositions of VAR and require explicit assumptions for the dynamic system under consideration. For example, the Choleski decomposition (see Enders, 1995) is associated with a triangle matrix representation of coefficients in VAR which requires one to set some coefficients equal to zero. In order to apply such a decomposition it is necessary to understand the nature of the dynamic economic system first. Therefore, one has to apply economic theory combined, however, with element of subjectiveness.

In conclusion, time series analysis based on Sims methodology is the major tool for this study because it could give us answers to almost all questions associated with the macroeconomic consequences of the Chernobyl accident.

3.4. Estimation of basic dynamic equation

In chapter 2 the basic equation which describes dynamics of the Soviet economy in terms of productivity was derived in general form as follows:

$$y_{t+1}=\frac{(1+r-d_t)^{\alpha_1}z_1y_t}{(1-\delta)+z_2h_t+z_3y_t}=f(y_t,h_t,d_t) \qquad (67)$$

However, the basic dynamic equation in form (67) does not explicitly explain fluctuations in productivity in the Soviet economy. In order to do so, it is necessary to perform econometric time series analysis. Stationarity of econometric time series and stability conditions of a difference equation are closely related. Furthermore, the stability condition of a difference equation is a necessary condition for a time series to be stationary.

In chapter two the difference equation (67) in general form was approximated by the first-order Taylor's expansion around potential steady state values. After some mathematical manipulations we ended up with the following stochastic linear difference equation

$$y_{t+1} = a_0 + a_2 y_t + e_{t+1} \quad \textbf{(68)}$$

In econometric sense the derived equation (68) presents first-order autoregressive process AR(1) for series y_t with disturbance e_t. It was noted that in case of the Soviet economy the disturbance e_t is driven by shocks to the depletion rate d_t which produces fluctuations in the productivity y_t. It is obvious that d_t is supply disturbance because it directly affects productivity y_t. It can be shown algebraically as well.

We consider supply side only. The aggregate production function for two consecutive periods is:

$$Y_{t+1} = qS_{t+1}^{\alpha_1} K_{t+1}^{\alpha_2} L_{t+1}^{\alpha_3} \quad \textbf{(69)}$$

$$Y_t = qS_t^{\alpha_1} K_t^{\alpha_2} L_t^{\alpha_3} \quad \textbf{(70)}$$

Dividing (69) by (70)

$$\frac{Y_{t+1}}{Y_t} = \frac{qS_{t+1}^{\alpha_1} K_{t+1}^{\alpha_2} L_{t+1}^{\alpha_3}}{qS_t^{\alpha_1} K_t^{\alpha_2} L_t^{\alpha_3}} = \left(\frac{S_{t+1}}{S_t}\right)^{\alpha_1} \left(\frac{K_{t+1}}{K_t}\right)^{\alpha_2} \left(\frac{L_{t+1}}{L_t}\right)^{\alpha_3} \quad \textbf{(71)}$$

or

$$Y_{t+1} = (1 + r - d_t)^{\alpha_1} Y_t \left(\frac{K_{t+1}}{K_t}\right)^{\alpha_2} g_N^{\alpha_3} \quad \textbf{(72)}$$

Dividing by K_{t+1}

$$\frac{Y_{t+1}}{K_{t+1}}=(1+r-d_t)^{\alpha_1}\frac{Y_t}{K_t}\left(\frac{K_{t+1}}{K_t}\right)^{\alpha_2-1}g_N^{\alpha_3} \tag{73}$$

and finally

$$y_{t+1}=(1+r-d_t)^{\alpha_1}y_t g_K^{\alpha_2-1}g_N^{\alpha_3} \tag{74}$$

which implies: if d_t increases, then productivity y_{t+1} decreases.

Furthermore, in chapter two it was stated that there is specific value of aggregate shortage h associated with specific price level which is fixed and set below equilibrium level. Relative shortage h_t is a gap between required level of productivity to satisfy aggregate demand and actual productivity. The latter is subject to fluctuations due to changes in depletion rate d_t which is shown above. It implies that any change in d_t affects productivity y_t with following change in the value of the relative shortage h_t. The outstanding role of the depletion rate d_t for dynamics of the Soviet economy can be shown with the help from the following analysis.

It is necessary to present one controversy which arises from analysis of the literature on Soviet economic growth. CIA analysts (1982, 1988, 1991) as well as Kornai and Simonovits (1985) claim that the Soviet economy experienced a kind of regime change in early 1970s along with other socialist economies. For instance, Kornai and Simonovits describe this change as follows:

"*(i) The intensity of shortage in some of the above countries is not decreasing significantly, and in a few of them has markedly increased; (ii) The efficiency of both production and investment in several countries has sharply deteriorated; (iii) The growth of investment, production, and* *consumption has slowed down a lot, and in some cases ceased altogether; (iv) Some socialist countries strive to maintain the rate of growth of capacity by continuously raising the investment ratio - whether this is at the cost of restricting consumption or of intensifying shortage" (Kornai and Simonovits, 1985, p.3)*

They call this state in a socialist economy a *chronic shortage* state. Furthermore, Simonovits (1992) claims that socialist economies have experienced constant structure in 1960-1972, period of slowdown in 1973-1978 and stagnation in 1979-1988[17].

On the other hand, a few prominent Soviet economists (Khanin, Selyunin, Aganbegyan, and others) admitted in late 1980s that the period of slowdown with further stagnation in the Soviet economy had begun since late 1950s - early 1960s. Spulber (1991) summarizes this opinion as follows: *"What is important, however, is that no matter what series one considers, the Soviet economy has been unmistakenly losing its dynamism since the end of the 1950s" (Spulber, 1991, p.158).*

Analysis of the Soviet economic growth presented and used in this study supports the latter viewpoint. Extensive economic growth causes envolvement of more and more natural resources and other factors of production. Extensive extraction and utilization of natural resources is crucial because economic theory states that given assumption of constant technology it is possible to increase inputs of production function in order to achieve increase in output only up to a point. Beyond such a point further increase in inputs results in diminishing returns. In case of natural resources such a statement is a reflection of reality: (i) extensive utilization of nonrenewable

[17] In econometric sense Simonovits' claim can be interpreted as follows: constant structure implies a stationary process around well defined steady state; slowdown and stagnation represent a trending process which results in persistent time series

resources causes necessity for extraction of low-grade deposits with higher marginal extraction cost; (ii) extensive harvesting of renewable resources decreases their natural regeneration. Furthermore, increase of investment in means of production (or capital goods), as a distinguishing feature of the Soviet economy, also leads to increased extraction of natural resources because these two factors of production are complements.

Therefore, eventually extensive economic growth leads to increase in depletion rate d_t with decrease in productivity y_t. In terms of equation (68) we can expect increase in disturbance e_t due to the change in d_t. However, as it was shown in chapter two, change in the depletion rate d_t affects productivity y_t in two ways: (1) through disturbance term e_t; (2) through change in the value of coefficient a_2. The latter implies change in dynamics of the equation (68).

Therefore, in econometric sense diminishing marginal return on resource stock as a factor of production leads to a parameter change in our basic dynamic equation and that is why we expect a structural break in an economy with extensive economic growth. The above discussion of the controversy on Soviet economic growth points at the period of late 1950s - early 1960s as a period of potential structural break. This period was associated with the end of the sixth five-year plan with some dramatic changes for the structure of the Soviet economy. For example, Weitzman (1970) argues that decline in the Soviet post-War productivity lies in the difficulty of substituting capital for labour. Desai (1976) concludes that decline in productivity was not due to substitutional difficulties but rather to a declining growth rate of the unexplained productivity residuals. *Appendix 3C* represents some findings based on analysis of Soviet statistical materials. In order to support the above theoretical discussion, it is necessary to test our hypothesis econometrically.

In general our workable hypothesis is: since late 1950s-early 1960s the extensive economic growth of the Soviet economy has begun to pay off through decrease in efficiency of resource utilization (see *Appendix 3C*). Such a decrease was due to overutilization of natural resource stock $\boldsymbol{S_t}$ which led to its exhaustion. Mathematically it means that the depletion rate $\boldsymbol{d_t}$ has significantly increased affecting both, stochastic disturbance $\boldsymbol{e_t}$ and coefficient $\boldsymbol{a_2}$ which we consider to be a structural break. Eventually upward trending $\boldsymbol{d_t}$ series led to downward trending $\boldsymbol{y_t}$ series. Simonovits (1992), describing the period of slowdown in a socialist economy, writes: "*The period of slowdown is characterized by time variant structure of an economy... When the structure of the economy is time variant, the concept of normal [shortage] path cannot be defined*". Therefore, there has not existed the normal shortage path in the Soviet economy as it is defined by Kornai (1982) since the structural change.

So, the structural change in the Soviet economy which led to severe (chronic) shortages later on is associated with extensive growth. The extensive growth resulted in diminishing productivity of the resource stock due to its overdepletion under relatively constant technology ($\boldsymbol{q = const}$). Resource stock is an input in the Soviet aggregate production function. According to microeconomic theory, *if equal increments of an input are added, the resulting increments of product will decrease beyond some point under the assumption of constant technology* which is the law of diminishing marginal returns. Therefore, extensive economic growth inevitably leads to diminishing marginal returns on resource stock utilization as a factor of production. This is a very important feature of the Soviet economy. Even Simonovits (1992) admits: "*Note that the neglect of resources in these models prevents us from analysing an important feature of the extensive growth: the increasing relative utilization of resources" (p.81).* This study does take this important feature into account through depletion rate $\boldsymbol{d_t}$. Moreover, it appears that it is this feature that is in the heart of the break in the

Soviet economy's growth in the late 1950s-early 1960s. The structural change caused the appearance of a negative trend in the productivity series y_t (diminishing marginal returns) due to increasing d_t which explains supply disturbances with long-run permanent effects (see diagram 3.3).

Equation (68) was written for next period productivity y_{t+1}. We can use the same form of equation in order to test for the structural change. In this regard equation (68) lagged once is

$$y_t = a_0 + a_2 y_{t-1} + e_t \tag{75}$$

However, before testing for structural change, let us pre-test the productivity series y_t for a unit root over the period from 1950 to 1985, or before the Chernobyl accident, with Dickey-Fuller (1979) test (DF)[18]. Our test model is:

$$\Delta y_t = a_0 + \alpha y_{t-1} + e_t \tag{76}$$

where $\alpha = a_2 - 1$. We do not include time trend component in the test because series y_t represent the ratio Y_t/K_t. It means that the series y_t is already adjusted for the time trend since the ratio Y_t/K_t may be viewed as removal of a common time trend from series Y_t and K_t. *Appendix 3D* and diagram 3.3 present numerical values of the productivity series y_t over the period from 1950 to 1985.

The result of two-tail DF-test is

$$y_t = -0.014067 + 0.03188 y_{t-1} \tag{77}$$

with t_α - *statistic* = *1.704* and critical values of 3.629, 2.947 and 2.612 at 1%, 5% and 10%

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[18] The use of DF instead of augmented DF or ADF is based on econometric testing. Application of ADF rejected all lags of the term Δy based on Akaike and Schwartz criteria as well as t-statistic and maximum liklihood

significance levels respectively. Therefore, we cannot reject the unit-root hypothesis at any significance level.

Furthermore, it looks like the series y_t is driven by a random walk with drift process during period of 1950-1985. However, positive t_α *- statistic* is a good indicator of a possiblity that the model (77) is not correct. Moreover, our theoretical discussion suggests a structural change in the Soviet economy in the late 1950s-early 1960s. According to this discussion, our hypothesis can be re-formulated as follows: *the structural change in the Soviet economy which occurred in the late 1950s-early 1960s led to a regime switch from a stationary process to a non-stationary process in productivity series* y_t.

Therefore, the null hypothesis is a random walk with drift that excludes any structural change. The alternative hypothesis is a stationary process before the structural change at some unknown point and random walk with drift afterwards. Moreover, we expect the drift to be negative as a consequence of increasing depletion rate d_t.

Several works in the econometric literature consider the problem of testing for structural change with unknown changepoint. The most cited ones are Zivot and Andrews (1992), Ploberger, Kramer and Kontrus (1989), Andrews (1989), Chu (1989) and Hansen (1992). The problem which is considered in this study is more complex than those of the above mentioned works. Nonetheless, it is possible to make use of the existing methodologies with some adjustments. In this regard, the test strategy described by Zivot and Andrews (1992) was chosen for this study.

Zivot and Andrews revise Perron's (1989) findings associated with the Great Crash of 1929 and the Oil-Price Shock of 1973. In their opinion, Perron's conclusions are biased because they are based on pre-specified breakpoints. Instead, Zivot and Andrews propose a test strategy for endogenous breakpoint. Estimation procedure represented below makes use of some attractive features of this strategy.

Zivot and Andrews choose the following model for the null hypothesis

$$y_t = a_0 + y_{t-1} + e_t \tag{78}$$

which completely suits our null hypothesis described earlier - random walk with drift that excludes any structural change. We also accept their assumption that the breakpoint is the point that gives the least favourable result for the null hypothesis. According to Zivot and Andrews, the minimum value of t_α *- statistic* where $\alpha = 1 - a_2$ is associated with the breakpoint in the following model[19]

$$y_t = a_0 + a_1 D_L + a_2 y_{t-1} + e_t \tag{79}$$

where D_L is a level dummy which takes on value 1 if $t > T_B$ and 0 otherwise; T_B is a break-year. T_B varies from $T_B = 2$ up to $T_B = T - 1$ where T is sample size.

However, model (79) is not useful for our alternative hypothesis. Thus instead we introduce the following model as the alternative:

$$H_1 : y_t = a_0 + a_1 D_L + a_2 y_{t-1} + a_3 D_L y_{t-1} + e_t \tag{80}$$

Moreover, according to our alternative hypothesis the sum of coefficients a_2 and a_3 should be equal to unity which transforms the alternative into

$$H_1 : y_t = a_0 + a_1 D_L + a_2 y_{t-1} + (1 - a_2) D_L y_{t-1} + e_t \tag{81}$$

[19] Once again we omit time trend because of the reasons described earlier

According to H_0 and H_1, the testing strategy should be: *test* $H_0: a_1 = 0$ *and* $a_2 = 1$ which gives us model (78). In order to be able to use DF-test statistic to test H_0, we transform our model (81) under H_1 as follows.

Subtracting y_t from both sides

$$y_t - y_{t-1} = a_0 + a_1 D_L + a_2 y_{t-1} - y_{t-1} + (1 - a_2) D_L y_{t-1} + e_t \qquad \textbf{(82)}$$

Rearranging

$$\Delta y_t = a_0 + a_1 D_L + (a_2 - 1) y_{t-1} - (a_2 - 1) D_L y_{t-1} + e_t \qquad \textbf{(83)}$$

where $\Delta y_t = y_t - y_{t-1}$. Introducing $\alpha = a_2 - 1$, we end up with the following model for our alternative hypothesis:

$$\Delta y_t = a_0 + a_1 D_L + \alpha (y_{t-1} - D_L y_{t-1}) + e_t \qquad \textbf{(84)}$$

Testing $H_0: a_1 = 0$ *and* $\alpha = 0$ is the same as the null hypothesis specified above.

Following Zivot and Andrews, it is possible to run a sequence of regressions (84) each of which is associated with specific T_B. However, their criterion of minimum t_α ***- statistic*** is necessary but not sufficient for a break point to exist. According to our specification of the H_1, the sufficiency condition is $|t_{a1}| > 2$.

Therefore, if we apply the necessary and sufficient condition which is minimum t_α plus $|t_{a1}| > 2$ to a sequence of regressions (84), we will be able to test our hypothesis - structural break at some unknown point with stationary AR(1) process before the break and random walk with drift afterwards.

Table 3.10 represents the estimation results of the model (82) with OLS for different break-years.

Table 3.10. Results of the estimation of model (82)

Break-year	***t_{al} - statistic***	***t_{α} - statistic***	***Break-year***	***t_{al} - statistic***	***t_{α} - statistic***
1952	-0.528	-0.499	1969	1.031	1.204
1953	-1.038	-1.004	1970	0.720	0.939
1954	-0.773	-0.726	1971	0.810	1.047
1955	-0.301	-0.221	1972	1.392	1.590
1956	-0.292	-0.161	1973	0.998	1.257
1957	-1.983	-1.853	1974	1.217	1.472
1958	-1.963	-1.791	1975	1.611	1.830
1959	-2.768	-2.607	1976	1.414	1.676
1960	**-2.895**	**-2.754**	1977	1.385	1.671
1961	-2.492	-2.377	1978	1.478	1.764
1962	-1.331	-1.242	1979	1.731	1.970
1963	0.479	0.550	1980	1.529	1.826
1964	0.218	0.324	1981	1.387	1.746
1965	0.698	0.810	1982	1.144	1.637
1966	0.649	0.786	1983	0.843	1.550
1967	0.495	0.663	1984	0.630	1.579
1968	0.438	0.635			

The table indicates 1960 as the break-year according to our criterion[20]. The DF - statistic t_{α} = ***-2.754*** means: we reject H_0 at 10% significance level because the critical value at this level is ***-2.612.***

[20] As far as stationarity is concerned, positive values of t_{α} *- statistic* can be excluded from consideration. Nonetheless, it is necessary to admit that t_{α} = ***-2.754*** in 1960 represents the highest absolute value within 1952-1984 interval which indicates the year of 1960 as the break-year even if two-tail DF-test is employed

The ***p-value*** for t_α ***- statistic*** is ***0.0788*** which means that we accept our hypothesis at 92% confidence interval which is a very good result taking into account small sample size and precision of the Soviet data.

The above estimation procedure leads to the selection of the following model (with ***t-values*** in parenthesis):

$$y_t = 0.165471 - 0.172406D_L + 0.55141y_{t-1} + 0.44859D_L y_{t-1} \qquad \textbf{(85)}$$
$$(2.779) \qquad (-2.895) \qquad (3.386)$$

where $a_2 + a_3 = 1$ and $D_L = 1$ if $t > 1960$ and 0 otherwise. In order to support model (85), we test the restriction $a_2 + a_3 = 1$. The restricted model is (85) with sum of squared residuals equal to *0.000808* and unrestricted model is

$$y_t = 0.165471 - 0.166113D_L + 0.55141y_{t-1} + 0.425527D_L y_{t-1} \qquad \textbf{(86)}$$
$$(2.788) \qquad (-2.786) \qquad (3.398) \qquad (2.601)$$

with sum of squared residuals equal to *0.000777*. ***F*** - statistic[21] is equal to *1.277* and critical value of $\chi_{36}^2 = \mathbf{18.493}$ at 5% significance level. It means that we accept restriction $a_2 + a_3 = 1$. Estimation of model (85) shows that all parameters are significant which supports our hypothesis re-stated below:

The productivity series y_t in the Soviet economy had followed a stationary AR(1) process

$$y_t = 0.165471 + 0.55141y_{t-1} \qquad \textbf{(87)}$$

[21] F = [(T-K)/R]*[(RSSR-USSR)/USSR] = [(36-4)/1]*[(0.000808-0.000777)/0.000777] = 1.277

during 1950-1960. The structural break which occurred in 1960 led to random walk with negative drift process for the period of 1961-1985 which is[22]

$$y_t = -0.006935 + y_{t-1} \tag{88}$$

However, there is a necessity to test series y_t for a unit root over period of 1961-1985. The results of this estimation using augmented Dickey-Fuller test (1979) are presented below:

$$\Delta y_t = -0.001047 - 0.026187 y_{t-1} - 0.182332 \Delta y_{t-1} \tag{89}$$

with Augmented Dickey-Fuller (ADF) test statistic ***-1.37792*** and critical values of ***-3.7204***, ***-2.9850***, ***-2.6318*** at 1%, 5% and 10% significance levels respectively. Therefore, we cannot reject the hypothesis of a unit-root process during 1961-1985 at any significance level.

In order to be precise about random walk with drift process over 1961-1985, it is necessary to test series y_t in first differences over this period. This series should be stationary which implies that the original series y_t is ***I(1)*** or integrated of order one. The ADF unit-root test for Δy_t series for 1961-1985 period gives the following results:

$$\Delta^2 y_t = -0.008658 - 1.248833 \Delta y_{t-1} + 0.106108 \Delta^2 y_{t-1} \tag{90}$$

with ADF test statistic ***-3.921094***. It means that the hypothesis of a unit-root in series Δy_t for period 1961-1985 must be rejected. Thus, the productivity series y_t for 1961-1985 period is driven by

[22] In fact equation (88) was estimated. Estimation showed that *t*-statistic of the trend is -7.68 and *p*-value is 0.008804 which indicates significance of the drift

random walk with drift process represented by (88).

Conclusion

The period of 1950-1960 in the Soviet economy is characterized by steady economic growth with time invariant steady state which is associated with path of normal shortage. In turn, the period of 1961-1985 is characterized by non-stationary process, in particular random walk with drift. In economic and econometric sense random walk with drift represents two non-stationary components:

1. Deterministic trend ***-0.006935t*** which is long-run effect on productivity due to diminishing productivity of the resource stock. The trend explains supply disturbances and results in appearance of the chronic shortage where chronic shortage is defined as deviation of productivity series y_t from its steady state value y in period 1950-1960.

2. Stochastic trend $\sum e_t$, which is also long-run effect on productivity, presents intensifying fluctuations as a result of supply disturbances because of increasing depletion rate.

However, the main implication of the structural chage is: *the Soviet economy has become unstable since 1960 because its dynamics has been characterized by non-stationary process in productivity series* y_t.

Appendix 3A

Soviet macroeconomic variables by end use in constant 1973 prices for 1950-1970 period (billion rubles)

Year	Gross output	GNP	Investment	Consumption
1950	255.5	152.8	36.77	99.8
1951	275.9	165.5	40.63	102.0
1952	293.5	176.9	43.64	105.5
1953	310.6	186.6	44.21	115.5
1954	333.2	202.0	50.48	122.1
1955	356.6	217.9	54.73	118.3
1956	381.5	233.8	60.64	120.5
1957	397.5	240.8	65.85	125.7
1958	420.2	261.1	73.88	128.1
1959	440.8	270.2	80.68	125.3
1960	456.7	280.2	84.31	128.3
1961	473.6	290.6	85.07	137.6
1962	492.1	297.3	86.35	142.7
1963	498.0	299.0	87.81	145.0
1964	518.0	316.7	92.56	150.2
1965	533.5	328.8	97.18	162.3
1966	560.1	343.2	100.7	169.2
1967	596.5	361.0	105.6	176.8
1968	638.3	378.7	110.4	190.7
1969	652.6	384.0	110.3	197.8
1970	682.6	405.5	119.3	205.1

Soviet macroeconomic variables by end use in constant 1973 prices for 1971-1985 period (billion rubles)

Year	Gross output	GNP	Investment	Consumption
1971	716.4	420.8	122.7	212.6
1972	730.3	424.6	120.8	217.3
1973	770.9	449.0	134.6	222.9
1974	798.6	459.0	136.8	228.3
1975	820.8	463.3	132.7	233.6
1976	845.4	481.6	142.2	239.8
1977	865.6	495.0	149.6	244.7
1978	886.1	503.7	150.9	248.8
1979	885.9	506.2	148.4	252.8
1980	901.3	519.3	147.8	280.0
1981	914.4	529.5	150.6	265.8
1982	936.4	541.2	160.1	263.6
1983	960.4	551.5	165.8	266.6
1984	972.6	554.9	162.9	270.9
1985	978.5	552.2	156.3	271.8

Appendix 3B

Capital stock in constant 1973 prices for 1950-1985 period (billion rubles)

Year	Capital stock
1950	440.0
1951	465.6
1952	492.6
1953	521.1
1954	551.4
1955	583.3
1956	617.2
1957	653.0
1958	690.8
1959	730.9
1960	773.3
1961	822.0
1962	873.8
1963	928.8
1964	987.4
1965	1049.7
1966	1111.9
1967	1177.5
1968	1247.0
1969	1320.5
1970	1398.4
1971	1481.6

1972	1570.9
1973	1665.1
1974	1759.6
1975	1858.8
1976	1963.4
1977	2068.6
1978	2175.4
1979	2284.0
1980	2389.4
1981	2493.9
1982	2599.2
1983	2704.6
1984	2813.5
1985	2922.1

Appendix 3C

Based on Soviet statistical material, in particular *Narodnoye Khozyaistvo SSSR 1922-1972. Moscow: Statistika, 1972* and *Narodnoye Khozyaistvo SSSR za 70 let. Moscow: Finansy i Statistika, 1987*, the following table was derived:

Years	Annual increase of arable land,%	Annual increase of labour force,%	Annual increase of extraction of non-renewable resources, %	Annual increase of livestock, %	Annual increase of timber stock, %
1950s	1.5	1.4	8.3	2.5	3.3
1960s	0.2	2.4	5.8	2.4	0.4
1970s	0.5	1.6	4.5	1.5	0.6
1980s	-0.7	0.7	1.8	0.5	0.4

The table shows declining growth rates of some inputs of the aggregate production function - first of all in terms of utilization of the natural environment. Such a situation leads to decrease in productivity of the natural environment as well as the economy as a whole. This result is due to intensifying depletion of natural resource stock during rapid extensive economic growth of the 1950s and zero prices of the natural resources which eventually led to overutilization of the stock. By 1960 low marginal extraction cost deposits of non-renewable resources have been developed, new arable land has been brought under production, deforestation has resulted in decrease of the natural growth rate of timber biomass, etc. This points at the period of the late 1950s - early 1960s as a possible structural change in the Soviet extensive economic growth.

Appendix 3D

Productivity series y_t over the period from 1950 to 1985

Year	y_t
1950	0.347273
1951	0.355455
1952	0.359156
1953	0.358185
1954	0.366268
1955	0.373581
1956	0.378840
1957	0.368806
1958	0.377910
1959	0.369681
1960	0.362343
1961	0.353479
1962	0.340181
1963	0.321953
1964	0.320711
1965	0.312242
1966	0.308625
1967	0.306590
1968	0.303681
1969	0.290799
1970	0.289974
1971	0.284017
1972	0.270291

1973	0.269653
1974	0.260855
1975	0.249247
1976	0.245289
1977	0.239292
1978	0.231544
1979	0.221629
1980	0.217335
1981	0.212318
1982	0.208218
1983	0.203912
1984	0.197228
1985	0.188974

CHAPTER FOUR
MODELLING THE ENVIRONMENTAL SHOCK

The chapter presents a theoretical and econometric analysis of the Chernobyl accident as an adverse supply shock in the Soviet economy, based on the previously derived dynamic structure of this economy at the time of the accident. The major attributes of the Chernobyl shock are identified. These attributes are used to set up an econometric model to study the consequences of the shock. The direct impact of the Chernobyl accident in 1986 is estimated using Vector Autoregression analysis. The simulated time path of the productivity series over 1986-1990, based on the estimated Vector Autoregression, is compared with actual time path over the same period.

Partial Impulse Response Functions (IRF) are obtained by imposing the derived direct impact on the Vector Autoregression, and inverting it into Vector Moving Average form. Based on the partial IRF for productivity of the Soviet economy, the consequences of the shock are presented as deviations from potential time path of the productivity series without shock.

The major conclusion reached in this chapter is: the Chernobyl adverse supply shock has a permanent impact on the economy's productivity because the structure of the Soviet economy at the time of accident was characterized by a dynamic process with long memory, i.e. random walk with drift, which generated nonstationary productivity series. The conclusion is supported by explosive cyclical pattern of the IRF of productivity.

4.1. The large environmental impact as adverse supply shock

Previously it was noted that the large environmental impact has immediate negative effect on the natural environment with long-lasting consequences. In this study the depletion rate d_t was introduced to reflect changes in the natural environment by incorporating resource flow R_t and resource stock S_t at the same time. It is assumed that the large environmental impact is expressed through one-time increase in the value of d_t which immediately decreases the resource stock available for production in the period t with some changes in resource flow as well. Therefore, the direct impact of the Chernobyl accident was a one-time increase in the value of d_t. In chapter three it was shown that in general d_t series are responsible for supply disturbances in productivity series y_t of the Soviet economy. Thus, any large environmental impact in general, and the Chernobyl accident in particular is an adverse supply shock.

In explaining fluctuations in productivity, the RBC proponents have emphasized shifts of the real aggregate supply curve due to technological shocks (Kydland and Prescott, 1982; Plosser, 1989). Recently Hansen and Prescott (1993) have widened the interpretation of technological shocks so that " any changes in the production function or, more generally, the production possibility sets of the profit centres" can be regarded as a potential supply shock. The work of the RBC school and critique of this approach by other schools of economic thought (first of all by New-Keynesians) led to the following four stylized facts (for more see Snowdon, Vane and Wynarczyk, 1995):

1. Fluctuations in aggregate output are temporary deviations around a trend which underlies the natural rate of growth.

2. Technological progress is the determinant of the trend.

3. Aggregate instability from business cycles is socially undesirable.

4. Monetary factors are an important factor when it comes to explaining the business cycles.

How do these stylized facts fit into the Soviet economy?

First, it was shown that extensive economic growth is the determinant of the negative trend in the Soviet economy over 1961-1985 due to diminishing productivity of the natural resource stock. Second, fluctuations in productivity of the Soviet economy around the trend are permanent. According to these two statements, the following question arises: What really happened in the Soviet economy in 1960-1961 that resulted in regime change? The answer to this question is important to learn some lessons needed for the analysis of the Chernobyl accident as adverse supply shock.

In this regard it is possible to identify at least three macroeconomic aspects of the change:

1. The extensive economic growth used itself up by 1960. Almost all deposits of non-renewable resources with low marginal extraction cost as well as new available arable land were brought under production[23]. The diminishing productivity of the natural resource stock given constant technology has begun to dominate. It resulted in downward trend in the economy's productivity. Was it supply shock? According to the definition presented at the beginning of this section the answer is yes, if the supply shock is regarded as increase in cost of raw materials associated with higher extraction cost.

2. Monetary reform of 1961 mentioned in chapter 3 can be considered as demand shock which, to some degree, reflects the fourth stylized fact. The reform, which was actually a confiscation of cash holdings, negatively affected the desired level of personal consumption and resulted in change of the aggregate shortage value. From econometric viewpoint it might cause changes in pattern of deviations of productivity series y_t from steady state. As a result, both shocks combined have

[23] In the 1950s even marginal land in Kazakstan, the so-called "tselina" was recultivated

produced the chronic shortages in the Soviet economy since 1961.

3. Also it is necessary to bring in one more aspect. The end of the "Khruschev's spring"[24] by 1960 and monetary reform of 1961 resulted in the formation of pessimistic expectations in Soviet society. Since 1961 the majority of the Soviet population has given up their beliefs in ability of the Soviet government to provide "bright future" through the movement towards communism. Per capita consumption has begun to decline. Even though such a psychological aspect is difficult to measure, nonetheless it should be mentioned. However, we leave this aspect aside in this study.

Therefore, the structural change in 1960-1961 was due to two shocks - supply and demand, which is expressed in two non-stationary trends of random walk with drift process over period of 1961-1985: drift or deterministic trend and stochastic trend of error terms or fluctuations around drift. It gives us the required framework for the analysis of the Chernobyl accident as the supply shock.

Frisch (1933) subdivided all supply shocks as being driven by either impulse or propagation mechanisms. However, propagation mechanism also includes impulse as initial source. An impulse initiates a shock to cause a variable (say productivity) to deviate from its steady state value. If the deviations vanish over time, the initial shock is temporary. Propagation mechanism consists of those forces which carry the effects of the initial shock forward through time and cause the deviations from the steady state to persist. In such a case it said that the series carry long memory (see Peters, 1994).

Therefore, in an economic sense the decreasing deterministic trend in the productivity series y_t describes long-run properties of the model while the stochastic trend (fluctuations around the deterministic trend) describes short-run properties. Both have permanent negative effect on

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[24] The term "Khruschev's spring" relates to a significant decrease in state control over such fields of human activity as arts and science after famous 20th Congress of the Communist Party of the Soviet Union in 1956

productivity which means presence of a long memory in the economic dynamic system.

The other feature of a persistent time series is long-run correlation between current events and future events which means autoregressive nature of a system characterized by such persistent series. It justifies extending the process of long memory into the future to generate potential time path of the Soviet economy without the Chernobyl accident. It is a kind of counterfactual approach of the new economic historians (see, for example, McClosky, 1972) because it is characterized by a statement "what would be if...".

Two points follow from the above discussion: (i) it is possible to predict potential time path of a system driven by dynamic process with long memory; (ii) any shock to such a system is permanent. In this regard, the Chernobyl accident being adverse supply shock in the Soviet economy should affect the deterministic trend (one-time increase in the value of depletion rate $\boldsymbol{d_t}$) with secondary effect on stochastic trend because of the change in the value of net aggregate shortage $\boldsymbol{h_t}$. We call this secondary effect a *spillover effect*. As noted earlier, from econometric viewpoint both trends (drift and stochastic trend $\sum \boldsymbol{e_t}$), contained in a random walk with drift process of productivity series y_t of the Soviet economy, are non-stationary and, therefore, it is expected that the Chernobyl accident has had permanent effect for the structure of the Soviet economy.

The general effect of an environmental shock like the Chernobyl accident in the Soviet economy is explained below using the simple static diagram 4.1.

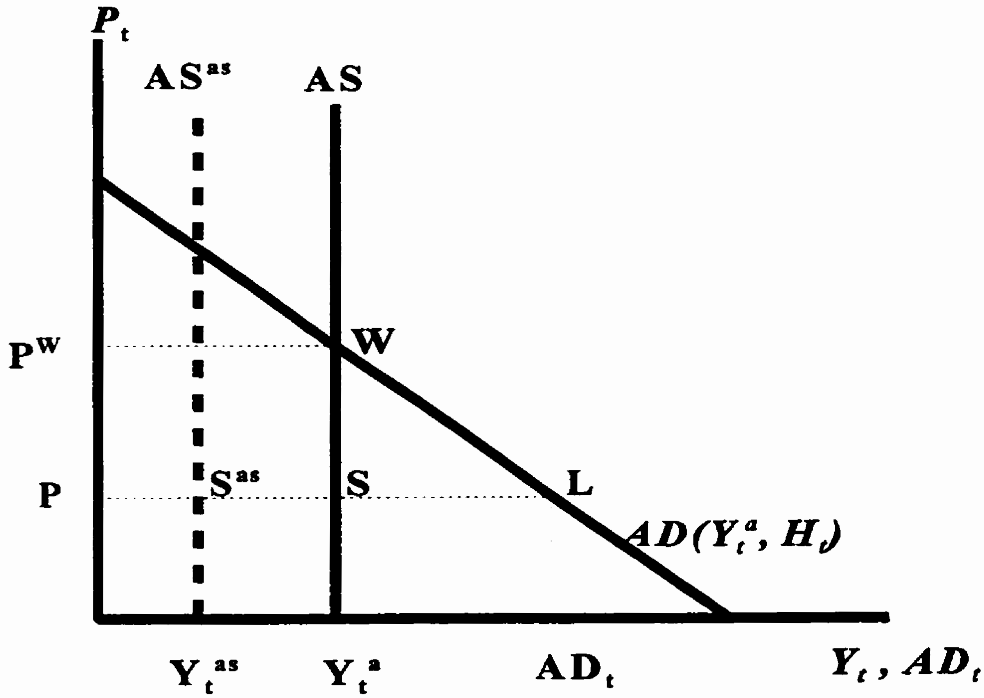

Diagram 4.1. After shock adjustment in Soviet economy

The Chernobyl accident immediately affected natural resource stock S_t in period t with following change in resource flow R_t. It resulted in one-time increase in the value of depletion rate d_t which, in turn, decreased productivity y_t. Graphically the Chernobyl shock caused leftward shift of the aggregate supply AS to AS^{as} (after-shock aggregate supply). From diagram 4.1. it is obvious that the value of net aggregate shortage H_t (distance SL) increased to $H_t^{as} = AD_t - Y_t^{as}$ (distance $S^{as}L$). Point S^{as} on diagram 4.1 presents new equilibrium of the Soviet macroeconomic system after the Chernobyl shock.

This is the general adjustment mechanism after a supply shock in the Soviet economy. However, the dynamic consequences of the environmental shock are more complicated. In general it appears that the dynamics of the environmental shock is more complicated than the dynamics of the pure technological shock. This statement follows from the analysis of the general macroeconomic consequences of the Chernobyl accident in the Soviet economy presented below.

The accident immediately affected the natural resource stock available for production through direct contamination of soil, water resources and air as components of the ecological and economic systems. It also affected humans in two ways: (i) the accident caused reallocation of victims as well as reallocation of labour force to fight the immediate consequences; (ii) the accident caused some immediate deaths and deterioration of health conditions of many people afterwards. There was another macroeconomic consequence which was associated with a necessity to redistribute and increase investment required for liquidation of the direct consequences of the accident.

Futhermore, by its nature the Chernobyl accident has had accumulative character since then because of physical properties of radioactive contaminants. Hence, the negative effects enumerated above have been carried forward through time. This analysis gives us the following attributes of the Chernobyl supply shock:

(1) immediate negative impact on resource stock as an environmental input in aggregate production function;

(2) immediate spillover effect on other inputs of the aggregate production function - labour and capital;

(3) long-lasting autoregressive effect on the entire macroeconomic system carried by interdependent macroeconomic variables.

Some of these attributes are unique for the Soviet economy in comparison with a market one. Chapter five compares consequences of the large environmental shock in Soviet economy with those of a market economy. The above enumerated attributes suggest to construct Vector Autoregression for macroeconomic variables of interest first, impose the direct environmental impact second, and trace the effects of the impact (shock) over time afterwards. Therefore, it is necessary to derive the direct impact of the Chernobyl accident in 1986.

4.2. The direct impact of the Chernobyl accident

In this section direct damage to the natural resource stock $\boldsymbol{S_t}$ with further effect on resource flow $\boldsymbol{R_t}$ is viewed as the direct impact of the Chernobyl accident. It results in a one-time increase in the depletion rate $\boldsymbol{d_t}$. In order to derive this value, two approaches can be applied.

A. Direct Approach

By definition depletion rate $\boldsymbol{d_t}$ is

$$d_t = \frac{R_t}{S_t} \tag{91}$$

where $\boldsymbol{R_t}$ is annual level of resource utilization; $\boldsymbol{S_t}$ is resource stock. Adverse environmental shock results in one-time increase in depletion rate $\boldsymbol{d_t}$ which in case of the Chernobyl accident is explained as follows.

According to (91), change in depletion rate or $\Delta \boldsymbol{d_t}$ is

$$\Delta d_t = \frac{1}{S_t}(\Delta R_t - \frac{R_t}{S_t}\Delta S_t) \tag{92}$$

where $\Delta \boldsymbol{R_t}$ is change in resource utilization due to adverse environmental shock; $\Delta \boldsymbol{S_t}$ is decrease in resource stock due to adverse environmental shock. Our analysis of the environmental consequences of the Chernobyl accident presented in section 1.1 suggests that ΔR_t consists of two components:

- increase in extraction of non-renewable resources to make up for the loss of one billion kwt-hours of nuclear electricity;
- decrease in harvesting of renewable resources (loss of agricultural production as well as production of forestry and fisheries).

In turn, ΔS_t consists of at least four components:

- loss of arable land;
- loss of livestock;
- loss of fish stock;
- loss of timber biomass.

The overall effect of the Chernobyl shock is obviously an increase in the value of d_t or $\Delta d_t > 0$ in 1986. In principle, it is possible to estimate all direct consequences of the Chernobyl accident specified above in order to obtain the value of Δd_{86} according to (92).

However, such a process requires additional information on direct consequences of the Chernobyl accident for the natural environment. An extensive literature review reveals that the exact consequences for the natural environment are re-estimated each year with unfolding of new information. For example, the OECD (1995) emphasizes that "*nine years after the Chernobyl disaster, scientific data for remedial and recovery programmes still need to be assembled and evaluated*". In RADNET (1996) we find the following: "*A reconsideration of the accident ten years later can only conclude that accurate information is still unavailable about actual deposition levels over vast areas...* ". And finally, Sich (1996) brings in one more argument for inaccuracy of the data on the Chernobyl accident: "*The manner in which some international organizations have dealt with* *the accident over past ten years has strengthened in me the conviction that, sadly, scientific inquiry and politics are inextricably linked...".*

Therefore, there does not exist the exact set of such estimates at the present moment. Moreover, discrepancies among existing estimates are large which makes them unreliable in general. While the framework described above can be applied when more accurate data become available, another approach was chosen in this study.

B. Simulation Approach

In the previous section three major attributes of the Chernobyl shock were identified:

(i) an immediate negative impact on the natural resource stock which is environmental macroeconomic variable;

(ii) an immediate spillover effect on macroeconomic inputs of the aggregate production function - capital and labour;

(iii) an autoregressive effect on the economic system of interdependent macroeconomic variables. The direct impact on the natural resource stock S_t with the following change in resource flow R_t is captured by a one-time increase in the value of d_t in 1986. The spillover effect results in changes in growth rate of labour force g_N and growth rate of capital g_K Eventually all the above affects productivity of the Soviet economy y_t. The autoregressive effect is carried by all enumerated variables over time. Therefore, it is possible to construct the Vector Autoregression (VAR), impose the shock Δd_{86} on y_{86} and trace the consequences of the shock over time with the help from the VAR. By assigning different values for Δd_{86}, it is possible to find time path that the best resembles the real time path over 1986-1990[25]. The value of Δd_{86} associated with such a path is the value of the direct impact. However, in order to detect the Chernobyl shock through simulation approach, it is necessary to separate two impacts that occurred almost at the same time: (1) restructuring of the Soviet economy since 1985 (the so-called *perestroika*); (2) the Chernobyl accident of 1986. In this study the following approach was chosen to separate the two.

According to Desai (1989), perestroika resulted in the freeing of wages and loss of "ruble control". Eventually this caused dramatic levels of inflation in 1986-1990. Therefore, we use GNP in established prices over period 1986-1990 and extend inflation of early 1980s, calculated by Steinberg (1990), to derive deflators for this period. Using these deflators we obtain new productivity series for period 1986-1990 which carry the environmental shock only. In such a case we remove only the so-called *guaranteed inflation*, and do not change the time path of real GNP. In other words, by extending only inflation that has already existed over 1980-1985 into 1986-1990 we artificially remove the economic impact which was caused by perestroika and which resulted in dramatic levels of inflation in 1986-1990. The extended guaranteed inflation captures the major dynamic features of the Soviet economy as they have been before Gorbachev's perestroika.

Thus, we construct the following 3×1 column vector x_t

$$x_t = \begin{pmatrix} y_t \\ g_{Kt} \\ g_{Nt} \end{pmatrix} \tag{93}$$

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[25] Once again it is necessary to emphasize that we are restricted by only five years of real data after the accident

Using the data over period of 1950-1985, derived in section 3.1, it is possible to estimate the VAR in general form as

$$x_t = A_0 + \sum_{i=1}^{p} A_i x_{t-i} + E_t \tag{94}$$

where A_0 and A_i are matrixes of constant terms and coefficients respectively. For example, the first-order VAR is:

$$x_t = A_0 + A_1 x_{t-1} + E_t \tag{95}$$

where A_0 is 3×1 column vector of constant terms, A_1 is 3×3 matrix of coefficients and E_t is 3×1 column vector of error terms. However, because the VAR expresses the interdependent nature of a dynamic system, the error terms in vector E_t

$$E_t = \begin{pmatrix} e_{yt} \\ e_{Kt} \\ e_{Nt} \end{pmatrix} \tag{96}$$

are composites of three elementary shocks η_{yt}, η_{Kt} and η_{Nt} which is shown rigorously later on. The supply shock Δd_{86} directly affects productivity y_{86} which is reflected in elementary shock η_{yt} with spillover effect on g_{Kt} and g_{Nt} through e_{Kt} and e_{Nt}.

In econometric sense it means that constant term a_{0l} in column vector

$$A_0 = \begin{pmatrix} a_{01} \\ a_{02} \\ a_{03} \end{pmatrix} \tag{97}$$

decreases by value of Δd_{86} at the time of impact or

$$y_t = a_{01} + a_{11} y_{t-1} + a_{12} g_{K(t-1)} + a_{13} g_{N(t-1)} - e_{yt} \tag{98}$$

where e_{yt} is a function of Δd_{86}. Then the spillover effect of the shock is captured by e_{Kt} and e_{Nt} which is discussed in the next section. Finally, the dynamic macroeconomic system carries these effects forward over time.

Therefore, it is possible to assign different values for Δd_{86} in order to simulate the time path of the vector x_t over 1986-1990 or after the shock. The econometric justification of the procedure as well as actual estimation are presented in the following section.

4.3. Econometric analysis of the Chernobyl shock

Estimation of equation (95) provides us with 3×1 column vector A_0 and 3×3 matrix A_1 as well as with 3×3 symmetric correlation matrix of error terms P which is

$$\mathrm{P} = \begin{pmatrix} 1 & \rho_{12} & \rho_{13} \\ \rho_{21} & 1 & \rho_{23} \\ \rho_{31} & \rho_{32} & 1 \end{pmatrix} \tag{99}$$

Taking into account the matrix P, it is possible to decompose the 3×1 column vector E_t as follows:

$$\begin{pmatrix} e_{yt} \\ e_{Kt} \\ e_{Nt} \end{pmatrix} = \begin{pmatrix} 1 & \rho_{12} & \rho_{13} \\ \rho_{21} & 1 & \rho_{23} \\ \rho_{31} & \rho_{32} & 1 \end{pmatrix} \times \begin{pmatrix} \eta_{yt} \\ \eta_{Kt} \\ \eta_{Nt} \end{pmatrix} \tag{100}$$

where

$$H_t = \begin{pmatrix} \eta_{yt} \\ \eta_{Kt} \\ \eta_{Nt} \end{pmatrix}$$

is 3×1 vector of independent and identically distributed error terms. We treat these independent error terms as elementary shocks to each of the three macroeconomic variables y_t, g_{Kt} and g_{Nt}. An environmental shock is a one-time elementary shock $\eta_{yt} = \Delta d_{86}$. Therefore, if we set $\eta_{Kt} = \eta_{Nt} = 0$ and $\eta_{yt} = \Delta d_{86}$, then

$$E_t = \begin{pmatrix} e_{yt} \\ e_{Kt} \\ e_{Nt} \end{pmatrix} = \begin{pmatrix} 1 & \rho_{12} & \rho_{13} \\ \rho_{21} & 1 & \rho_{23} \\ \rho_{31} & \rho_{32} & 1 \end{pmatrix} \times \begin{pmatrix} \Delta d_{86} \\ 0 \\ 0 \end{pmatrix} = \begin{pmatrix} \Delta d_{86} \\ \rho_{21}\Delta d_{86} \\ \rho_{31}\Delta d_{86} \end{pmatrix} \tag{101}$$

and $e_{yt} = \Delta d_{86}$, $e_{Kt} = \rho_{21}\Delta d_{86}$ and $e_{Nt} = \rho_{31}\Delta d_{86}$.

The next step is to re-write the VAR in a form of Vector Moving Average (VMA) as follows:

$$x_t = M + \sum_0^{\infty} A_1{}^i E_{t-i} \qquad \textbf{(102)}$$

where $M = (I - A_1)^{-1} \times A_0$ is a 3×1 column vector which stands for the unconditional mean of the process (95).

The VMA form in equation (102) has a very important interpretation: A_1^i is an impulse response of the vector x_t in period i to a one-unit change (impulse) in error terms or when

$$E_t = \begin{pmatrix} 1 \\ 1 \\ 1 \end{pmatrix} = \iota \qquad \textbf{(103)}$$

In econometric literature (see. for example, Enders, 1995) such a function is known as Impulse Response Function (IRF). Here impulse implies a one-time shock. In an economic sense, IRF represents a sequence of short-run impact multipliers after the shock. Let $\phi\ (i)$ be the value of the IRF i periods after the shock which occurred in period t. Then the IRF in general can be written in a matrix form as follows:

$$\phi(i) = A_1{}^i \times E_t \qquad \textbf{(104)}$$

Taking into account (101)

$$\phi(i) = \begin{pmatrix} \phi_1(i) \\ \phi_k(i) \\ \phi_n(i) \end{pmatrix} = \begin{pmatrix} a_{11} & a_{12} & a_{13} \\ a_{21} & a_{22} & a_{23} \\ a_{31} & a_{32} & a_{33} \end{pmatrix}^i \times \begin{pmatrix} \Delta d_{86} \\ \rho_{21}\Delta d_{86} \\ \rho_{31}\Delta d_{86} \end{pmatrix} \qquad \textbf{(105)}$$

At the time of the shock $i = 0$. Therefore, from (105) it follows

$$\phi(0) = \begin{pmatrix} \phi_y(0) \\ \phi_k(0) \\ \phi_n(0) \end{pmatrix} = \begin{pmatrix} \Delta d_{86} \\ \rho_{21}\Delta d_{86} \\ \rho_{31}\,\Delta d_{86} \end{pmatrix} \tag{106}$$

which is the shock (impulse) to the vector x_t in period t.

Then one period after the shock:

$$\phi(1) = \begin{pmatrix} \phi_y(1) \\ \phi_k(1) \\ \phi_n(1) \end{pmatrix} = \begin{pmatrix} a_{11} & a_{12} & a_{13} \\ a_{21} & a_{22} & a_{23} \\ a_{31} & a_{32} & a_{33} \end{pmatrix} \times \begin{pmatrix} \Delta d_{86} \\ \rho_{21}\Delta d_{86} \\ \rho_{31}\Delta d_{86} \end{pmatrix} = \begin{pmatrix} a_{11}\Delta d_{86} + a_{12}\rho_{21}\Delta d_{86} + a_{13}\rho_{31}\Delta d_{86} \\ a_{21}\Delta d_{86} + a_{22}\rho_{21}\Delta d_{86} + a_{23}\rho_{31}\Delta d_{86} \\ a_{31}\Delta d_{86} + a_{32}\rho_{21}\Delta d_{86} + a_{33}\rho_{31}\Delta d_{86} \end{pmatrix} \tag{107}$$

and so on.

As a result we end up with three partial IRFs. in particular ϕ_y, ϕ_k and ϕ_n or responses of all three macroeconomic variables to the environmental shock as adverse supply shock. The impulse response function ϕ_y is of the most interest because it is the response of productivity on the environmental shock that takes into account all attributes of the environmental shock discussed earlier (direct impact. spillover effect and autoregressive long-run effect).

The above discussion suggests the following algorithm for derivation of the direct impact:

1. Estimate matrixes A_0 and A_1 of vector x_t over 1950-1985 period as well as matrix P.

2. Assign value for Δd_{86} in 1986.

3. Generate the time path of the vector x_t after the shock as follows:

- to start, choose the value of x_t in 1985 or

$$x_0 = \begin{pmatrix} y_{85} \\ g_{K85} \\ g_{N85} \end{pmatrix} \qquad \textbf{(108)}$$

- calculate the impact of the shock in 1986 as

$$\begin{pmatrix} y_{86} \\ g_{K86} \\ g_{N86} \end{pmatrix} = \begin{pmatrix} a_{01} \\ a_{02} \\ a_{03} \end{pmatrix} + \begin{pmatrix} a_{11} & a_{12} & a_{13} \\ a_{21} & a_{22} & a_{23} \\ a_{31} & a_{32} & a_{33} \end{pmatrix} \begin{pmatrix} y_{85} \\ g_{K85} \\ g_{N85} \end{pmatrix} - \begin{pmatrix} \Delta d_{86} \\ \rho_{21}\Delta d_{86} \\ \rho_{31}\Delta d_{86} \end{pmatrix} \qquad \textbf{(109)}$$

- generate the time path of x_t for 1987-1990 through

$$x_{t+1} = A_0 + A_1 x_t \qquad \textbf{(110)}$$

where t = *1986*.

4. Compare the generated time path of y_t with real over period of 1986-1990; make adjustment in the value of Δd_{86} and go back to step 3.

5. Chose the value of Δd_{86} using the following criterion:

$$\min \sum (y_t - y_t^d)^2 \qquad \textbf{(111)}$$

where y_t is the real value of productivity; y_t^d is the simulated value of productivity associated with a specific value of Δd_{86} and t = 1986, 1987, 1988, 1989, 1990.

The following diagrams 4.2 and 4.3 present elements of vector x_t as time series. *Appendix E* reproduces numerical values of the vector.

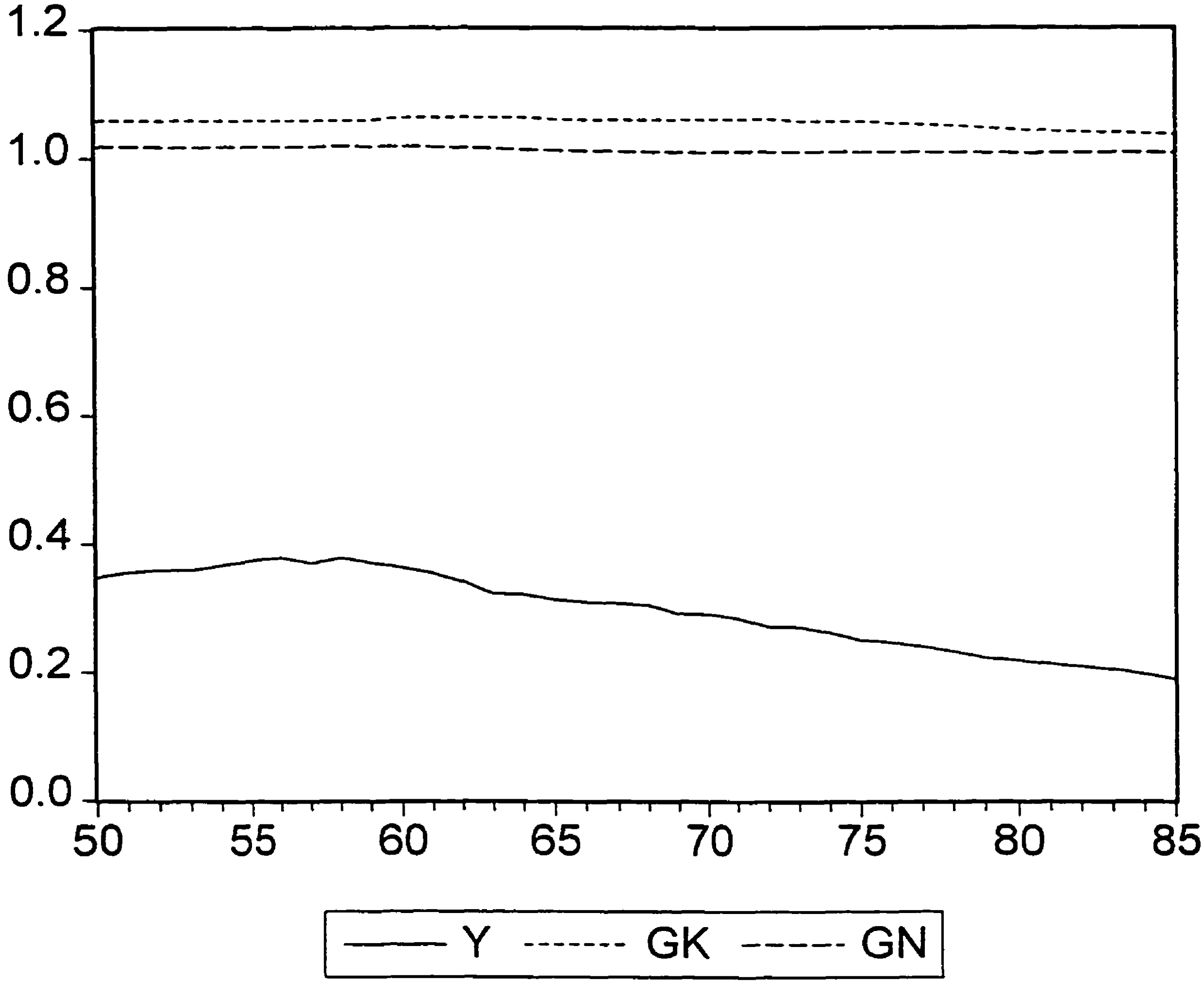

Diagram 4.2. Elements of vector x_t : y = productivity series; gk = growth rate of capital series; gn = growth rate of population series

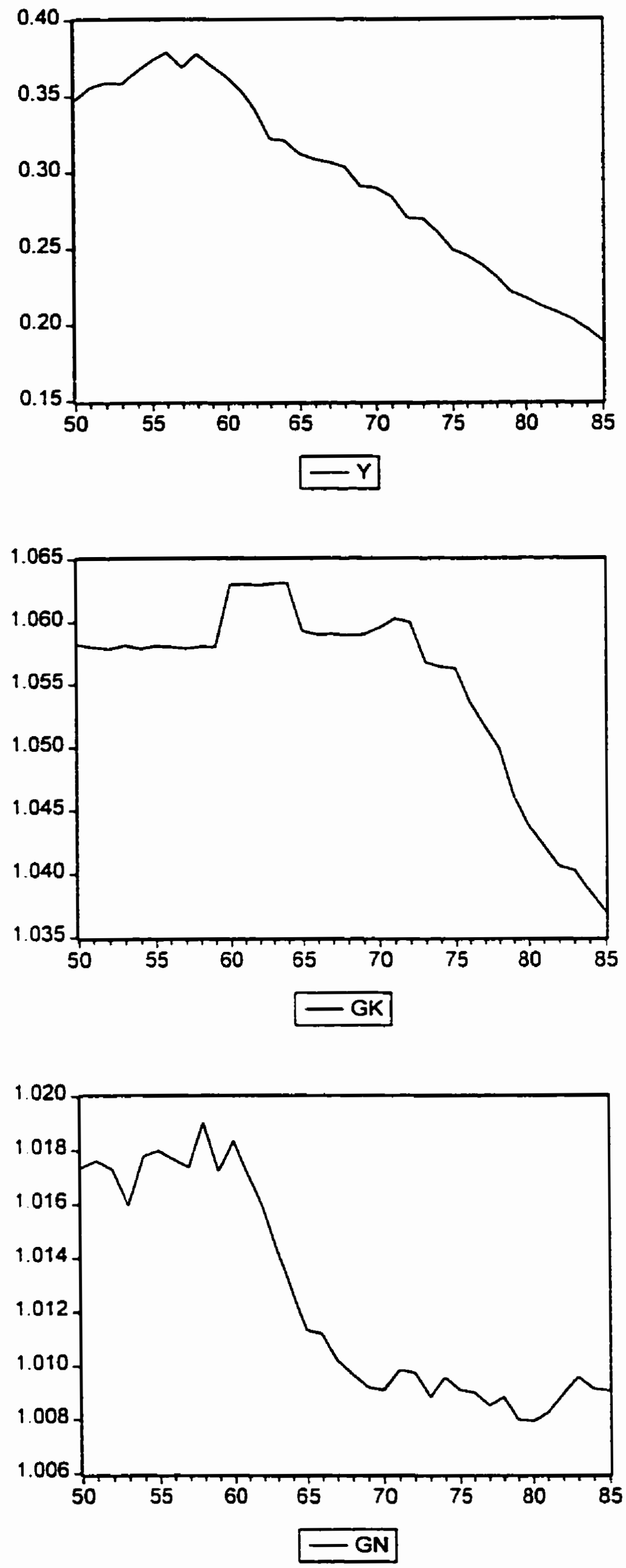

Diagram 4.3. Elements of vector x_t

Realization of the described algorithm brought the following results.

Step 1. *Eviews* produces these parameter estimates:

$$A_0 = \begin{pmatrix} 1.375220 \\ 0.489294 \\ 0.500125 \end{pmatrix} \quad A_1 = \begin{pmatrix} 1.136741 & -0.6637408 & -0.711089 \\ 0.049703 & 0.849102 & -0.341201 \\ 0.033353 & -0.157662 & 0.660352 \end{pmatrix}$$

$$P = \begin{pmatrix} 1 & -0.242002 & 0.430510 \\ -0.242002 & 1 & 0.249118 \\ 0.430510 & 0.249118 & 1 \end{pmatrix} \qquad (112)$$

The diagnostics are presented in table 4.1.

Table 4.1. Results of estimating equation (95) $x_t = A_0 + A_1 x_{t-1} + E_t$

	y_t	g_{Kt}	g_{Nt}
Constant	1.37520 (1.16)	0.489294 (2.05)	0.500125 (3.47)
y_{t-1}	1.136741 (13.53)	0.049703 (2.94)	0.033353 (3.28)
$g_{K(t-1)}$	- 0.663741 (-1.93)	0.849102 (12.25)	- 0.157663 (3.78)

$g_{N(t-1)}$	- 0.711089 (-0.78)	- 0.341201 (-1.85)	0.660352 (5.94)
Adjusted - R^2	0.98969	0.972965	0.963576
Log likelihood	130.0436	186.1767	203.9026
Akaike AIC	-10.04036	-13.24797	-14.26087
Schwartz SC	- 9.862609	-13.07022	-14.08312

Step 2. The following values of Δd_{86} were assigned: *0.0080, 0.0085, 0.0087, 0.0090, 0.0093, 0.0094, 0.0095, 0.0096, 0.0097, 0.0098, 0.0100 and 0.0110*[26].

Step 4. The initial value of the vector x_t :

$$x_{85} = \begin{pmatrix} y_{85} \\ g_{K85} \\ g_{N85} \end{pmatrix} = \begin{pmatrix} 0.188974 \\ 1.036925 \\ 1.009048 \end{pmatrix} \qquad (113)$$

According to step 1, the 3×1 column vector E_t becomes[27] :

$$E_{86} = \begin{pmatrix} -\Delta d_{86} \\ 0.242002\Delta d_{86} \\ -0.430510\Delta d_{86} \end{pmatrix} \qquad (114)$$

Here it is necessary to point at one peculiar aspect associated with estimation of E_t. The vector

[26] The range of values for Δd_{86} was chosen on the basis of combined grid search and Newton's method to minimize sum of squared errors (SSE). Here we only present the interval associated with global minimum of SSE.

[27] We change signs of all elements of the vector E_t because according to (107) the environmental shock Δd_{86} is an adverse shock

(114) shows that the environmental shock has negative impact on productivity y_t and growth rate of labour g_N . However, the impact increases the growth rate of capital g_K. This result has consistent economic explanation. The environmental shock decreases productivity of the economy because it is an adverse supply shock[28]. Decrease in growth rate of labour can be explained by two reasons: (i) decrease due to reallocation of victims of the accident; (ii) decrease due to reallocation of labour force to fight direct consequences of the accident because, in fact, the labour force is diverted from participation in actual production process. Increase in growth rate of capital is due to increase in investment required for liquidation of the direct consequences of the accident.

Now we are able to calculate values of vector x_t in 1986 as follows:

$$x_{86} = A_0 + A_1 x_{85} + E_{86} \qquad \textbf{(115)}$$

and iterate the vector x_t over 1987-1990 with

$$x_{t+1} = A_0 + A_1 x_t \qquad \textbf{(116)}$$

assigning values for t = *1986, 1987, 1988, 1989.*

Step 4. Table 4.2 presents actual values of productivity and generated values over period of 1986-1990 according to different values of Δd_{86} from step 2 with the help from *MATHCAD*.

[28] Which implies downward shift of aggregate production function or leftward shift of aggregate supply

Table 4.2. Results of the simulation of the time path of productivity y_t over 1986-1990

Δd_{86}	1986	1987	1988	1989	1990	$SSE*10^{-9}$
0.0080	0.176262	0.172194	0.167970	0.163893	0.160162	25,326
0.0085	0.175762	0.171698	0.167433	0.163287	0.159466	17,518
0.0087	0.175562	0.171500	0.167218	0.163042	0.159188	15,042
0.0090	0.175262	0.171202	0.166895	0.162677	0.158770	13,365
0.0093	0.174962	0.170905	0.166573	0.162313	0.158352	11,715
0.0094	0.174862	0.170806	0.166466	0.162191	0.158213	11,581
0.0095	0.174762	0.170707	0.166358	0.162069	0.158073	11,580
0.0096	0.174662	0.170608	0.166251	0.161948	0.157934	11,706
0.0097	0.174562	0.170509	0.166143	0.161826	0.157795	11,965
0.0098	0.174462	0.170409	0.166036	0.161705	0.157658	12,340
0.0100	0.174262	0.170211	0.165821	0.161462	0.157377	13,521
0.0110	0.173262	0.169220	0.164746	0.160248	0.155984	27,237
real y_t	**0.174522**	**0.168124**	**0.165665**	**0.163561**	**0.159538**	**0**

Note: $SSE = \sum(y_t - y_t^d)^2$ is sum of squared errors

Step 5. According to table 4.3, the value of $\Delta d_{86} = 0.0095$ is the estimated value of the direct impact from the Chernobyl accident.

On the other hand, in order to find more precise value of Δd_{86}, it is possible to run the following regression[29] :

$$SSE = \alpha_0 + \alpha_1 \Delta d_{86} + \alpha_2 (\Delta d_{86})^2 \qquad \textbf{(117)}$$

[29] The relationship $SSE = f(\Delta d_{86})$ is obviously quadratic which follows from the definition of the SSE

where ***SSE*** is sum of squared errors. From criterion ***min SSE***, the first order condition is:

$$\alpha_1 + 2\alpha_2 \Delta d_{86} = 0 \tag{118}$$

and

$$\Delta d_{86} = -\frac{\alpha_1}{2\alpha_2} \tag{119}$$

Estimation of the regression (117) based on table 4.2 gives us the following adjusted value for Δd_{86}

$$\underset{(109.1)}{SSE = 0.00059} - \underset{(-106.8)}{0.123\Delta d_{86}} + \underset{(107.0)}{6.516(\Delta d_{86})^2}$$

$$\Delta d_{86} = 0.009438$$

Therefore, imposing the derived value of $\Delta d_{86} =$ ***0.009438***, it is possible to generate the IRF as follows:

$$\phi(i) = \begin{pmatrix} \phi_y(i) \\ \phi_k(i) \\ \phi_n(i) \end{pmatrix} = \begin{pmatrix} 1.136741 & -0.663741 & -0.711089 \\ 0.049703 & 0.849102 & -0.341201 \\ 0.033353 & -0.157662 & 0.660352 \end{pmatrix}^{i} \times \begin{pmatrix} -0.009438 \\ 0.002284 \\ -0.004063 \end{pmatrix} \tag{120}$$

where $i = 0$ in 1986. The values of the three partial IRF over fifteen years are represented in table 4.3 below.

Table 4.3. Values of the Partial Impulse Response Functions over fiften years

Period, i	$\phi_y(i)$	$\phi_k(i)$	$\phi_n(i)$
0	-0.009438	0.002284	-0.004063
1	-0.009355	0.002857	-0.003358
2	-0.010143	0.003106	-0.002980
3	-0.011473	0.003150	-0.002796
4	-0.013144	0.003058	-0.002725
5	-0.015034	0.002874	-0.002720
6	-0.017062	0.002621	-0.002751
7	-0.019179	0.002316	-0.002799
8	-0.021348	0.001968	-0.002853
9	-0.023545	0.001583	-0.002906
10	-0.025749	0.001166	-0.002954
11	-0.027943	0.000718	-0.002993
12	-0.030112	0.000242	-0.003022
13	-0.032242	-0.000260	-0.003038
14	-0.034318	-0.000786	-0.003040
15	-0.036326	-0.001336	-0.003029

The following diagrams 4.4, 4.5 and 4.6 show IRF for productivity as well as all three partial IRF.

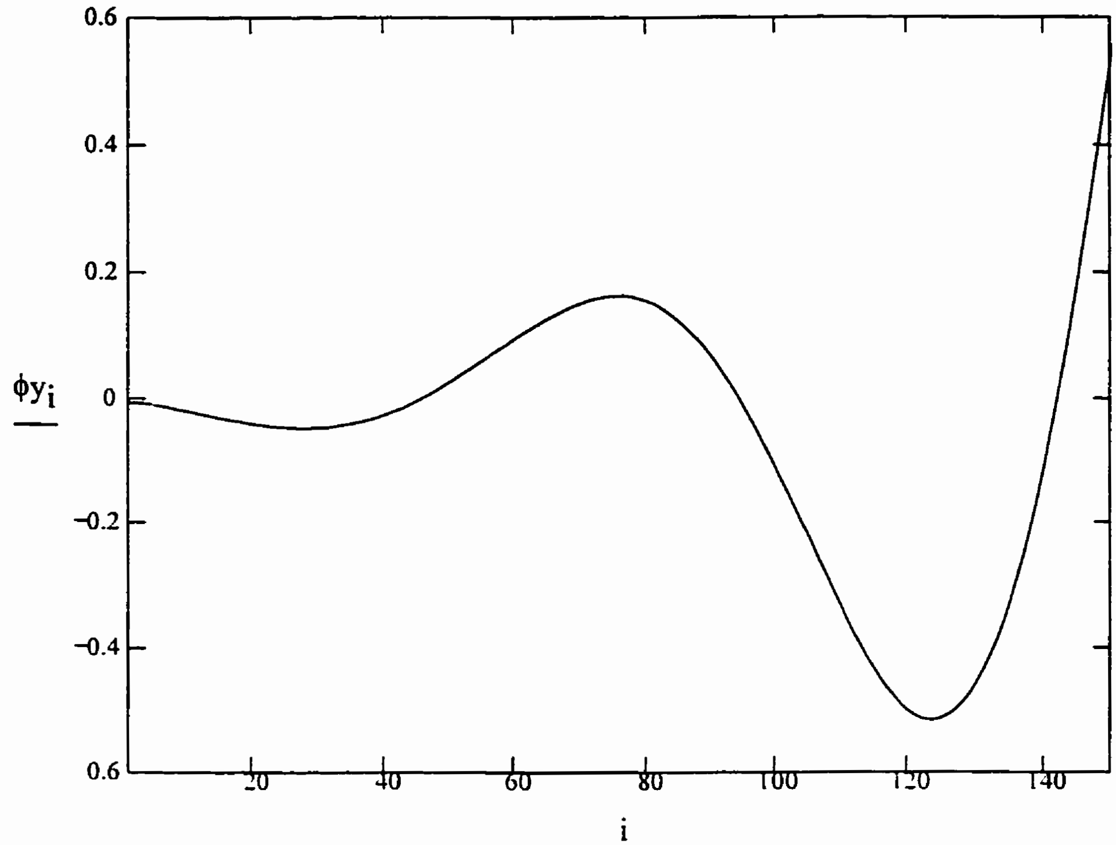

Diagram 4.4. Impulse response of productivity after environmental shock (years)

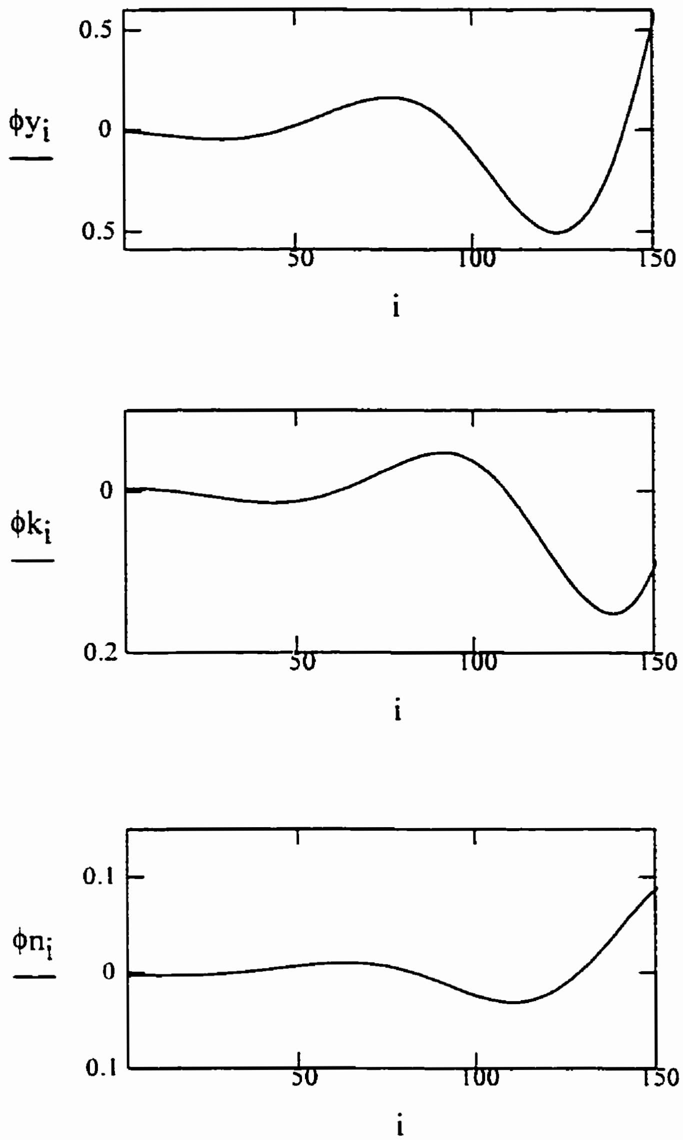

Diagram 4.5. Partial impulse response functions (years)

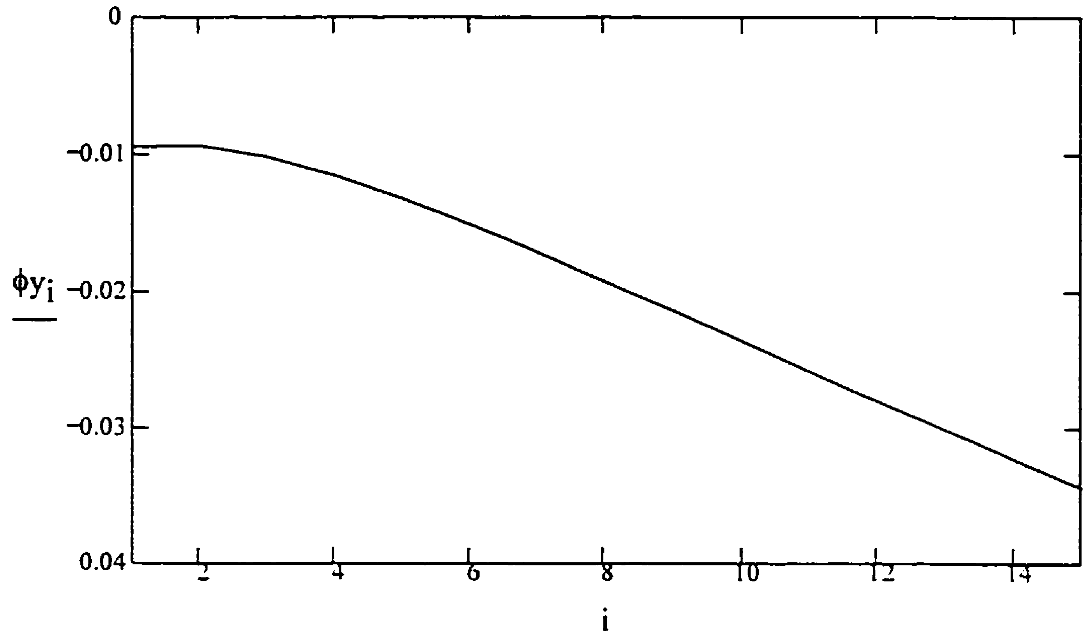

Diagram 4.6. Magnified impulse response of productivity over fifteen years

As expected from our previous discussion, the function $\phi_y(i)$ does not decay with passage of time which implies a permanent impact of the Chernobyl accident on productivity y_t of the Soviet economy. Furthermore, according to the diagram 4.4, the partial impulse response function $\phi_y(i)$ exhibits an explosive cyclical pattern. It is possible to approximate the pattern by an ***AR(3)*** process. The results of the estimation of such a process using generated values of $\phi_y(i)$ over 150 periods are represented below

$$\phi_y(i+3) = 2.645527\phi_y(i+2) - 2.278112\phi_y(i+1) + 0.630576\phi_y(i) \qquad \textbf{(121)}$$

which gives us three roots: $r_1 = 1.02 + 0.07i$, $r_2 = 1.02 - 0.07i$ and $r_3 = 0.6$. From (121) it is obvious that the process is non-stationary with two complex roots. Complex roots are responsible for the explosive cyclical pattern of the partial IRF $\phi_y(i)$ because they have real parts outside the unit circle.

Conclusion

The following conclusions are drawn, based on the econometric analysis presented in this chapter:

1. The Chernobyl accident was an adverse supply shock in the Soviet disequilibrium economy.

2. The shock has three major attributes:

(i) an immediate negative impact on productivity through direct damage to the natural resource stock with following change in resource flow which resulted in one-time increase in depletion rate d_t;

(ii) an immediate spillover effect for macroeconomic variables expressed in one-time changes in growth rates of capital and labour, g_K and g_N respectively;

(iii) a long-lasting autoregressive effect for the structure of the Soviet macroeconomic system carried by vector x_t over time.

3. Because at the time of the accident the Soviet macroeconomic system was characterized by a dynamic process with long memory, i.e. random walk with drift , the Chernobyl accident has had permanent effect on the structure of this system.

4. The Chernobyl accident started an explosive cyclical response of the productivity series.

5. The explosive cyclical character of the economy's response shows its loss of stability.

Appendix E

Values of vector x_t over period of 1951-1985

Year	y_t	g_{Kt}	g_{Nt}
1951	0.355455	1.057990	1.017621
1952	0.359156	1.057856	1.017316
1953	0.358185	1.058146	1.015957
1954	0.366268	1.057853	1.017801
1955	0.373581	1.058118	1.018004
1956	0.378840	1.058004	1.017686
1957	0.368806	1.057887	1.017378
1958	0.377910	1.058049	1.019034
1959	0.369681	1.058011	1.017241
1960	0.362343	1.062977	1.018362
1961	0.353479	1.063017	1.017106
1962	0.340181	1.062943	1.015909
1963	0.321953	1.063092	1.014318
1964	0.320711	1.063095	1.012792
1965	0.312242	1.059255	1.011324
1966	0.308625	1.058998	1.011197
1967	0.306590	1.059023	1.010221
1968	0.303681	1.058941	1.009696
1969	0.290799	1.058993	1.009186
1970	0.289974	1.059497	1.009102
1971	0.284017	1.060273	1.009840
1972	0.270291	1.059966	1.009744

1973	0.269653	1.056753	1.008846
1974	0.260855	1.056376	1.009566
1975	0.249247	1.056273	1.009080
1976	0.245289	1.053581	1.008998
1977	0.239292	1.051629	1.008530
1978	0.231544	1.049922	1.008843
1979	0.221629	1.046147	1.008003
1980	0.217335	1.043735	1.007940
1981	0.212318	1.042223	1.008252
1982	0.208218	1.040551	1.008929
1983	0.203912	1.040265	1.009587
1984	0.197228	1.038600	1.009131
1985	0.188974	1.036925	1.009048

CHAPTER FIVE

MACROECONOMIC CONSEQUENCES

OF THE CHERNOBYL ACCIDENT

The chapter discusses theoretical and practical findings from the analysis of this thesis. First, unique features of the large environmental impact in the Soviet economy are identified and compared to impacts to be expected in a free market economy.

Second, the macroeconomic consequences of the Chernobyl accident are derived quantitatively. In doing so an impact from *perestroika* and the Chernobyl shock which occurred in 1985-1986 are separated. As a result, aggregate impact from each of them is estimated in terms of real GNP loss. Six different scenarios of the Soviet economy's development since the Chernobyl accident are considered.

Finally, the chapter discusses strengthes and limitations of the realized approach.Some methodological findings of the study are identified.

5.1. General consequences of the large environmental impact in the Soviet economy in comparison with a free market economy

The deep crisis in the Soviet economy by 1991 was manifested in decreasing levels of production, disproportion between production and consumption, widening gap between population's income and availability of goods and services, disorder in money supply, destruction of existing ties between industrial branches, low productivity of agriculture, increasing inflation, accumulating external and internal debt, etc.

Many Soviet economists have tried to understand major causes of the crisis. It appears to be that its roots were in the structure of the Soviet economy. For example, Pervushin (1991) wrote: *"We think that one of the major causes of the destruction of the [Soviet] economy is irrational structural policy that has been employed for decades. It implied constant increase in the share of production of means of production, in particular production of all branches of heavy industry, at the expense of development of branches associated with production of consumer goods and services".*

The last claim is supported by table 5.1 that was derived from the annual book of Soviet statistics *Narodnoye Khozyastvo SSSR*. As it was already noted, the total output in the Soviet economy has been divided into two groups: (i) group A - production of means of production; (ii) group B - production of consumer goods. In this regard, table 5.1 represents shares of the two groups over 1940-1990.

Table 5.1. Shares of groups A and B over 1940-1990, %

Years	Group A	Group B
1940	61.0	39.0
1960	72.5	27.5
1970	73.4	26.6
1980	73.8	26.2
1985	74.8	25.2
1986	75.3	24.7
1987	75.1	24.9
1988	74.8	25.2
1989	74.0	26.0
1990	72.4	27.6

The table indicates significantly higher share of group A's production that has been a trade mark of the Soviet economy for decades. Only *Gorbachev's perestroika* (1985-1990) brought about some change in the existing pattern. Nonetheless, the group A's share has remained high enough.

On the other hand, as long as the major part of demand for means of production has been satisfied by extensive factors, i.e. by increase in extraction of natural resources in the first place, burden on the natural environment has become more severe. Eventually such a burden began to affect the entire macroeconomic system of the Soviet Union. Cost of extraction of natural resources increased which resulted in very high value of the ratio "cost of raw materials to national income" which in 2-3 times exceeded similar indicator in the developed economies. Share of mining industry also increased accounting for 8-9% of total production compared to just 5% in the developed economies (see Pervushin, 1991).

However, the most important conclusion is: such an irrational structure of the Soviet economy eventually led to the destruction of the environmental balance. Mining, processing and heavy industries have been the most destructive force in an environmental aspect during all times in the Soviet economy and especially during 1986-1990. Lemeshev (1990), a famous Soviet economist in the field of environmental economics claims: "*Extensive economic growth not only destroys the nature, but it also brings in huge economic and social losses. According to my calculation, total economic damage from environmental destruction reached 45-50 billion rubles per year*".

Given the crisis described above and from the analysis presented in this study, it is obvious that the Chernobyl accident significantly contributed to the overall destruction of the natural environment in the Soviet Union. As it was shown earlier, a distinguishing feature of the Soviet economic development over all periods has been the extensive economic growth. Dmitri Steinberg (1990) also attracts attention to this feature of the Soviet economic growth: "*The Soviet economy came to an inevitable halt in the mid-1970s when Soviet planners lost their ability to maintain the extensive type of economic growth, which was fuelled during the preceding decades primarily by the rapid expansion of production facilities, particularly in industries that mine and process basic materials*". In economic sense it implies: the natural resources stock was a major input in the Soviet aggregate production function. The Chernobyl accident dramatically decreased this input which caused productivity of the entire economy to decline even faster. As it was shown earlier in this study, at the time of the accident the Soviet macroeconomic system was already unstable due to structural change of 1960-1961. However, the Chernobyl shock, combined with restructuring of the Soviet economy that was going on at that time, was the last blow for the unstable macroeconomic system. As analysis in this study shows, the shock was irreversible in principle within the existing macroeconomic system. The Soviet macroeconomic system being rigid could not react properly to exogenous adverse shocks. The only way to change the undesired pattern after the shock was by accelerating technological progress. However, the Soviet economy did not provide incentives to speed up technological progress. Therefore, it became necessary to replace the entire system in order to create a set of required incentives.

Thus, the break-up of the Soviet Union was the objective result of the sequence of events among which the most important were:

1. Structural change of 1960-1961 that started the Soviet macroeconomic system on an unstable path.
2. Ad hoc restructuring of the economy within old institutional framework since 1985.
3. The Chernobyl supply shock of 1986.

With respect to the structural change let us quote Dmitri Steinberg who discusses the slowdown of the late 1980s:

"This slowdown must be undoubtedly viewed as a sign of a prolonged Soviet economic slump. A more detailed analysis of estimation results further reveals that the current Soviet socio-economic crisis did not occur suddenly; it evolved gradually over two decades and thus could have been predicted more than decade ago...

Its first signs were already manifested in the early 1970s which witnessed a notable slowdown in the growth of consumption and fixed investment. Starting in the mid-1970s the slowdown was replaced with a negative per capita growth which by the mid-1980s evolved into negative absolute growth" (Dmitri Steinberg, 1990, p. 181)

It is necessary to note two major conclusions that follow from the above quotation: (i) first signs of the slowdown were in early 1970s; (ii) negative absolute economic growth since mid-1980s. With respect to the first one this study showed that even though the first signs (consequences) of the slowdown in the Soviet economy were manifested in the early 1970s, its roots (causes) had been in 1960-1961 structural change. The second conclusion completely supports the analysis presented in this study: by 1985 Soviet economy was already unstable and the year of 1986 brought absolute negative economic growth.

Therefore, according to the analysis realized in this study, the Chernobyl shock was imposed on a system that was ready to break up and "was waiting" for any opportunity to do so. Has not the Chernobyl shock occurred, any other adverse exogenous shock would have resulted in the break-up of the system.

On the other hand it is necessary to emphasize that the Chernobyl accident was also a result of the extensive economic growth. Increase in energy capacity as a major input for production through increase in nuclear energy capacity had been achieved at the expense of safety. As a result, the accident occurred causing disastrous macroeconomic consequences . In 1990 a prominent Soviet newspaper *Izvestiya* admitted that "... *according to recent data, liquidation of the consequences of the Chernobyl accident will require not 6-8 billion rubles, as it was estimated in 1986, but at least 34 billion rubles of which 18 billion rubles in 1986-1990" (Izvestiya, 26 March, 1990, p.3).* However, even this amount is underestimation which is shown in this study.

Hence, it appears to be that there are two unique features behind the consequences of the large environmental impact in the Soviet economy. They are: (i) price rigidity; (ii) extensive economic growth. Both underlie specific dynamic properties of the Soviet economy which caused explosive response of the economy to the Chernobyl shock. As a result, stability of the system was changed which was manifested in a growing chronic shortage.

For comparison, what would the likely consequences of the large environmental shock have been in a free market economy? First, such an economy would feel the same immediate impact on the resource stock, shifting its production possibility frontier. After that the similarity with the Soviet economy disappears. In the latter, the large environmental impact immediately spills over the entire macroeconomic structure (represented by increase in growth rate of capital and decrease in growth rate of labour). In a free market economy the initial impact is offset by increase of the general price level in the short-run, then it results in increase of resource-saving investment in the long-run. One feature of the extensive growth of the Soviet economy is complementarity of environmental and economic variables. In a free market economy such a complementarity is no longer present. Instead, it is assumed that rational agents solve a set of optimization problems in order to arrive at optimal combination of environmental and economic variables. Therefore, the agents treat these variables as substitutes rather than complements. A support for the last claim is found in Stiglitz (1974) who introduced the following aggregate production function:

$$Y_t = A K_t^{\alpha} L_t^{\beta} R_t^{\gamma} e^{\tau t}$$

where A = technological constant; K_t = physical capital; L_t = labour; R_t = resource flow; τ = rate of technological progress; α, β, γ = shares of capital labour and resources respectively, and $\alpha + \beta + \gamma = 1$ and $\tau > 0$. This Cobb-Douglas form of the aggregate production function assumes substitutability between environmental and economic variables. It implies that capital investment saves resources or decrease in resource stock (or flow) increases capital investment. Therefore, the immediate decrease in resource stock and resource flow due to the large environmental impact would eventually increase resource-saving investment. Therefore, in the long-run we would expect improvements associated with resource-saving technologies.

Of course, there should be some adjustment process in both real aggregate supply and real aggregate demand. For example, after second oil shock in 1980 consumers switched to more economic vehicles as a result of dramatic increase of oil price. However, the overall effect of this adjustment process is ambiguous in general because it depends on dynamic properties of a specific economy. On the other hand, there are strong incentives for technological progress which may offset some of the negative consequences of the large environmental impact in a free market economy.

Two outcomes are possible: (i) with passage of time adjustments in real aggregate supply and demand return macroeconomic system on the previous time path (temporary shock); (ii) a permanent change in the time path after the shock. Theoretically the second outcome may lead to a more efficient time path if the impact from the environmental shock is more than completely offset by technological improvements. On the other hand, an economy may end up along less efficient time path if the ecological consequences of the impact are stronger compared to technological improvements.

Therefore, it appears that substitutability between environmental and economic variables is a crutial feature of a market economy because it creates a set of proper incentives to overcome the consequences of the large environmental impact. Furthermore, the literature on sustainable development suggests some extra incentives in such a case in a free market economy. For instance, Pezzey (1992) argues: "*... analysis shows that a proportional conservation subsidy [to extractors] (subject to certain restrictions on parameter values) can move the economy onto an optimal growth path by countering all the depletion and utility effects: a higher subsidy will slow resource depletion and raise the growth of utility*". Solow (1974) also suggests a policy solution of resource conservation subsidies as well as of severance (resource depletion) taxes that fall through time.

Strictly speaking, the negative consequences of the large environmental impact in a free market economy might be offset through three channels: (i) increase in the rate of technological progress; (ii) decrease in the utility discount rate; (iii) implementation of conservation subsidies or depletion taxes. In this regard, the combination of internal forces (immediate short-run increase in prices and resource-saving investment) and external forces (policy decisions) might help to eventually overcome the consequences of the large environmental impact in a free market economy.

As it has already been shown, the Soviet economy does not provide any incentives to use the above enumerated opportunities because of price rigidity and extensive economic growth. In a mathematical sense, the extensive economic growth is not associated with time path which is a result of the solution of a set of optimization problems. Therefore, the spillover effect as well as negative long-lasting autoregressive effect are unique features of the large environmental impact in the Soviet economy. Moreover, it appears to be that the large environmental impact in a socialist economy with extensive economic growth leads to permanent negative consequences unless the required set of incentives is found. However, the latter is associated with institutional or structural change.

5.2. Derived estimates of the macroeconomic consequences of the Chernobyl accident in the Soviet economy

Before presenting the derived estimates of the Chernobyl accident for the Soviet economy, it is necessary to justify the data used for simulation of the Soviet economy's performance over 1986-

1990. It appears that this period in the Soviet economic development remains the most controversial. The complexity of the period is associated with two major events - the change in the Soviet leadership in 1985[30] and the Chernobyl accident. Therefore, both events have to be accounted for in order to separate the Chernobyl shock.

Discussion represented below is dedicated to this issue first and to the comparison of some existing estimates second. In this regard, different scenarios of the Soviet economic development over 1986-1990 are presented and analysed. As a result, the aggregate value of the shock is derived as well as the social costs of the Gorbachev's perestroika.

Based on the literature review the following scenarios of the Soviet economic development over 1986-1990 have been identified.

1. The moderate scenario

This scenario is used in this study to derive the value of the Chernobyl accident through Impulse Response Function. It is based on the following estimates:

- extension of Dmitri Steinberg's deflators over period 1980-1985 into period 1986-1990 (Steinberg, 1990, table 1G, p.216);
- Gross National Product derived by Dmitri Steinberg for period 1986-1990 (Steinberg, 1990, table D1, p.169).

These estimates produce the following real GNP in constant 1973 prices.

[30] Gorbachev became the Secretary General of the Communist Party of the Soviet Union in April 1985

Table 5.2. The moderate scenario

Years	GNP in established prices, billion rubles	Deflators	GNP in constant 1973 prices, billion rubles
1986	798.5	1.51	528.8
1987	825.0	1.56	528.8
1988	875.4	1.62	540.4
1989	924.1	1.67	553.4
1990	965.3	1.73	558.0

2. The Goskomstat's scenario

The scenario is derived based on publications by the Head of Goskomstat Victor Kirichenko (1990, 1991). According to these publications the level of inflation in the Soviet economy has been as follows: 7.2% in 1986-1988; 7.5% in 1989 and 10% in 1990. Taking these levels of inflation and deflator of 1.46 in 1985[31] reported by Dmitri Steinberg (1990) the following table was constructed:

Table 5.3. The Goskomstat's scenario

Years	GNP in established prices, billion rubles	Deflators	GNP in constant 1973 prices, billion rubles
1986	798.5	1.49	535.9
1987	825.0	1.53	539.2
1988	875.4	1.56	561.2

[31] We use Steinberg's estimates for 1985 as the basis for comparison of all scenarios represented in this chapter

1989	924.1	1.68	550.1
1990	965.3	1.85	521.8

3. Steinberg's reconstructed scenario

Dmitri Steinberg also reports Kirichenko's inflation levels for period of 1986-1988, however, he concludes: "... *it can be tentatively concluded that Soviet GNP actually declined by 1-1.5% in 1989. This was a disastrous performance even in comparison with the stagnation of 1987-1988 period when the Soviet GNP grew by 1.3-1.5%" (Steinberg, 1990, p.181)*. Therefore, for this scenario GNP in 1986 is unchanged, however, GNP in 1987 and 1988 is assumed to increase by 1.3% with 1% decrease in 1989 and by 5.2% decrease in 1990 as it was in the previous scenario. Table 5.4 summarizes these calculations.

Table 5.4. Steinberg's reconstructed scenario

Years	GNP in constant 1973 prices, billion rubles
1986	535.9
1987	542.9
1988	549.9
1989	544.4
1990	516.4

Table 5.5 below combines all three scenarios discussed above.

Table 5.5. Comparison of the three scenarios

Years	Moderate scenario, GNP in billion rubles	Goskomstat's scenario, GNP in billion rubles	Steinberg's reconstructed scenario, GNP in billion rubles
1986	528.8	535.9	535.9
1987	528.8	539.2	542.9
1988	540.4	561.2	549.9
1989	553.4	550.1	544.4
1990	558.0	521.8	516.4

Diagram 5.1 below shows time paths of the Soviet GNP over 1986-1990 associated with each of these scenarios. The diagram indicates that the moderate scenario does not have dramatic ups and downs like the other two. Furthermore, all three scenarios show decrease in the real GNP in 1986 in comparison with 1985. Even though the reconstructed Steinberg's and Goskomstat's scenarios seem to be more realistic, nonetheless the moderate scenario is more suitable for the purposes of this study because of the reasons described in chapter four. Two scenarios, second and third, contain disturbances other than those caused by the environmental shock. In the moderate scenario we have artificially removed the impact from perestroika.

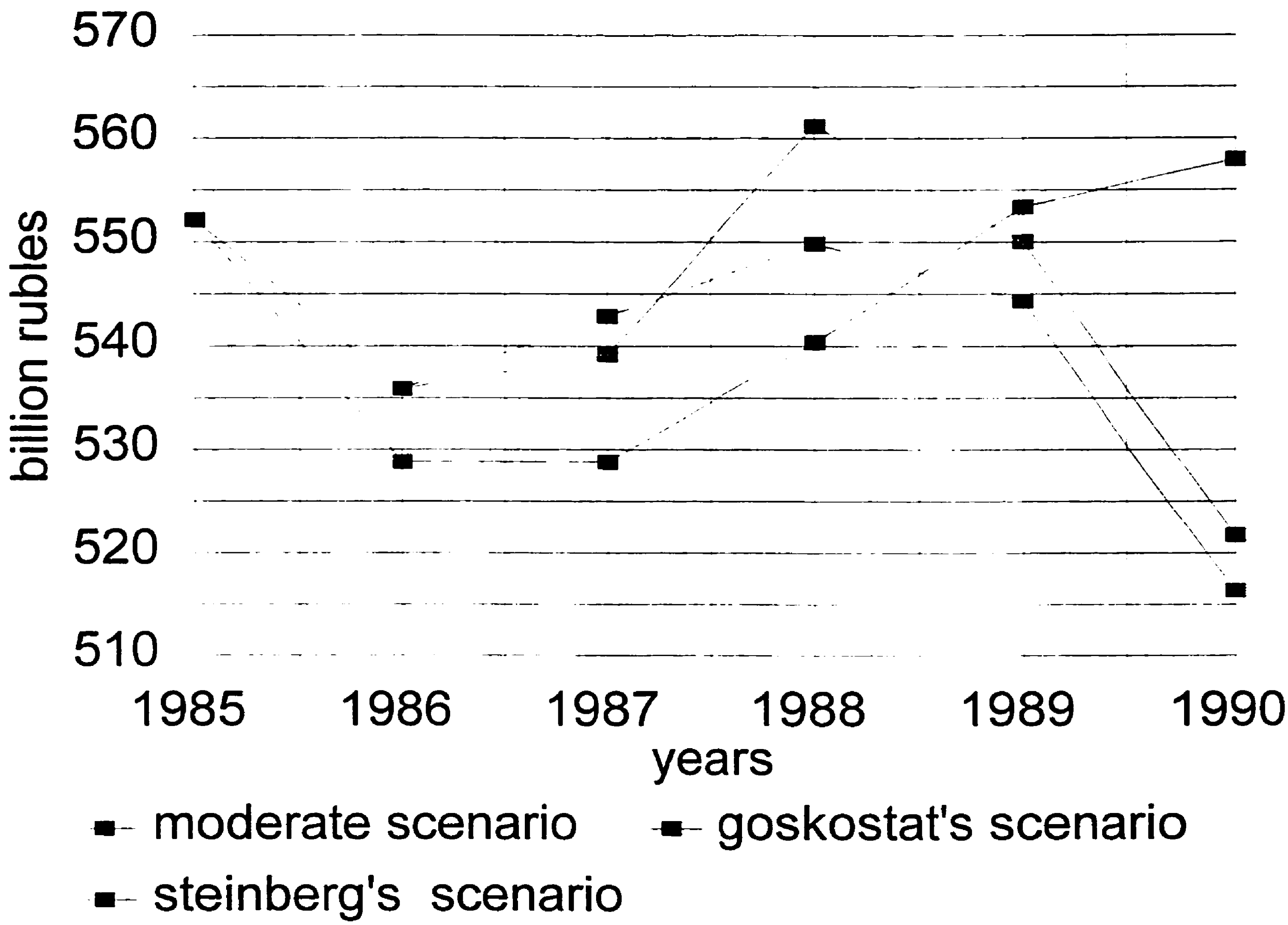

Diagram 5.1. Comparison of three scenarios of the Soviet economy's development, 1985-1990

Actually the period of 1986-1990 was affected by two exogenous shocks: (i) bad macroeconomic management since 1985 due to the change in the entire macroeconomic strategy (demand and supply side shock); (ii) the Chernobyl accident in 1986 (supply side shock). Bad macroeconomic management was associated with an attempt to restructure the Soviet economy within existing institutional framework through the so-called *market socialism*. Therefore, we hypothesize that the moderate scenario contains only the environmental shock whereas the other two scenarios contain both shocks.

In this regard, it is possible to derive potential time path of the Soviet economy without either the Chernobyl accident or perestroika. The potential time path is obtained through the following calculations:

$$GNP_t = [y_t + \phi_y(i)] \times K_t \qquad \textbf{(114)}$$

where $\boldsymbol{i}$ = 1986, 1987, 1988, 1989, 1990; y_i = simulated values of the productivity as result of the environmental shock; ϕ_y *(i)* = absolute values of the IRF of productivity; $\boldsymbol{K_i}$ = capital stock in Soviet economy. Table 5.6 summarizes the results of these calculations.

Table 5.6. Derivation of the potential GNP over 1986-1990

Years	y_t	ϕ_y *(i)*	K_t, billion rubles	GNP_i, billion rubles
1986	0.174862	0.009438	3030.0	558.4
1987	0.170806	0.009355	3145.3	566.7
1988	0.166466	0.010143	3262.0	576.1
1989	0.162191	0.011473	3381.2	587.2
1990	0.158213	0.013144	3497.6	599.3

The difference between the values of GNP under the moderate scenario (table 5.2) and derived potential GNP (table 5.6) gives us the aggregate value of the Chernobyl accident over 1986-1990 which is summarized in table 5.7.

Table 5.7. Aggregate value of the Chernobyl accident over 1986-1990

Years	Potential GNP without environmental shock, billion rubles	GNP with environmental shock, billion rubles	Value of the environmental shock, billion rubles	Relative value of environmental shock, % of potential GNP
1986	558.4	528.8	29.6	5.3
1987	566.7	528.8	37.9	6.7
1988	576.1	540.4	35.7	6.2
1989	587.2	553.4	33.8	5.8
1990	599.3	558.0	41.3	6.7

Therefore, according to table 5.7, the aggregate value of the Chernobyl accident over 1986-1990 is 178.3 billion rubles.

4. The realistic scenario

However, even though the Goskomstat's and Steinberg's reconstructed scenarios exhibit higher levels of inflation than our basic moderate scenario, the real inflation seems to have been even higher over 1986-1990. In chapter 1 (section 1.2, table 1.3) the levels of inflation calculated by two Soviet research institutes were reported. Table 5.8 below reproduces these levels as well as levels of inflation associated with the Goskomstat's and Steinberg's reconstructed scenarios.

Table 5.8. Inflation in the Soviet economy during 1986-1990, %

Years	GERI	CBRI	Goskomstat	Steinberg
1986	6.2	6.2	2.34	2.34
1987	7.3	7.3	2.34	2.0
1988	8.4	10.0	2.34	4.6
1989	10.0	12.0	7.5	6.8
1990	18.6	18.6	10.0	10.0

Furthermore, Shmarov and N.Kirichenko (1990) present the following levels of inflation for 1988-1989: 8.1% in 1988 and 11.0% in 1989. Isayev (1990) reports 14-15% inflation in 1989. Levin (1990) estimates inflation in 1989 as 10%. All estimates presented above are significantly higher than those assumed in Goskomstat's and Steinberg's scenarios. Choosing averages of the estimates reported by the Soviet economists, the real GNP in constant 1973 prices over period of 1986-1990 was calculated as follows:

Table 5.9. Real GNP based on inflation levels calculated by the Soviet economists

Years	GNP in established prices, billion rubles	Inflation, %	Deflators	GNP in constant 1973 prices, billion rubles
1986	798.5	6.2	1.55	515.2
1987	825.0	7.3	1.66	497.0
1988	875.4	8.1	1.79	489.1
1989	924.1	10.0	1.97	469.1
1990	965.3	18.6	2.32	416.1

We call this scenario realistic because it contains both impacts. The difference between the moderate scenario and the realistic scenario gives us the social cost of perestroika. Table 5.10 presents these calculations.

Table 5.10. Social costs of perestroika

Year	Moderate scenario, GNP in billion rubles	Realistic scenario, GNP in billion rubles	Difference, billion rubles	Relative value, % of potential GNP
1986	528.8	512.2	16.6	3.0
1987	528.8	497.0	31.8	5.6
1988	540.4	489.1	51.3	8.9
1989	553.4	469.1	84.3	14.3
1990	558.0	416.1	141.9	23.6

According to the calculation presented above, Gorbachev's perestroika has had even stronger impact than the Chernobyl accident. The aggregate value of the Chernobyl accident is 178.3 billion rubles over 1986-1990 whereas the social costs of perestroika are 325.9 billion rubles or in 1.8 times higher.

It is also useful to present two more scenarios of the Soviet economic development over 1986-1990. We call them Soviet official and CIA's.

5. Soviet official scenario

In 1991 Soviet officials submitted economic data to the Joint Committee which consisted of specialists from the World Bank for Reconstruction and Development, International Monetary Fund, Organization for Economic Cooperation and Development and European Bank for Reconstruction and Development. Growth rates of the Soviet national income over 1986-1990 were among these data. Table 5.11 reproduces these rates.

Table 5.11. Growth rates of the Soviet national income

Years	Growth rate, %
1986	2.3
1987	1.6
1988	4.4
1989	2.5
1990	-4.0

Source: Ekonomika SSSR: Vyvody i recomendatsii. Voprosy Ekonomiki, 3, 1991, 6-72

As it was already noted, growth rates of GNP surpass those of the national income by 0.5% for the Soviet economy. If this fact is taken into account along with the value of GNP in 1985 as 552.2 billion rubles derived by Steinberg (1990), then the following scenario arises:

Table 5.12. Soviet official scenario

Years	GNP growth rate, %	GNP in constant 1973 prices, billion rubles
1985	-	552.2
1986	2.8	567.7
1987	2.1	579.6
1988	4.9	608.0
1989	3.0	626.2
1990	-3.5	604.3

6. CIA scenario

The scenario is derived from the Report to the Honorable Daniel Patrick Moynihan which has been prepared by US Senate in September 1991. The Report contains growth rates of the Soviet GNP over 1986-1990. Once again the value of GNP in 1985 or 552.2 billion rubles is used as the basis for comparison. Table 5.13 represents the results of this scenario.

Table 5.13. CIA scenario

Years	GNP growth rates, %	GNP in constant 1973 prices, billion rubles
1985	-	552.2
1986	4.0	574.3
1987	1.3	581.8
1988	2.1	594.0
1989	1.5	602.9
1990	-4.5	575.8

From tables 5.12 and 5.13 it is obvious that the last two scenarios are very close to each other. However, we find in Spulber (1991): "*Many Soviet economists - Abel Aganbegyan, for instance - now consider CIA estimates **too optimistic***". Aslund (1989) admits: "*We might never obtain an accurate assessment of Soviet economic growth, but it appears to have ceased in 1978 as Alec Nove and Michael Ellman suggested as early as 1982*". Furthermore, in June 1987 Gorbachev characterized situation in the Soviet economy as *pre-crisis* (see Aslund, 1989). However, if we accept the last two scenarios, the performance of the Soviet economy can hardly be cited as evidence of a deep crisis except for the year of 1990. We call this scenarios as *optimistic*. Curiously enough but the derived potential pattern of the Soviet GNP over 1986-1990 comes very close to these two optimistic scenarios. Table 5.14 reflects this finding by comparing three scenarios.

Table 5.14. Comparison of the optimistic scenarios and potential path of GNP

Years	Potential GNP, billion rubles	Soviet official GNP, billion rubles	CIA GNP, billion rubles
1986	558.4	567.7	574.3
1987	566.7	579.6	581.8
1988	576.1	608.0	594.0
1989	587.2	626.2	602.9
1990	599.3	604.3	575.8

So, based on the analysis realized in this study, the major consequences of the Chernobyl accident are:

1. The Chernobyl accident significantly affected one of the ,p+21Xinputs of the Soviet aggregate production function - the stock of natural resources.

2. The direct impact of the Chernobyl accident for the structure of the Soviet economy was 29.6 billion rubles or 5.3% of the Soviet GNP.

3. The aggregate cumulative impact of the Chernobyl accident over 1986-1990 was 178.3 billion rubles.

4. All the above characterizes the Chernobyl shock as a large adverse supply shock.

5. The Chernobyl accident is a permanent shock for the structure of the Soviet economy.

6. The main dynamic consequence of the accident is the cyclical explosive response of the productivity, implying loss of stability of the Soviet economy as dynamic system.

With respect to shortages as an indicator of the socialist disequilibrium economy, it appears that the two significant shocks in 1985-1986 increased already existing chronic shortage in the Soviet economy. It was shown earlier that the period of 1950-1960 was characterized by a stationary process with a well-defined steady state. In this regard, increase in shortage can be measured by increase in deviations with respect to the steady state value of productuvity. The shortage has increased by 2.8% annually on average over 1961-1990. On the other hand, it has increased by 3.4% annually over 1986-1990. It means that the two shocks - perestroika and the Chernobyl accident - made the unstable path of the Soviet economy irreversible in principle. If the potential time path (or path without both shocks) over 1986-1990 is taken into consideration, it exhibits just 1.8% annual increase in shortage which is less than reported above 3.4% during the same period. The 1.8%-increase is due to extensive economic growth or trending depletion rate. The difference between 3.4% and 1.8% gives us the consequence of two shocks in terms of shortages.

Therefore, as potential time path shows, the process of stagnation in the Soviet economy could have been slowed down. It does not mean that the process could have been stopped. However, the point is: after the two significant shocks it was just impossible.

5.3. Limitations of the study

The first and the most important limitation of any study on Soviet economic growth is the Soviet data. Steinberg (1990) fairly admits: "... *it was demonstrated that reliable estimates of Soviet economic growth depend to a large extent on the availability of data in current established prices*". On the other hand, conclusions which are made in this study seem to be consistent enough with what has been observed in reality by the Soviet people including the author of this study. The derived data allowed us to answer the question about the major causes of the disintegration of the Soviet economy more completely than in other studies.

There were many optimistic forecasts of the Soviet economy's future. Surprisingly enough, these assessments were made by highly qualified experts who, unfortunately, did not recognize the real causes of the slowdown. Once again it is helpful to quote Dmitri Steinberg (1990):

"It is now recognized that the rapid disintegration of the Soviet economy in the late 1980s has caught most experts by surprise... Today when many leading Soviet economists echo Cassandras' warnings about the imminent collapse of the Soviet socio-economic order, their words are accepted as an unconditional truth. Soon, the past optimistic assessment will be forgotten as are other unsuccessful forecasts" (Dmitri Steinberg, 1990, p.199)

Even though this study does not pretend to be a precise description of the Soviet economic growth, nonetheless it does reflect its most important tendencies and trends. Moreover, it does capture the overall dynamics of the Soviet economy according to recent opinions of the leading Soviet economists who have had access to the detailed information.

In this regard, the extensive economic growth as the major cause of the disintegration of the Soviet macroeconomic system is admitted by all experts on Soviet economic growth. This study captures this feature through direct introduction of the natural resource stock into Soviet aggregate production function. Of course, one-sector one-good model cannot convey details of the importance of the natural resources in the Soviet economy. Therefore, it would be more helpful to disaggregate the growth model into at least two-sector model or even into multiple-sector model. However, the error associated with such disaggregation now would increase as well. On the other hand, as soon as the detailed, true disaggregated data become available, this limitation may be overcome.

The next limitation is directly associated with derivation of the consequences of the Chernobyl accident. A researcher who wants to analyse this accident as supply shock faces a problem of separation of the impact of this shock from other exogenous disturbances. This study attempts to remove such disturbances by extending existing time path of the Soviet GNP by the time of the accident into the future. This is a kind of *counterfactual* approach, and it is associated with all controversies that surround the dispute between traditional economic historians and representatives of the so-called *new economic history*. New economic historians introduce a new branch within their field known as *cliometrics* (see, for example, McCloskey, 1987). Cliometrics combines economic history, economic theory and econometrics. This study is exactly of this nature. On the other hand, in this particular case the choice of the counterfactual approach is prompted by the impossibility of applying conventional econometric tools to estimate the Chernobyl shock. However, one possible application of a rigorous econometric analysis is mentioned at the end of the chapter 3 for an environmental shock when a long time series is available after the shock.

The application of the counterfactual approach points at another limitation of this study. The consequences of the Chernobyl accident are more simulated than detected through time series analysis. Therefore, some degree of bias is brought in by the researcher. On the other hand, a series of five years is not enough to detect the shock and its consequences through, for instance, Perron's (1989) test. Thus, simulation appears to be an appropriate way to analyse the consequences and the nature of the Chernobyl shock.

Three main features or attributes of the environmental shock were identified in this study. It is obvious that deterioration in health conditions of the Soviet population, especially Ukrainians, Byelorussians and Russians, was a very important consequence of the Chernobyl accident. This feature of the accident is not explicitly incorporated in the model. Instead it is assumed that the deterioration of health conditions was manifested in decrease in labour or rather growth rate of labour. Also the accident caused an increase in subsidies to industry and agriculture which is not taken into account explicitly either. With respect to the long-run consequences, the model tries to capture them through the first-order Vector Autoregression which is approximation. However, in econometric sense the first-order autoregressive process which is used in this study can be inverted into an infinite moving average process. It implies that the AR(1) process does carry a long memory (long-run consequences) over time. Therefore, it is not a bad approximation.

Measurement of the Soviet GNP through expenditures (consumption and investment) in 1986 may be misleading. From personal experience the author knows that consumption of alcoholic beverages has increased dramatically since the Chernobyl accident. It is a well-known fact that revenues from the sale of alcoholic beverages have been one of the major sources of national income during entire Soviet history. For example, Dmitri Steinberg (1990) admits: *"The brief review of the Goskomstat report for 1989 indicates that alcoholic beverage and consumer electronics were star performers in the Soviet economy"*. Therefore, increased consumption of alcohol could shade the real decrease in productivity in 1986. It is rather a negative consequence of the accident, and it should be added to the social costs of the Chernobyl accident. However, once again it requires detailed sectoral analysis.

On the other hand, increase in alcohol consumption points at another limitation of this study. The Chernobyl accident has formed extremely pessimistic expectations within Soviet society, and increase in alcohol consumption may be viewed as a reflection of this fact. It seems that these expectations have played a very important role in the further development of the Soviet economy. Impact of these expectations is not accounted for in this study, however, the author believes that such an impact has to be thoroughly analysed which requires extension of the model.

5.4. Concluding Remarks

It was shown that the period of 1986-1990 in the Soviet economy is characterized by several impacts each of which contributed to the break-up of the Soviet Union. Separation and analysis of different impacts require disaggregated data which were not available at the time of current analysis. Therefore, the results which were obtained in this study are rather guidelines for further analysis. If reliable disaggregated data were available, then it would have been possible to use microeconomic underpinnings to better describe dynamics of the Soviet economy. Such underpinning are essential part of theoretical work by Desai (1987), Weitzman (1986), Desai and Martin (1983), Ericson (1983), Thornton (1971) and some other economists who have analyzed the Soviet economy.

On the other hand, it is useful to present the following two quotations:

"Nothing can be quantified absolutely (except by God), for everything is relative" (Fromm and Klein, 1971)

and

"As our knowledge and understanding of the complex world in which we live increases, so must our tools become more refined and our description more detailed" (Kermit Gordon, 1968)

In this regard, the study shows that, in principle, it is possible to detect the consequences of the large environmental impacts through dynamic macroeconomic analysis which is the answer to the question stated at the very beginning. Furthermore, the study provides tools for such an analysis and shows a practical way to estimate aggregate damage from the large environmental impacts quantitatively.

It is also necessary to present some strong features of this study. The study is dedicated to macroeconomic analysis of the consequences of a large environmental impact as oposite to microeconomic consideration accepted by majority in the field of environmental economics. Based upon macroeconomic analysis, dynamic properties of the Soviet economy were analysed through co-movements of interdependent macroeconomic variables. The study explicitly incorporates two unique features of the Soviet economy - constant prices set below equilibrium level and extensive economic growth - which is reflected in designed disequilibrium model. In order to convey the extensive character of economic growth, natural resources were introduced as a complement to conventional factors of production into aggregate production function.

The disequilibrium growth model allowed us to study dynamic properties of the Soviet economy. As a result, we came up with stability conditions, and economic and econometric justification of the structural change in the Soviet economy that was a source of instability at the time of the Chernobyl accident.

Theoretically designed framework helped us to identify attributes of the Chernobyl accident in the Soviet economy on the one hand, and to set up a proper way to estimate the consequences of the accident quantitatively on the other.

Summarizing the above, it is necessary to admit that this type of analysis is the first attempt to study Soviet economy using existing macroeconomic theory and modern econometric tools. It became possible due to the author's background obtained in three countries - former USSR, USA and Canada.

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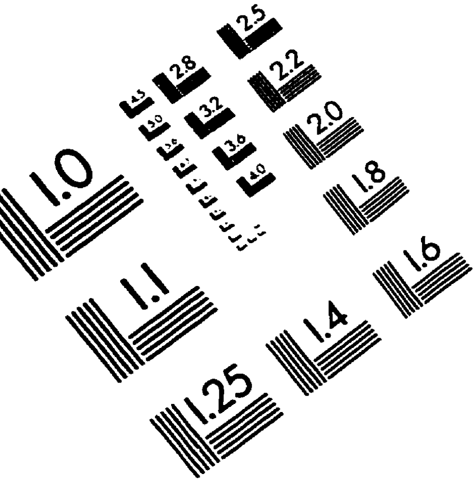
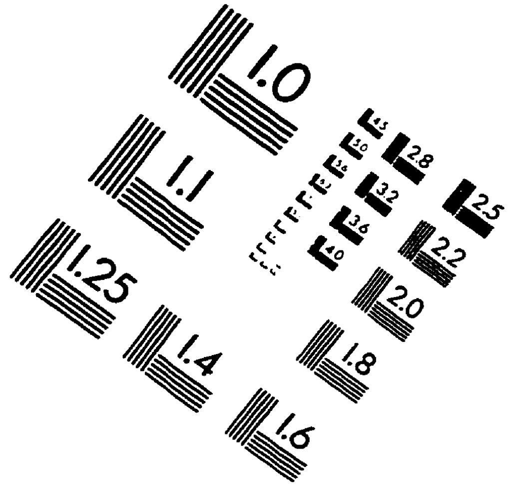
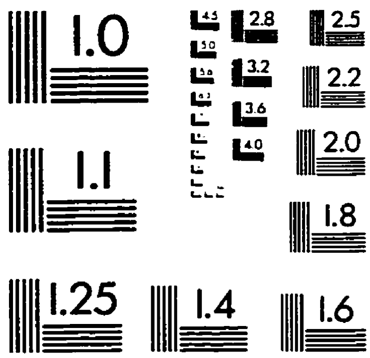
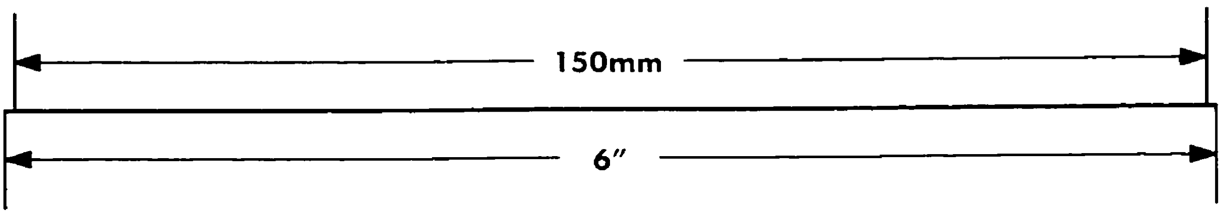
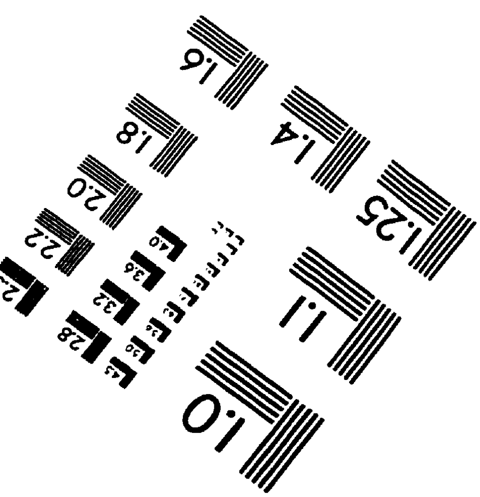
IMAGE EVALUATION TEST TARGET (QA-3)

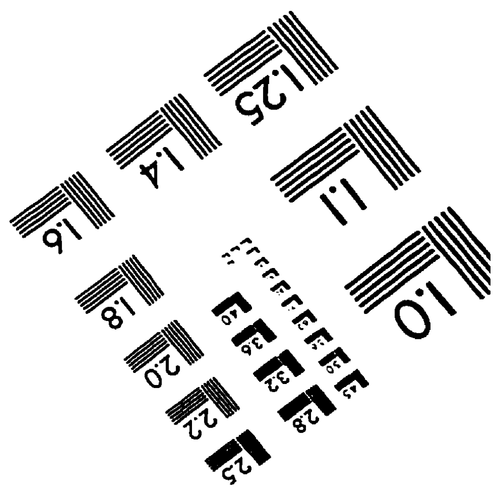












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